THE SOURCES OF JUSTIFICATION USED BY UNIVERSITY STUDENTS AND THEIR CHANGE DURING ARGUMENTATION PROCESS

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ABSTRACT

THE SOURCES OF JUSTIFICATION USED BY UNIVERSITY STUDENTS AND THEIR CHANGE DURING ARGUMENTATION PROCESS

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This research aims to examine the sources of justification upon which students base their claims and observe how faithfully they adhere to these sources or change their justifications in an argumentation environment created by using counter-intuitive physics problems. The study was conducted with 25 first-year university students enrolled in the 'Elementary Science Teaching Undergraduate Program.' They engaged in an argumentation process over eight weeks, preparing argumentation worksheets for each task. When examining the sources used in the participants' justifications, a total of 10 different sources of justification under four main categories emerged. The main categories emerged as 'Daily Life Experiences,' 'Daily Life Observations,' 'School,' and 'Implicit.' During the argumentation processes, when changes in participants' justifications were analyzed, it was generally found that 'Justifications Based on Daily Life Experiences' were more effective in changing the justifications of other participants. In contrast, 'Justifications Based on School,' generated from educational settings (e.g., teacher, textbook, classroom experiments/demonstrations, school environment), were more susceptible to being easily influenced by the justifications presented by other participants during the argumentation processes.

Keywords: Scientific Argumentation, Justification, Science Education.

ÖZ

ÜNİVERSİTE ÖĞRENCİLERİNİN ARGÜMANTASYON SÜRECİNDE KULLANDIKLARI GEREKÇELERİN KAYNAKLARI VE BU KAYNAKLARIN DEĞİŞİMLERİ

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Bu araştırma, sezgiye zıt fizik problemleri ile oluşturulan tartışma ortamlarında öğrencilerin iddialarını dayandırdıkları gerekçelerin kaynaklarını ve bu kaynaklara ne kadar sadık kaldıklarını veya değiştirdiklerini incelemeyi amaçlamaktadır. Araştırma, 'İlköğretim Fen Bilgisi Öğretmenliği Lisans Programı'na kayıtlı 25 birinci sınıf üniversite öğrencisi ile gerçekleştirilmiştir. Öğrenciler sekiz hafta boyunca her bir problem için argümantasyon çalışma kağıtları hazırlayarak argümantasyon süreçlerine katılmışlardır. Katılımcıların gerekçelerinde kullandıkları kaynaklar incelendiğinde, dört ana kategori altında toplam 10 farklı gerekçe kaynağı ortaya çıkmıştır. Ana kategoriler 'Günlük Yaşam Deneyimleri,' 'Günlük Yaşam Gözlemleri,' 'Okul,' ve 'Örtük' olarak ortaya çıkmıştır. Argümantasyon süreçlerinde, katılımcıların gerekçelerindeki değişimler analiz edildiğinde; genel olarak 'Günlük Yaşam Deneyimlerine Dayalı Gerekçeler,' diğer katılımcıların gerekçelerini değiştirmede daha etkili olmuştur. Buna karşın, eğitim ortamlarından (örneğin, öğretmen, ders kitabı, sınıf deneyleri/gösterileri, okul ortamı) üretilen 'Okula Dayalı Gerekçeler,' argümantasyon süreçlerinde diğer katılımcıların öne sürdüğü gerekçelerden daha fazla etkilenmiştir.

Anahtar Kelimeler: Argümantasyon, Gerekçelendirme, Fen Eğitimi.

To my daughter, Karaca and my son, Aslan…

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ABBREVIATIONS

AAAS	: American Association for the Advancement of Science
CSIs	: Controversial Science Issues
NGSS	: Next Generation Science Standards
NOS	: Nature of Science
NRC	: National Research Council
OECD	: The Organization for Economic and Cooperative Development
POE	: Predict-Observe-Explain
PSTs	: Pre-Service Science Teachers
TAP	: Toulmin’s Argumentation Pattern

CHAPTER 1

INTRODUCTION

Philosophy regards the concept of argumentation as central, and philosophers significantly depend on arguments to justify claims. This leads to extensive reflection over millennia on the nature and the process of argumentation. As multifaceted phenomena, arguments and argumentation find broad application across various disciplines, including political science, computer science, cognitive science, linguistics, law, science, and also education, and continue to be subjects of extensive research (Dutilh Novaes, 2021).

1.1 Background to the Study

In the latter half of the twentieth century, innovative educational methodologies emerged in response to societal changes, diminishing the traditional authority of teachers and promoting greater autonomy among learners, encouraging the collaborative construction of knowledge and repositioning educators as coordinators and mentors (Schwarz & Baker, 2017). Our era's evolving societal, cultural, political, and environmental shifts significantly impact various aspects of life and necessitate sophisticated cognitive skills for understanding and engaging in the world. This necessitates a focus in education on developing skills in argumentation and justificatory reasoning such as expressing ideas persuasively and assessing other viewpoints as key educational objectives (Lee, Looi, Khan, Soong, & Neale, 2019; Salminen, Marttunen, & Laurinen, 2012). Thus, given this significance of argumentation and justification skills, a critical question arises: Why are these skills crucial in practice? In reality, argumentation plays an important role in influencing all aspects of our everyday life. Since, in daily life, from choosing political candidates to making personal and commercial decisions, we constantly evaluate options and their advantages and disadvantages to make sound decisions. This decision-making process inherently involves argumentation, a key component of critical thinking that affects all aspects of life, guiding us to make informed and precise choices.

Various scholars emphasize the critical role of argumentation skills in diverse fields such as democracy, medicine, and education for enabling critical thinking and sound decision-making (Boğar, 2019b; Kolstø, 2006; Nussbaum, 2008). This significance is underscored by the constant exposure to claims in everyday life, necessitating skills in evaluation and reasoning (American Association for the Advancement of Science [AAAS], 1993). The critical role of argumentation in formal settings such as courts, parliaments, and education has also been emphasized, highlighting its societal pervasiveness (Abbas & Sawamura, 2011; Dutilh Novaes, 2021; van Eemeren, Grootendorst, Henkemans, Blair, & Johnson, 1996). Furthermore, other researchers extend this pervasiveness by highlighting the interdisciplinary interest in argumentation, from psychology and philosophy to communication technology and computer science (Hahn, Harris, & Corner, 2009; Walton, Reed, & Macagno, 2008). Argumentative exchanges often serve as a form of competitive discourse where individuals defend their claims and counter others' viewpoints until one side is convinced (Berland & Reiser, 2009; Rips, Brem, & Bailenson, 1999). While these interactions occur in various settings, such as classrooms and family gatherings, their impact can be significant, influencing areas from theory acceptance to election outcomes (Rips et al., 1999; von der Mühlen, Richter, Schmid, Schmidt, & Berthold, 2016). In modern democratic societies, argumentation is increasingly recognized as a critical competency for democratic citizenship, essential for navigating abundant information and diverse discussions and for negotiating solutions through collaborative and reasoned deliberations (Asterhan & Schwarz, 2016; D'Souza, 2017; Kolstø, 2006; McNeill & Knight, 2013).

Thus, argumentation is a fundamental aspect of intelligent human behavior and is crucial for handling opposing views, opinions, beliefs, assumptions, aims, and other mental states (Villata, 2018). If so, what is the meaning of argument and argumentation? In the literature, scholars provide various definitions of argument and argumentation, often using examples to clarify these terms. According to O'Keefe (1977) and many other scholars (Berland & McNeill, 2010; Dutilh Novaes, 2021; Jiménez-Aleixandre & Erduran, 2007; Kuhn & Udell, 2003; Sampson & Clark, 2008), the term 'argument' has two distinct meanings, leading to two definitions: 'argument' as a product (individual perspective) and 'argumentation' as a process (social perspective). Beyond these individual and social perspectives, 'argumentation' is broadly defined as the process of convincing, persuading, or refuting opposing views (Ryu & Sandoval, 2012; Toulmin, 2003; van Eemeren & Grootendorst, 2003; van Eemeren et al., 1996; Walton, 1996), with a widely accepted definition from van Eemeren and colleagues emphasizing its structured nature and persuasion goal (Abbas & Sawamura, 2011; Asterhan & Schwarz, 2016; Ford, 2008; McNeill & Knight, 2013; McNeill & Pimentel, 2010; Knight, 2015; Osborne, Henderson, MacPherson, Szu, Wild, & Yao, 2016; Wang, 2020). Many science scholars also typically use the term 'argumentation' as a complex interactive process in which people put forward their claims, ideas, and explanations and justify, criticize, and evaluate them, and the term 'argument' as the artifacts people produce in order to prove their claims at the end of this process (Sampson & Clark, 2008). The structural composition of a scientific argument involves a reality-based claim supported by evidence and reasoning (Driver, Newton & Osborne, 2000; Duschl & Osborne, 2002; Ford, 2008; Jiménez-Aleixandre & Erduran, 2007; Iordanou & Constantinou, 2015; Ludwig, Priemer, & Lewalter, 2021; McNeill, Lizotte, Krajcik, & Marx, 2006; McNeill, González-Howard, Katsh-Singer, & Loper, 2016; McNeill, González-Howard, Katsh-Singer, & Loper, 2017; Sampson & Clark, 2008; Simon, Erduran, & Osborne, 2006). Defining scientific argumentation from a common individual perspective involves scientific reasoning (Duschl & Osborne, 2002; Jiménez-Aleixandre & Erduran, 2007; Knight, 2015; McNeill et al., 2006; Lee, Liu, Pallant, Roohr, Pryputniewicz, & Buck, 2014; Sampson & Clark, 2008), analyzing opposing views (Aydeniz & Gürçay, 2013; Iordanou & Constantinou, 2015; Wang, 2020), expression via writing besides thinking (Driver et al., 2000), and categorizing justifications (Beniermann, Mecklenburg, & Belzen, 2021; Knight, 2015; Ludwig et al., 2021; Maciejewski & Star, 2019; Makowski, 2021; Sandoval & Çam, 2011). Considering the dialogue-based and social aspect of the scientific argumentation, it involves a collaborative community process where members construct, shape, validate, and persuade each other's claims (Berland, 2011; Berland & Reiser, 2010; Driver et al., 2000; Jiménez-Aleixandre & Erduran, 2007; Iordanou & Constantinou, 2015; Knight, 2015; Kuhn, 1993; McNeill & Pimentel, 2010; McNeill et al., 2016; McNeill et al., 2017; Nussbaum, 2011; Osborne, 2010; Sampson & Clark, 2008; Simon et al., 2006). This communicative, social exchange transcends individual assessments, emphasizing the dynamic exchange of reasons, ideas, or arguments at the end (Dutilh Novaes, 2021; Iordanou & Constantinou, 2015; Kim & Roth, 2018; Kuhn, 1993; Mercier, 2016; van Eemeren & Grootendorst, 2003). Therefore, in line with established goals, in this study, scientific argumentation is viewed as both creating justifications for claims and engaging in a dialogical social exchange process to share, critique, revise, and potentially change these justifications in a science classroom, encompassing both written and spoken forms.

The study of argumentation is now a crucial part of academic programs, and argumentation theory experts generally deal with the formation, examination, and assessment of arguments. Philosophical models of argumentation, particularly theories of argumentation, are foundational for psychological theories that explore how individuals process, generate, and judge arguments in educational contexts (Dutilh Novaes, 2021; Nussbaum, 2008; Nussbaum, 2011; van Eemeren et al., 1996).

Science education studies have shown that through prolonged implementations focusing on the teaching and practice of argumentative skills, students can effectively learn to argue. Recognizing this, major educational initiatives worldwide, including Next Generation Science Standards (NGSS), National Research Council (NRC), American Association for the Advancement of Science (AAAS), The Organization for Economic and Cooperative Development (OECD), and 21st-Century Skills, have updated their educational goals, benchmarks, and standards, emphasizing a stronger focus on argumentation. This increased emphasis on argumentation in the science curriculum has led to the development of more detailed assessment methods (Asterhan & Schwarz, 2016; Pearson, Knight, Cannady, Henderson, & McNeill, 2015). During this assessment process, all researchers articulated their shared concern using a single term: “methodology” (Erduran, 2007, p. 47). In science education, the adoption of argumentation theory as a theoretical foundation has resulted in the development of various methodological approaches, techniques, and tools, such as analytical frameworks (Driver et al., 2000; Erduran, 2007). The prevalent use of these analytical frameworks for studying argumentation often emphasizes the qualitative aspects of both the argument’s structure (claims, data, and warrants) and the processes involved in argumentation (Erduran, 2007; Sampson & Clark, 2008; Sandoval & Millwood, 2005). When evaluating argumentation interventions, various parameters emerge, with a common emphasis on the “quality of arguments (argumentation).” Researchers address challenges in evaluating argument quality, especially in educational and scientific contexts (Knight & Grymonpré, 2013). Nonetheless, studies have provided detailed definitions, criteria, and characteristics for high-quality arguments, with an emphasis on logical structure, scientific accuracy, and diverse justifications. Effective assessments take these aspects into account. High-quality arguments are recognized as those that are well-supported and incorporate relevant, multiple, and scientifically accurate justifications, all grounded in scientifically sound information. Arguments exhibiting these characteristics are considered high-quality, whereas those lacking these aspects are seen as less effective (Aydeniz & Gürçay, 2013; Bilican, 2018; Sampson & Clark, 2008; Zohar & Nemet, 2002). This understanding is part of a broader research effort to understand how students develop and articulate scientific arguments (McNeill et al., 2016). In line with these extensive research efforts that have significantly evolved and refined since the 1990s, analytical frameworks and methodological approaches in education have been developed for argumentative discourse. These frameworks enable the description, assessment, and understanding of the quality and nature of arguments. They aid educators in evaluating students' thinking and argumentative skills (Duschl, 2007, 2008; Sampson & Clark, 2008, p.160). Similarly, in science learning contexts, the trend of research focusing on analyzing argumentative discourse aligns with these extensive research efforts. This research aims to evaluate the quality and depth of students' scientific argumentation skills (Jiménez-Aleixandre & Erduran, 2007; McNeill et al., 2016; Sandoval & Millwood, 2005). Among the range of analytical frameworks developed for assessing the nature and quality of scientific arguments, science educators often show a preference for specific types. These frameworks are categorized into two main types: domain-general and domain-specific approaches, each having its own distinct applicability (Boğar, 2019b; Erduran, 2007; Clark, Sampson, Weinberger, & Erkens, 2007; Sampson & Clark, 2008).

An overview of these favored analytical frameworks for examining argumentation's quality and nature in science education reveals a prevalent orientation towards TAP. Moreover, TAP—which acts as a foundation for further evaluation (van Eemeren et al., 1996)—and these frameworks have been overviewed by researchers (Lee et al., 2014; Nussbaum, 2011; Sampson & Clark, 2008) in various contexts. Characterized by their distinct methodologies and evaluation criteria for assessing students' abilities in argumentation (Lee et al., 2014; Nussbaum, 2011), these frameworks provide invaluable insights into understanding the strength and validity of arguments. As highlighted by Sampson and Clark (2008), these insights, information, and perspectives gained through these frameworks make a great contribution to shaping the instructional resources, materials, pedagogical strategies, and educational settings that enhance the efficacy of argumentation practices within the science classroom.

However, analyzing argumentation in science education using these various analytical frameworks is not without its limitations and criticisms. The application of these frameworks introduces specific issues, critiques, challenges, and complexities that must be carefully considered, given their implications for both theory and practice in science education. There are five key issues that stand out and require further inquiry and critique. These range from critiques about analytical frameworks to the recommendation of justification analysis. One of these issues relates to a commonly used framework (Nussbaum, 2011; Sandoval & Millwood, 2005; van Eemeren et al., 1996): TAP. The primary criticism of TAP is that it is unnecessarily challenging to make analytical evaluations to distinguish between the components of an argument, such as claims, data, warrants, and qualifiers. This difficulty, coupled with reliability issues and a lack of clarity in coding, leads to questions about TAP's utility in this field (Evagorou, Jiménez-Aleixandre, & Osborne, 2012; Kim & Roth, 2018; Sandoval & Millwood, 2005; van Eemeren et al., 1996). Secondly, its effectiveness as an evaluative model for assessing the quality or logic of arguments is limited (Driver et al., 2000; Sandoval & Millwood, 2005; van Eemeren et al., 1996). Lastly, TAP struggles to capture the dynamic social and epistemic aspects of argumentation, especially in complex classroom interactions (Kim & Roth, 2018). Another issue relates to various analytical frameworks. In fact, concerns over evaluating argument quality are not exclusive to TAP (Erduran, 2007; Nussbaum, 2011; Sandoval & Millwood, 2005) and have been acknowledged in numerous research efforts critiquing these frameworks. These critiques encompass a range of issues, including the need for mechanisms to quantify adequate supporting data, disagreements among experts over normative criteria for the correctness of ideas, concerns over the level of detail in the information used, and inconsistencies in framework-based assessments of argument quality. While these frameworks vary in approach—from structural to rhetorical and dialectical perspectives— they often struggle with defining and prioritizing the structure, content, and nature of justifications in arguments, leading to inconsistent evaluations of argument quality (Clark et al., 2007; Duschl, 2007, 2008; Erduran, 2007; Nussbaum, 2011; Sampson & Clark, 2008). The third issue in argument analysis emphasizes the importance of field-dependent criteria. Various frameworks, including Toulmin's, highlight that the effectiveness and appropriateness of argumentation analysis are significantly influenced by the specific context and field in which the argument is developed. This perspective underscores that the nature of the argument structure, the criteria for its quality, and the evaluation of its strength must align with field-specific epistemological norms and methodologies, as different fields possess unique standards and approaches to reasoning and debate (Erduran, 2007; Mendonça & Justi, 2014; Sampson & Blanchard, 2012; Sampson & Clark, 2008; Sandoval & Millwood, 2005; van Eemeren et al., 1996). The fourth issue in argument analysis highlights the need for justification analysis. Ludwig et al. (2021) highlight that justifications in arguments vary depending on the academic field and cultural context, demonstrating that justification is both field-dependent and contextually sensitive. Building on this, Sampson and Clark (2008) emphasize the importance of a more holistic approach in analyzing arguments in science education. They suggest that frameworks should not only focus on structural aspects but also on the content, adequacy, accuracy, and epistemic characteristics of justifications. Also, they pointed out that there is a growing demand in science education that allows a broader and more authentic analysis of "overarching patterns of justification" in relation to both content and structure (p. 467). This approach is necessary for a deeper understanding of the nature and quality of scientific argumentation. Ludwig et al. (2021) stress the importance of exploring justifications, especially in laboratory work in science education, for a clearer understanding of students' knowledge generation processes. Ryu and Sandoval (2015) and Iwuanyanwu (2022) further argue that examining the content and rationale of justifications reveals students' thought processes, making it a crucial aspect of argument analysis. Lee et al. (2014) note that students' performance in scientific argumentation heavily relies on their justifications, which connect theory and evidence. As Bricker and Bell (2008) stated, "issue of justification is central to argumentation, and argumentation is understood only by examining justifications (p. 490). All of these perspectives collectively underscore the necessity of a thorough analysis of justifications in argumentation, highlighting that a comprehensive analysis of justifications has a significant role in understanding and evaluating the quality of scientific reasoning in science education.

The fifth issue in argument analysis for scientific argumentation emphasizes the importance of analyzing persuasion, a central process in argumentation. Justification and persuasion are fundamentals in students' arguments as they work to validate and convince others of their ideas (Mendonça & Justi, 2014; Skoumios, 2013). Despite its importance, the aspect of analyzing persuasion is often overlooked (Allchin & Zemplén, 2020; Sandoval & Millwood, 2005). The diversity of analytical frameworks, which include general argument patterns, persuasion, and dialectical reasoning, reflects the multifaceted nature of argumentation (Duschl, 2007; 2008; Lee et al., 2014). Argument quality is multidimensional, involving not only the construction of the argument but also the evaluation of its persuasiveness, including counter-arguments and rebuttals (Nussbaum, 2011; Sandoval & Millwood, 2005). Sandoval and Millwood (2005) emphasize the need to assess more than the formation of arguments, arguing that focusing only on structural aspects can leave gaps in the assessment process. They defend evaluating the persuasiveness of students' arguments, noting that understanding the development of scientific arguments requires an evaluation that extends beyond their formation or structure to include an assessment of their persuasiveness.

To address these issues more effectively and align with the multidimensional nature of scientific argumentation analysis, many researchers have adapted existing frameworks or explored alternative new methods and approaches. For example, to address the challenge of distinguishing between components and the validity and reliability problems of utilizing TAP, many researchers formulated 'the notion of justification' and preferred to analyze an argument simply by accepting it as its claim and its justification (Erduran, Simon, & Osborne, 2004; Evagorou et al., 2012; Kim & Roth, 2018; Sampson & Clark, 2008; Sandoval & Millwood, 2005; Zohar & Nemet, 2002). To summarize, researchers in education, regardless of their use of the TAP, face significant challenges in assessing argument quality, which leads to uncertainties in analysis (Nussbaum, 2011; Erduran, 2007; Ludwig et al., 2021; Mendonça & Justi, 2014; Sampson & Clark, 2008). These challenges are particularly pronounced in less-explored areas of argumentation in science classrooms (Erduran, 2007), such as justification and persuasion. Moreover, employing qualitative research methods is crucial for understanding the social and cognitive dynamics in educational settings, enhancing the study of argumentation (Nussbaum, 2008). Considering all these issues and critiques mentioned above, a clear need is observed for a shift or transition from evaluating the quality of arguments to focusing on the analysis of the justifications behind them. This shift involves moving from assessing the strength and effectiveness of arguments to a detailed examination of the justifications that support their validity and persuasiveness. A deeper understanding of the fundamentals of persuasive discourse is essential.

Justification analysis in science education is vital for linking scientific assertions to data and is a core component of argumentation (Brigandt, 2016; Ludwig et al., 2021; Skoumios, 2013). It plays a significant role in classroom practices and is essential in collaborative teaching activities (Salminen et al., 2012; Vieira, Dias, Melo, & Nascimento, 2016). This analysis is crucial for problem-solving and question-answering, reinforcing the connection between argumentation strength and justification quality (Erduran et al., 2004; Nussbaum & Bendixen, 2003). Understanding and analyzing justifications in scientific discourse is important as it plays a central role in advancing scientific understanding and shaping educational practices and standards (Bricker & Bell, 2008; Ludwig et al., 2021; Skoumios, 2013). When reviewing the studies focused on the analysis of justification, it becomes clear that these research efforts exhibit diverse perspectives. In justification analysis studies from an epistemological perspective (Bråten, Ferguson, Strømsø, and Anmarkrud, 2013: Bråten, Ferguson, Strømsø, and Anmarkrud, 2014; Krist, 2020), the focus is on understanding the nature and acquisition of knowledge, examining how epistemological constructs like personal epistemology, epistemic beliefs, criteria, and cognition influence the formation, structure, and evaluation of justification. Justification analysis studies conducted from another perspective (Skoumios, 2013) focus on the criteria individuals or groups use to justify scientific knowledge claims. This perspective examines the selection and impact of these criteria on the structure of justification, highlighting the influence of social, cultural, and personal factors in scientific justification's decision-making and evaluative processes. Some of the justification analysis studies (Beniermann et al., 2021; Maciejewski & Star, 2019; Makowski, 2021; Premo, Cavagnetto, Honke, & Kurtz, 2019) belong to other perspective focus on identifying and classifying various types of justifications. It bridges theoretical concepts with practical applications in scientific knowledge justification, offering a comprehensive view of justifications' diverse forms and structures. Alongside these three approaches, there is another significant perspective in justification analysis studies: the determination and categorization of sources of justification. In recent science education, the involvement in argumentation research typically focuses on analyzing arguments, their sources, and justifications (Allchin & Zemplén, 2020; Sandoval & Çam, 2011), and "the types of justification sources are valued within the scientific community (McNeill et al., 2016, p.264)." Studies conducted from this perspective (Bilican, 2018; Bråten, Strømsø, and Andreassen, 2016; Knight, 2015; Ludwig et al., 2021; McNeill & Pimentel, 2010; Salmerón, Macedo-Rouet, & Rouet, 2016; Sandoval & Çam, 2011) explore the variety of sources used in the justification process, evaluating their influence on the quality of the justifications provided. They highlight the significance of the origin and nature of information and evidence in shaping justification.

In summary, the current literature in science education notably lacks studies focusing specifically on justification analysis. This research gap is highlighted in terms of the types, contents, and nature of justifications in student arguments, as well as how students transfer schooled knowledge and justification skills to unschooled contexts (Beniermann et al., 2021; Cheng, Bråten, Yang, & Brandmo, 2021; Skoumios, 2013). It is also evident that there is a notable gap in the research surrounding 'sources of justification analysis,' particularly in how students construct and critique these sources within scientific argumentation (Knight, 2015; Sandoval & Çam, 2011).

Therefore, this study intends to investigate and categorize the different sources of justifications. Additionally, to the best of our knowledge, no study has yet simultaneously categorized types of justification sources and monitored the changes in these sources within the argumentation process. Consequently, the purpose of this study was to conduct the analysis of justification as a key component of constructed arguments. More precisely, the research investigated students' justifications for their claims in the realm of physics and categorized the diverse types of sources used to support these justifications. It also explores the change in these sources during argumentation practices.

1.2 Rationale of the Study

In light of the aspects in argumentation literature mentioned above, it is observed that researchers generally analyze whether students can construct an argument with all its parts (claim, data, warrant, backing, qualifier, counterclaims, and rebuttals), whether all parts of the argument are grounded in scientifically sound information, and whether these arguments incorporate various relevant, multiple, and scientifically accurate justifications. Thus, scholars aim to determine the quality of students' arguments, their argumentation skills, and their levels of argumentativeness. In other words, the general focus of argumentation literature is actually on ‘argumentation for argumentation,’ i.e., whether students can handle argumentation and the overall quality of an argument.

The question is whether it is sufficient to assess the quality of an argument by only checking its logical structure, scientific accuracy, and the diversity of its justifications.

This consideration is essential because what constitutes a high-quality argument or justification in scientific contexts may not align with the standards in a general school setting. The criteria for determining sufficient justification for a claim, or what is considered a good argument, might vary between school-based inquiry tasks and professional scientific research (Ludwig et al., 2021; Sandoval, 2003). The concepts of argumentation and persuasion can be understood differently among students and educators. In everyday language, these concepts are often seen as competitions or zero-sum games, meaning when one side wins, the other loses. Students generally approach these processes not in an epistemic way but rather in a political (with the aim of persuading or winning) manner (Allchin & Zemplén, 2020).

In fact, from the students' perspective, the quality of an argument lies in the strength of its justifications, which means the ability to persuade and change opposing viewpoints in argumentation-based learning environments.

Furthermore, in a well-organized dialogic argumentation environment, it is observed that justifications can change. More detailed observations in this learning environment reveal that specific justifications can easily replace others when justifications interact. Similarly, some justifications appear to be easily influenced by different ones.

Consequently, several questions arise. In well-organized, dialogic, argumentation-based learning environments, what types of justifications emerge? How do these different types of justifications interact with each other? How does one justification affect others, and how does one justification respond to other justifications? Essentially, what are the types of justifications and their effects on one another?

Ultimately, this study aims to convey that while it is important for an argument to be constructed with all its parts, to maintain scientific accuracy, and to have relevant, multiple, and scientifically accurate justifications, there are other crucial elements to consider. One such element is the type of justification used, as well as its persuasive power in changing opposing justifications. Therefore, it is essential to examine the sources that feed these justifications, classify the justifications based on these sources, and consider their interactions during argumentation.

To achieve this goal, the learning environment where dialogic knowledge-building argumentation takes place must be carefully designed, and appropriate tasks should be selected. This is because students need not only to think and organize their ideas to establish their justifications but also engage in a debatable environment where these justifications can compete and actual argumentation occurs. In this competitive environment, the chosen tasks should enable the formation of various claims and justifications. Moreover, to enrich the debate, students should have access to an environment where they can collect and analyze data.

To ensure these necessary conditions and facilitate well-organized dialogic knowledge-building argumentation processes, employing an instructional strategy such as 'Predict-Observe-Explain' (POE) along with debatable inquiry tasks, particularly those that include 'Counter-Intuitive Physics Questions,' is a suitable choice.

The POE instructional strategy is notably effective for incorporating argumentation into learning environments (Ha & Kim, 2018; Osborne, Erduran, & Simon, 2004). It actively involves students with empirical evidence in a way that's supportive of argument development. This approach aligns with the insights of Osborne et al. (2004), who prepared "nine generic frameworks as the essential principles for initiating argument in the science classroom (p. 1002)." Drawing on their examination of the current literature, they crafted these frameworks to effectively encourage argumentative discourse in classroom environments. A summary of these frameworks provides a roadmap for creating resources that aid and enhance argumentation in science teaching. This emphasis on structured frameworks highlights POE as one of the crucial activities that creates an effective argumentation environment. This strategy involves students making initial predictions about an unseen phenomenon, discussing their expectations, and justifying their reasoning.

After observing the actual phenomenon, students are encouraged to compare their initial predictions with the actual outcomes, leading to a critical reevaluation of their original arguments if there are discrepancies (Osborne et al., 2004). This methodology not only fosters a dynamic learning environment rich in argumentation but also encourages students to engage deeply with the process of scientific inquiry and reasoning.

Moreover, incorporating debatable inquiry tasks with counter-intuitive questions not only fosters a diversity of claims but also encourages the development of varied justifications, thus enriching the discussion. Additionally, the cognitive conflict, discrepant events, or epistemological doubts students experience following demonstrations designed to answer such counter-intuitive questions can provoke deeper thinking. In other words, counter-intuitive questions can create a more controversial and stimulating argumentation environment, especially when combined with the POE strategy. Given that an examination of the current literature reveals that counter-intuitive physics questions have mainly been abundant and excessively produced, particularly within the mechanics unit, this study has selected the mechanics unit as its focus in physics.

1.3 Purpose and Research Questions of the Study

The argumentation process designed for this study aims to examine the sources of justifications upon which students base their claims; and observe how faithfully they adhere to these sources or change their justifications in an argumentation environment. Within the scope of this study, first-year university students majoring in the ‘Elementary Science Teaching Education’ department were given eight tasks involving counter-intuitive physics questions related to the mechanics unit during the argumentation process. Each task consisted of six phases. The six phases involved in this argumentation process, which employs the POE instructional strategy, are briefly described below:

'Phase 1: Initial Justifications': Participants presented their initial claims and justifications regarding the question provided in the given task.

'Phase 2: Group Discussion 1 - Before the Demonstration': Participants engaged in discussions in groups of 4-5 people, sharing their initial claims and justifications about the given question.

'Phase 3: Revised Justifications After Group Discussion 1 - Before the Demonstration': After the group discussion, participants reviewed their initial justifications, considering all the justifications that emerged during the discussion.

'Phase 4: Revised Justifications After the Demonstration': Participants observed the demonstration and the slow-motion video related to the correct answer to the given problem. Then, participants reviewed their justifications again and made the necessary changes.

'Phase 5: Group Discussion 2 - After the Demonstration': Participants, in groups of 4-5 people, discussed their observations regarding the demonstration experiment and, if applicable, shared new justifications that emerged after this phase.

'Phase 6: Final Justifications After Group Discussion 2 - After the Demonstration': Participants reviewed their justifications, made necessary changes, and provided the final version of their justifications.

In this study, we seek answers to the following research questions in the context of a dialogic argumentation process conducted with first-year university students, which employs the POE instructional strategy and involves debatable inquiry tasks, including counter-intuitive physics questions related to the mechanics unit:

1. What types of justification sources emerged during the argumentation process?
2. How do the types of justification sources vary across the six phases of the argumentation process?
3. How do the types of justification sources vary across the eight tasks?

4. How do participants' justification source types change after Group Discussion 1 (before the demonstration)?
   4.1. How do participants' justification source types change after Group Discussion 1 (before the demonstration) across eight tasks?
   4.2. How do participants' justification source types change after Group Discussion 1 (before the demonstration) in terms of being relevant or irrelevant justifications?
5. How do participants' justification source types change after Group Discussion 2 (after the demonstration)?
   5.1. How do participants' justification source types change after Group Discussion 2 (after the demonstration) across eight tasks?
   5.2. How do participants' justification source types change after Group Discussion 2 (after the demonstration) in terms of being relevant or irrelevant justifications?

1.4 Significance of the Study

The analysis of scientific argumentation is complex and multidimensional, necessitating an integrated, multifaceted approach to assessment (Duschl, 2007, 2008; Lee et al., 2014; Nussbaum, 2011; Sampson & Clark, 2008).

This comprehensive assessment, which goes beyond structural analysis to include content and social dynamics, is emphasized in current trends in science education. As Sampson and Clark (2008) state, while the structural analysis of arguments remains predominantly preferred and essential in science education for evaluating argument quality, there is a growing consensus on the need for more comprehensive, holistic approaches. These emerging perspectives should encompass not only the structure but also the content, epistemic attributes, and social dynamics of arguments. Additionally, exploring why and how certain themes and patterns emerge in arguments within educational contexts is important. The consideration of "causal mechanisms and core concepts" is also essential. Focusing on the adequacy and epistemic characteristics of justification is now accepted in science education. Thus, there is a growing demand in science education for a broader and more authentic analysis of "overarching patterns of justification" (p. 467).

Many researchers also emphasize the necessity of a thorough analysis of justifications in argumentation, highlighting that a comprehensive analysis of justifications has a significant role in understanding and evaluating the quality of scientific reasoning in science education (Bricker & Bell, 2008; Brigandt, 2016; Iwuanyanwu, 2022; Lee et al., 2014; Ludwig et al., 2021; Ryu & Sandoval, 2015; Skoumios, 2013), and in classroom practices (Salminen et al., 2012; Vieira et al., 2016).

Additionally, scholars underline the importance of the origin and nature of information in shaping justifications, namely the necessity of determining and categorizing the sources of these justifications (Allchin & Zemplén, 2020; Knight, 2015; Ludwig et al., 2021; McNeill & Pimentel, 2010; McNeill et al., 2016; Sandoval & Çam, 2011).

For the comprehensive assessment mentioned above, another essential consideration is the importance of analyzing persuasion as a central process in argumentation, which many researchers have highlighted and recommended (Allchin & Zemplén, 2020; Duschl, 2007; 2008; Hoeken, Timmers, & Schellens, 2012; Lee et al., 2014; Mendonça & Justi, 2014; Nussbaum, 2011; Sampson & Clark, 2008; Sandoval & Millwood, 2005; Skoumios, 2013). Both the criteria students use to decide which evidence or reasons are most persuasive (Hoeken et al., 2012; Sampson & Clark, 2008; Skoumios, 2013) and the persuasiveness of arguments, counter-arguments, and rebuttals (Nussbaum, 2011) should be analyzed. Therefore, As Ludwig et al. (2021) discussed, "it seems especially important to investigate the relationship between persuasion and the use of different justifications" (p. 839).

However, the current overview of science education research reveals a significant gap in the study of justification analysis (Beniermann et al., 2021; Cheng et al., 2021; Skoumios, 2013). Despite its critical role in developing a comprehensive understanding of scientific argumentation, justification analysis remains an underexplored area. This lack of attention highlights the urgent need for more studies focused on how students formulate and use justifications in their arguments.

Moreover, some research also explores the variety of sources used in the justification process, evaluating their influence on the quality of the justifications provided (Bilican, 2018; Bråten et al., 2016; Knight, 2015; Ludwig et al., 2021; McNeill & Pimentel, 2010; Salmerón et al., 2016; Sandoval & Çam, 2011). It is evident that there is also a notable gap in the research surrounding the 'sources of justification analysis,' particularly in the context of science education (Knight, 2015; Sandoval & Çam, 2011), and this gap emphasizes the urgent need for more research on the sources of justification.

Additionally, argumentation studies have gained significant attention within the field of science, with a notable concentration in science education. However, it is worth noting that this prominence is not equally reflected in the fields of physics, chemistry, and biology. In these specific scientific disciplines, the density of research and scholarly investigations related to argumentation appears to be comparatively lower (Boğar, 2019a). Also, the investigation of argumentation, specifically within the physics laboratory, remains limited in the existing literature (Demircioğlu, 2022; Ludwig et al., 2021). Furthermore, while the importance of implementing argumentation in science classrooms is well acknowledged, there is also a strong emphasis on equipping pre-service science teachers (PSTs) with these argumentation skills, as they will be the future practitioners of these educational strategies. However, there is a need for more studies in various contexts within the field of science to address the pedagogical knowledge and skills that PSTs must acquire in this area (Aydeniz & Gürçay, 2013).

At the intersection of all these needs, this research's primary aim is to comprehensively examine justifications in the argumentation process. This aim will involve exploring and classifying the diverse sources of justification. Moreover, the study will also examine the change in these sources throughout the argumentation process.

To the best of our knowledge, no prior study has simultaneously categorized types of justification sources and monitored the changes in these sources within the argumentation process.

Consequently, recognizing the importance of analyzing scientific argumentation from various aspects, including structure, this study aims to conduct an analysis of justification as a key component of constructed scientific arguments. The intent of this study was to examine, from the perspective of physics education, the various types of justification sources that emerge during the argumentation process and to analyze the consequences of their interaction. This analysis primarily focused on sources such as personal experiences from daily life, observations from daily life, and prior knowledge. These sources are often thought to be left behind when they enter the classroom (National Research Council [NRC], 2000), but in reality, they are not (Sandoval & Çam, 2011). Another goal was to investigate how changes occur in these different sources of justifications, such as the ways in which various justifications convince each other and how one justification can change another.

This study significantly contributes to the field by providing a detailed analysis of the types of justification sources that PSTs use, particularly within the context of physics laboratory work. By examining the nature of these justifications, their sources, and how they change, this research not only adds depth to the existing literature but also establishes a foundational basis for future similar investigations as it enhances our understanding of justifications in educational contexts. Therefore, this study is expected to serve as a valuable resource for similar research attempts, providing a detailed overview of current research and a guide for future exploration in this field.

Additionally, this study offers valuable insights into several key areas, particularly in enhancing our understanding of PSTs' use of justifications within the argumentation process. By conducting a comprehensive examination of the emerging diverse types of justification sources and their interactions, especially in the context of physics, this research deepens our knowledge of the cognitive processes involved in scientific reasoning and argumentation. Such an understanding is crucial, considering the significant role that justifications play in scientific argumentation and understanding. Moreover, this study sheds light on the ways in which PSTs use justifications. The insights gained from this research are not only significant for the field of science education but also have broader implications for understanding how reasoning and argumentation skills develop in educational settings. Consequently, this contribution is significant, as it provides a more comprehensive understanding of the mechanisms and practices involved in the effective use of justifications in scientific discourse.

In terms of contributions to educators and teacher trainers, this study offers significant benefits. By analyzing and categorizing the different types of justification sources that students use, it presents an "overarching pattern of justification," as stated by Sampson and Clark (2008, p. 467). Insights from these patterns are crucial for researchers, educators, teachers, and pre-service teachers, as these insights help in comprehending the possible justifications in physics they may encounter in their science classrooms. Moreover, the research provides insights into how PSTs use justifications in physics, which is essential for educators training PSTs. These insights help them guide PSTs to recognize and apply a range of scientific justifications more effectively. Gaining a better understanding of the types of justification sources used by PSTs to support their ideas is crucial for both researchers and school teachers. Such understanding plays an essential role in improving students' science learning, as it helps them to analyze arguments and assess evidence more critically and effectively.

Finally, such research is also crucial for developing more effective teaching strategies that can foster these skills in students. The limited research in justification analysis not only highlights a rich and productive area for future scholarly work but also offers researchers a chance to make significant contributions to the discipline. Exploring this overlooked area could lead to new insights and methodologies in science education, particularly in understanding how students' use and comprehension of justifications influence their learning processes and outcomes.

1.5 Definition of Important Terms of the Study

This section introduces key concepts crucial to our discourse: ‘Argument,’ ‘Argumentation,’ ‘Justification,’ and ‘Sources of Justification.’

‘Argument’ and ‘Argumentation’ are defined as a product (from the perspective of the individual) and as a process (from the perspective of the social), respectively. At the individual level, an argument represents the information formulated by someone ‘to justify a claim or an explanation.’ This is part of a process where people endeavor to verify, support, or justify various conclusions or claims through individual reasoning. Conversely, from a social standpoint, an argument is more interactive, transcends individual reasoning, and becomes a collective engagement. It involves expressing and defending viewpoints on a subject as defended by participants in opposition during a debate or disagreement. This engagement of argumentation may be described as a collective, verbal, and logical process that can be collaboratively shaped through dialogue or formulated rhetorically in either written or verbal form (Berland & McNeill, 2010; Dutilh Novaes, 2021; Jiménez-Aleixandre & Erduran, 2007, p.12; Kuhn & Udell, 2003; Sampson & Clark, 2008). Therefore, the term encompasses both the individual act of reasoning (argument) and the more

interactive and collaborative act of engaging in dialogue, discussion, or debate, reflecting different aspects of communication and critical thinking (argumentation).

'Justification' is the rational assessment process of giving good reasons to show that a certain claim, idea, or statement should be believed or accepted (Ferreira, El-Hani & da Silva-Filho, 2016). It also comprises "information components such as data-warrants-backings-reasons" contained in the arguments (as cited in Sampson & Clark, 2008, p. 467).

'Sources of Justification' refer to the origins or bases from which justification is derived. There are different sources of justification for a claim in scientific discourse, including "empirical evidence, science ideas, appeals to authority, plausible mechanisms, and prior experiences," each holding varied epistemological value (Knight, 2015, p.35).

CHAPTER 2

REVIEW OF RELATED LITERATURE

The literature review related to argumentation is presented in this chapter. For the clarity and ease of reading, the chapter is divided into the following main sections: ‘Argumentation’, and ‘Analyses of Argumentation Process in Science Education.’

2.1 Argumentation

Philosophy considers the concept of argumentation central serving as a foundational element that forms the basis for exploration and examination of various ideas, perspectives, and theories within the discipline. In order to justify their claims, philosophers depend significantly on arguments; this leads to reflections on the nature of arguments and the process of argumentation. Research into argumentation engages experts across various fields, highlighting its importance and widespread application, extending beyond philosophy to areas like political science, computer science, cognitive science, linguistics, law, science, and also education. Thus, the scholarly works related to arguments and argumentation are diverse, and as multifaceted phenomena, arguments and argumentation continue to be subjects of extensive research across different domains (Dutilh Novaes, 2021).

In education, innovative pedagogical methodologies during the latter half of the twentieth century correlate with societal shifts like the ‘erosion of adults’ and consequently the diminishing authority of teachers. And this has provided more autonomy to the learners. These shifts have effectively fostered an environment where the learners voices to be recognized during small group discourse. In this environment, learners could collaboratively construct their own understanding, with the educator serving as a coordinator and mentor rather than a sole source of knowledge for students to absorb (Schwarz & Baker, 2017, p. 135).

Besides, in our contemporary era, political, cultural, societal, and environmental shifts have a profound influence on our cognitive processes, political affairs, commercial activities, human rights issues, and conflict resolution strategies. Given their complexity and ever-changing nature, these shifts demand sophisticated cognitive abilities to comprehend the world around us. Such abilities involve both expressing our ideas persuasively and assessing others' viewpoints and arguments in a constructive manner. As a result, the skill of formulating, elaborating, and analyzing an argument is considered a significant educational objective (Salminen et al., 2012). Also, the critical necessity of students, who are future contributors to society, gaining the ability to use justificatory reasoning skills has been emphasized by researchers (Lee et al., 2019).

In light of the previous mention of collaborative student knowledge building and the demand for advanced cognitive abilities in our complex and rapidly changing world, the significance of argumentation skills becomes apparent. Thus, a critical question arises: What is the importance of these argumentation skills, and why are these skills crucial in practice?

In reality, argumentation plays an important role in influencing all aspects of our everyday life. In our daily lives, we all want to be able to make sound decisions in various contexts, such as selecting the right candidate in democratic elections, conducting commercial activities like purchasing a house or a car, planning a suitable career path that meets our needs, selecting our employees; choosing a school for our children and planning where to spend our vacation. During each of these decision-making stages, we explore all options with their pros and cons, discuss them, and aim to make the most precise and sound decision. The ability to make sound decisions essentially embodies argumentation, because argumentation is a primary tool for critical thinking and sound decision-making, permeating all stages of daily life.

Similarly Nussbaum (2008) stated that using argumentation skills effectively, such as making arguments and evaluating counter-arguments about the situations encountered in many different fields of everyday life such as democracy, medicine, and education, is very important, and in this way, critical thinking and sound decision-making are realized. Kolstø (2006) pointed out that in everyday contexts of the real world, there’s been an inclination to emphasize the examination of human reasoning and also for “thoughtful decision-making” in science teaching, the ability to use arguments is important (p. 1712). When we look at the argumentation literature in general, it is understood that the argumentation approach is important in order to define and solve the problems that may be encountered in daily life (Boğar, 2019b). Since “in everyday life, people are bombarded with claims-claims about products, about how nature or social systems or devices work, about their health and welfare, about what happened in the past and what will occur in the future” (AAAS, 1993, p. 298)

Therefore, arguing is a fundamental aspect of our daily lives, playing a critical role not only in courts, parliaments, and scientific communities (platforms we are frequently discussing) but also in several distinct and structured social activities. Its relevance is particularly pronounced in the legal, political, scientific, and educational spheres, emphasizing the pervasive nature of argumentation throughout our society (Abbas & Sawamura, 2011; Dutilh Novaes, 2021; van Eemeren et al., 1996).

In our era, this pervasiveness of argumentation in our daily routines is undeniable; it influences everything from critical legal, political, and academic discussions to everyday decisions and plans on what actions to take and how to conduct them. Therefore, it has unsurprisingly drawn attention from multiple disciplines, including psychology, and philosophy as well as the fields of linguistics, logic, communication technology, education, and computer science (Hahn et al., 2009; Walton et al., 2008).

Commonly, argumentative exchanges in our daily routines are interpreted as a form of competitive discourse. Within these exchanges, individuals propose their claims (or assertions), defend the justifications for these claims, and either agree with or refute others' viewpoints, claims, and justifications by producing counter-arguments. These exchanges typically continue until one side convinces the other and thus wins the argument (Berland & Reiser, 2009; Rips et al., 1999).

Moving beyond the competitive nature of argumentation, von der Mühlen et al. (2016) stated that this competitive discourse can take many forms. This could be seen when politicians try to convince us to vote for their parties, columnists in newspapers try to provide a unique viewpoint on societal problems, or individuals try to make sound decisions about their career paths. On a more detailed level, these competitive discourses are common in settings such as classrooms, family gatherings, or workplaces. While some of these discussions are brief and straightforward (dialogues on cinema, sports, magazines, etc.), others can turn into longer, significant debates (dialogues on politics, legal or academic issues, etc.). The importance of these in-depth debates becomes evident when they influence the acceptance of a theory by persuading others and the results of an election (Rips et al., 1999).

As emphasized by numerous scholars in our modern democratic societies, argumentation has emerged as a critical competency in the context of democratic citizenship. With the rise of technologies, especially in communication, the ability to effectively argue has become vital. Citizens today interact with an abundance of information and engage in discussions on a multitude of topics with people from diverse backgrounds. The ability to negotiate solutions through collaborative and reasoned deliberations is increasingly vital for citizenship (Asterhan & Schwarz, 2016). Argumentation is a critical skill not only for the enhancement of scientific literacy but also vital for enabling citizenship (Kolstø, 2006; McNeill & Knight, 2013). Further emphasizing its importance, D’Souza (2017) suggests that these argumentation skills are essential components in the fostering of democratic citizenship.

2.1.1 Definitions for Argument and Argumentation

The practice of argumentation is essential for managing opposing views, opinions, beliefs, assumptions, aims, and other mental states. It is a common aspect of intelligent human behavior (Villata, 2018).

If so, what is the meaning of argumentation? The dictionary has different definitions for the term argument, representing another aspect or context of the word. Some of these represent the formal or academic aspect of argumentation and encompass a broader meaning of the term, such as “a coherent series of reasons, statements, or facts intended to support or establish a point of view” and “the act or process of arguing, reasoning, or discussing: argumentation”. Others address more specific usages of an argument, such as reasons given concerning a subject or “a form of rhetorical expression intended to convince or persuade” (Argument, 2023).

When examining the literature related to argument and argumentation, similar to what is observed in dictionaries, scholars try to define these terms through diverse definitions, providing examples to clarify these definitions.

According to O’Keefe (1977), in daily conversation, the term ‘argument’ is consistently utilized to denote two distinct concepts. One of these refers to a specific type of expression (‘argument-1’), and the other to a form of interactive communication (‘argument-2’). Specifically, argument-1 refers to the communication act of a single individual, while argument-2 denotes an interaction that occurs between two or more individuals. This is the fundamental difference between the two concepts. Argument-1: This represents a structure created, presented, or articulated by an individual. Essentially, it’s a type of expression or an act of communication. It embodies the meaning found in everyday statements like “he made an argument”. Argument-1 is classified in the same category as “promises, commands, apologies, warnings, invitations, orders”, and other similar acts of communication. Argument-2: This represents an interaction in which two or more individuals are involved or participate. It embodies the meaning found in everyday statements like ‘They had an argument’. Argument-2 can be classified with other conversation types like “bull sessions, heart-to-heart talks, quarrels, discussions, and so on” (O’Keefe, 1977, p. 121). If argument is viewed as a product—specifically, a series of propositions from which a conclusion can be drawn based on the premises—then these concrete products that emerge as a result of the reasoning, either collectively with others or individually, serve as an example of Argument-1 (Nussbaum, 2008). Conversely, if argument is viewed as a social process, an instance of Argument-2 would be a classroom discussion or debate where at least two students construct their own arguments and evaluate each other's arguments, specifically having the opportunity to assess many different arguments (Nussbaum, 2008; Nussbaum, 2011).

Similar to O’Keefe, there exist other scholars who characterize the notions of argument and argumentation as a product (from the perspective of the individual) and as a process (from the perspective of the social) respectively (Berland & McNeill, 2010; Dutilh Novaes, 2021; Jiménez-Aleixandre & Erduran, 2007; Kuhn & Udell, 2003; Sampson & Clark, 2008). At the individual level, an argument represents the information formulated by someone ‘to justify a claim or an explanation.’ This is part of a process where people endeavor to verify, support, or justify various conclusions or claims through individual reasoning. Conversely, from a social standpoint, an argument is more interactive, transcends individual reasoning, and becomes a collective engagement. It involves expressing and defending viewpoints on a subject as defended by participants in opposition during a debate or disagreement. This engagement of argumentation may be described as a collective, verbal, and logical process that can be collaboratively shaped through dialogue or formulated rhetorically in either written or verbal form (Berland & McNeill, 2010;

Dutilh Novaes, 2021; Jiménez-Aleixandre & Erduran, 2007, p.12; Kuhn & Udell, 2003; Sampson & Clark, 2008). Therefore, the term encompasses both the individual act of reasoning (argument), and the more interactive and collaborative act of engaging in dialogue, discussion, or debate, reflecting different aspects of communication and critical thinking (argumentation).

However, beyond these individual and interactive perspectives to argumentation definition, there exists a broader approach for argumentation as well. In this approach, many of the other definitions highlight argumentation as a process in which one convinces others, persuades them to accept a standpoint, or refutes opposing views (Ryu & Sandoval 2012; Toulmin, 2003; van Eemeren & Grootendorst, 2003; van Eemeren et al., 1996; Walton, 1996). In this context, as Asterhan and Schwarz (2016) stated, the definition of argumentation that is broadly accepted and captures the basic idea of argumentation belongs to van Eemeren and his colleagues. "Argumentation is a verbal, social, and rational activity aimed at convincing a reasonable critic of the acceptability of a standpoint by putting forward a constellation of propositions justifying or refuting the proposition expressed in the standpoint" (van Eemeren & Grootendorst, 2003, p. 1). Some scholars (Abbas & Sawamura, 2011; Ford, 2008; Knight, 2015; McNeill & Knight, 2013; McNeill & Pimentel, 2010; Osborne et al., 2016; Wang, 2020) also seem to share this common definition of argumentation which emphasizes its structured nature of argumentation and the goal of persuasion (increasing or decreasing the acceptability of a viewpoint).

Science progresses through scientific thought, and it is shaped by inter-personal discussions and not merely by individual thoughts. So, it is inherently a collaborative process, a social engagement. To comprehend how scientific ideas evolve, it is crucial to consider this "arena of public debate" or "social exchange" where these ideas are commonly presented, examined, refined, defended, expanded, and often even first originated. From the positivist view of science, which perceives science as absolute and continually growing, no scientific method can separate science from argument or debates. In this arena of social dialogue, even both theories and facts in science could turn into debatable constructs (Kuhn, 1993). In other words, argumentation is a fundamental aspect of scientific practice that involves presenting knowledge claims supported by evidence, assessing critically these scientific propositions, and determining underlying assumptions, and then selecting among contradicting assertions based on evidence. In essence, argumentation can be viewed as a process of examining and revising knowledge claims in the context of the evidence at hand over time (Jiménez-Aleixandre, 2014; Jiménez-Aleixandre & Erduran 2007; McNeill et al., 2016; Osborne, 2010). In the realm of science education, with increasing focus of science educators (Jiménez-Aleixandre, 2014), argumentation practice includes analysis of data and justifications to build explanations (Osborne et al., 2004; Simon et al., 2006).

Many science scholars also typically use the term 'argumentation' as a complex interactive process in which people put forward their claims, ideas, and explanations and justify, criticize, and evaluate them, and the term 'argument' as the artifacts people produce in order to prove their own claims at the end of this process (Sampson & Clark, 2008).

In other words, they define scientific argumentation from two perspectives: its structural composition and function as a dialogical process.

The structural composition of a scientific argument is based on a claim about reality, backed by scientific evidence and reasoning. A claim is an assertion about a topic; evidence comprises measurable facts or observations; scientific reasoning provides justification for claim by using supporting evidence (Driver et al., 2000; Duschl & Osborne, 2002; Ford 2008; Jiménez-Aleixandre & Erduran, 2007; Iordanou & Constantinou, 2015; Ludwig et al., 2021; McNeill et al., 2006; McNeill et al., 2016; McNeill et al., 2017; Sampson & Clark, 2008; Simon et al., 2006). Therefore, defining scientific argumentation concerning the common individual perspective—particularly its composition—is perceived as an individual activity. This activity involves scientific reasoning (Duschl & Osborne, 2002; Jiménez-Aleixandre &

Erduran, 2007; Knight, 2015; McNeill et al., 2006; Lee et al., 2014; Sampson & Clark, 2008), presenting and analyzing opposing views to assess which view holds greater merit (Aydeniz & Gürçay, 2013; Iordanou & Constantinou, 2015; Wang, 2020), and is expressed through both writing and thinking (Driver et al., 2000). Additionally, it emphasizes the categorization of justifications (Beniermann et al., 2021; Knight, 2015; Ludwig et al., 2021; Maciejewski & Star, 2019; Makowski, 2021; Sandoval & Çam, 2011).

The dialogue-based and social aspect of the scientific argumentation process is based on social activity within a community where members collaboratively construct, shape, validate, and persuade each other of their claims (Berland, 2011; Berland & Reiser, 2010; Driver et al., 2000; Jiménez-Aleixandre & Erduran, 2007; Iordanou & Constantinou, 2015; Knight, 2015; Kuhn, 1993; McNeill & Pimentel, 2010; McNeill et al., 2016; McNeill et al., 2017; Nussbaum, 2011; Osborne, 2010; Sampson & Clark, 2008; Simon et al., 2006).

In this socially negotiated interaction, participants collaboratively articulate, defend, and refine their views, especially in contexts of disagreement. This communicative, social exchange transcends individual assessments, emphasizing the dynamic exchange of reasons, ideas, or arguments at the end (Dutilh Novaes, 2021; Iordanou & Constantinou, 2015; Kim & Roth, 2018; Kuhn, 1993; van Eemeren & Grootendorst, 2003). "The social exchange of arguments often leads to good reasoning performance" (Mercier, 2016, p.151).

For scientific argumentation, the NRC's framework for K-12 Science Education (NRC, 2012) highlights the significance of constructing scientific arguments from evidence and engaging in the scientific argumentation process in scientific knowledge production and meaningful science learning. According to NRC (2012), scientific argumentation is the foundation of knowledge production in science, where "scientists use evidence and reasoning to make a justified claim about the world." A critical part of scientific argumentation involves the engagement to "critique and defend scientific arguments" and "identifies weaknesses and limitations, leading to potential changes and improvements in proposed models, explanations, or designs" (p. 46, 71, 251).

All of the various aspects of scientific argumentation mentioned above have been considered for the current study. Therefore, in line with our established goals, in this study, scientific argumentation is perceived as the generation of justifications for articulated claims as well as a dialogical social exchange process in which these justifications are shared, critiqued, revised, and ultimately changed within a science classroom, involving both written and spoken expression.

2.1.2 Historical Aspects in Argumentation Theory

Generally, argumentation theory experts are concerned with the challenges associated with forming, examining, and assessing argumentation. Argumentation theory is now an integral component of academic programs (van Eemeren et al., 1996, p. 12-353). To advance the study of argumentation in education, it is essential to consider the philosophical models of argumentation, namely the theories of argumentation (Dutilh Novaes, 2021; Nussbaum, 2008; Nussbaum, 2011), since these argumentation theories can provide a strong basis for psychological theories about "how individuals comprehend, produce and evaluate argument information" (Nussbaum, 2011, p.85).

From a historical perspective, the theory of argument, which has become a multidisciplinary field today, has developed and changed over time, from ancient times to the Renaissance period, under the influence of views and approaches specific to each period. We see that the theory of argument, the first traces of which were seen in the ancient Greek period in Socrates, Plato, and especially Aristotle's work 'Rhetoric,' became modern argument theories in the 20th century.

The historical evolution of argumentation theories shows that interest in this field can be traced back to the foundations of Western culture. Platonic dialogues are early exemplars, capturing the essence of argumentation in emotionally rich yet critically reasoned exchanges. Aristotle's pioneering contributions in “Logic, Dialectic, and Rhetoric” stand as the foundational work, setting the stage for modern argumentation theory (Alaz Meriç; 2019; Asterhan & Schwarz, 2016; Brooke, 2015; Nussbaum, 2008; Wardeh, 2009). Aristotle defined argumentation in three distinct ways: Analytical, which is accuracy based on the theory of logic, concluding by induction or deduction; Dialectic, which is about finding acceptable reasons through reasoning; and Rhetoric, which focuses on being persuasive or convincing (Alaz Meriç; 2019; Asterhan & Schwarz, 2016; Boğar, 2019b; Brooke, 2015; Dutilh Novaes, 2021; Seppanen, 2022; Wardeh, 2009). From the time of Aristotle to the present century, argumentation has continuously developed as a theory (Alaz Meriç, 2019; Asterhan & Schwarz, 2016; Boğar, 2019b; Brooke, 2015; Dutilh Novaes, 2021; Seppanen, 2022; Wardeh, 2009). Aristotle’s historical heritage has laid the groundwork for contemporary scholars to develop comprehensive theories of argumentation. Modern argumentation theories draw systematically upon Aristotle. These influential works are grounded in real-world dialogues, drawing examples from judicial settings, political arenas, journalistic articles, and family conversations (Alaz Meriç, 2019; Asterhan & Schwarz, 2016; Dutilh Novaes, 2021; Wardeh, 2009).

Stephen Toulmin’s model: Toulmin’s Argumentation Pattern (TAP), initially presented in his “seminal” book *The Uses of Argument* in 1958, has become a foundational framework in argumentation theory. Since the mid-20th century, most contemporary studies in argumentation theory have been based on TAP. This approach has been extensively accepted, preferred, adapted, and cited in various fields, including educational research, AI, and philosophy. It serves as a foundational tool for analyzing arguments (Clark et al., 2007; Erduran, 2007, p.60; Kim & Roth, 2018; Nussbaum, 2008; Nussbaum, 2011; van Eemeren et al., 1996). The perspective of Toulmin's argumentation model greatly influences science education researches also (Erduran, 2007; Kim & Roth, 2018; Lee et al., 2014; Sampson & Clark, 2008).

In the Toulmin model, first introduced in his book *The Uses of Arguments* in 1958 and later refined in its second edition in 2003, an argument is composed of six components: 'claim, data, warrants, backing for warrants, rebuttals, and qualifiers.' In any argument, there is a claim or an assertion. The data are the facts we use to form the basis for our claims. The warrant consists of general, hypothetical statements that we use as a bridge between our claim and our data, namely propositions. Qualifiers and rebuttals are used to comment on the position of the warrant between the claim and the data of the argument, that is its effectiveness. The strength of the warrant is explained with the qualifier, while the conditions under which the warranted claim would be considered invalid are addressed by the rebuttal. To enhance the validity of the argument's warrant, there is a need for assurances, namely backing, which can stand behind the warrant (Toulmin, 2003, p. 97). Toulmin noted that an argument might not include all six components of his model, and some of these components may be implicit. However, he clarified that the presence of all six components does not necessarily make an argument strong (Nussbaum, 2011). He emphasized the contextual nature of argumentation, pointing out that different domains use various types of backing for their arguments. Consequently, the strength of an argument should be assessed using standards specific to its respective domain, as these standards are closely linked to the unique epistemology of each field or discipline. Therefore, the model does not serve as a basis for determining the strength or quality of an argument (Nussbaum, 2011; Sampson & Clark, 2008; van Eemeren et al., 1996). Essentially, Toulmin's model is non-normative. It is analytical in nature, focusing on evaluating the structure of an argument rather than the content or the nature of its justification (Kim & Roth, 2018; Nussbaum, 2011; Sampson & Clark, 2008). In the Toulmin model, several limitations arise due to various factors: students' interpretations may belong to more than one component; researchers' personal perspectives can influence the differentiation between these components; and there are inter-rater reliability issues in coding arguments, which means difficulties in distinguishing between the components of an argument (Evagorou et al., 2012; Kim & Roth, 2018; Nussbaum, 2011; Sampson & Clark, 2008; van Eemeren et al., 1996). Additionally, the model cannot serve as a basis for psychological theories that explain why the concept of counterargument does not develop in argumentation by explaining factors such as "information limitations, metacognition, interference, and lack of task understanding." Similarly, the model falls short in providing a foundation for theories that examine the effect of argumentation on learning by explaining "cognitive conflict and information integration." Therefore, the Toulmin model is not "evaluative," nor "descriptive" in the social and psychological practices of how arguments are produced, processed, and discussed. With its analytical structure, the model can be based on only three issues: a) different backings can be used for arguments, b) there may be exceptions in arguments, and c) arguments can develop during "dialectical question-answer" (Nussbaum, 2011, p.86).

Toulmin initially stated he was interested in the epistemology of the twentieth century. Namely, his main aim was actually to align the study of logic more closely with real-life argumentation and its application in various academic disciplines, and he did not aim to explain a theory of argumentation (Dutilh Novaes, 2021; Nussbaum, 2011; van Eemeren et al., 1996). However, this model has been widely accepted as an argumentation theory for analyzing spoken and written discourse, offering transparency and serving as a foundation for further evaluation. Perhaps one of its most appealing aspects is the model's explicit focus on argumentation as it occurs in everyday language and ordinary real-life situations. In summary, Stephen Toulmin's contributions have not only shaped theoretical approaches to argumentation but have also had practical implications in education, enhancing both understanding and teaching methods (van Eemeren et al., 1996). Despite some ambiguities and problems in his model, Toulmin's work has had a lasting impact on various fields, including computer science, philosophy, speech communication, law, and critical thinking education (Dutilh Novaes, 2021; van Eemeren et al., 1996). TAP continues to be a significant tool for both scholars and practitioners (van Eemeren et al., 1996).

In the previous century, argumentation theory, which started to develop especially with the guidance of 'Toulmin's argumentation model' in 1958, has developed considerably over the years, and different approaches have emerged in philosophy, cognitive science, linguistics, and communication theory. Among these, some contemporary alternatives that can be theoretically and practically useful to educational researchers are 'Walton's Dialogue Theory,' 'the Bayesian Approach to Argumentation,' and 'van Eemeren and Grootendorst's Critical Discussion Model (Dutilh Novaes, 2021; Nussbaum, 2011; Wardeh, 2009).

Douglas Walton has synthesized various ideas about argumentation from the field of philosophy through his work in nearly 40 books. He presents 'dialogue theory' as a comprehensive framework that reflects many developments in this field. This theory, which is dialectical in nature, emphasizes the importance of producing counter-arguments, rebuttals, and asking questions, as well as recognizing the speech acts used in argumentation. This approach, originating from the ancient Greeks, regained popularity in the 1970s when analytical philosophers began applying it to informal fallacies. Adapting tools from formal logic and broadening their application to include a wider variety of arguments than those traditionally handled by standard logical systems, Walton was at the forefront of developing the argument schemes method in argumentation (Dutilh Novaes, 2021; Kim & Roth, 2018; Nussbaum, 2011). In Walton's 'dialogue theory,' different types of discourse exist, such as persuasive discourse, inquiry dialogue, and negotiations, each has their own aims, critical questions, and argumentation schemes. Additionally, the plausibility and defeasibility of arguments are important aspects of his theory (D'Souza, 2017; Nussbaum, 2008; Nussbaum, 2011; van Eemeren et al., 1996). This broad dialogue theory, which includes many elements such as type of dialogue, argumentation schemes, critical questions, plausible reasoning, and dialectical shifts, clearly states most of the various dimensions that the concept of argument quality has. For the analysis of argument quality, useful criteria have also been identified by Walton that can be used in scoring rubrics and the qualitative analysis of the development of students' argumentation. These valuable criteria include how argument schemes are processed and which arguments can be refuted (Nussbaum, 2011). Argumentation schemes describe the relationship between the premises of an argument and its conclusion, characterizing how a standpoint is justified or refuted. Analyzing these schemes in a discourse reveals the underlying criteria, principles, and assumptions used in attempts to justify or challenge a particular viewpoint (van Eemeren et al., 1996). However, although dialogue theory allows researchers to identify and code argumentation schemes used in discourse, the reliability of this process is not always clear. While some researchers may be able to identify these schemes, others may not distinguish them reliably. Walton has noted that some schemes contain others, and the connections between them are still being determined. In other words, there are challenges in clearly defining which scheme applies to the types of arguments that emerge (Nussbaum, 2011).

'The Bayesian Approach to Argumentation' is another leading approach in argumentation theory proposed by Thomas Bayes. Nussbaum (2011) argues that Bayesian probability theory is tied to dialogue theory because he highlights that critical questions are asked when evaluating probabilities for evidence in Bayesian analysis, and thus it adds a mechanism to dialogue theory to assess argument strength. In summary, when we look at these two alternative frameworks to the Toulmin model for both Walton and Bayesian theories:

> …. the pedagogical goal is not to really resolve the issue through argumentation but to gain greater insight into different points of view, including one's own (Nussbaum, 2011, p. 99).

Bayesian probability theory, which evaluates the probability of an outcome being true, is preferred in deciding the strength of the argument. *Probability* is a subjective measure that determines how strong the belief in the truth of a proposition is. At the center of the theory is the Bayesian theorem (mathematical updating of previous probability beliefs in the light of new information). Bayesian probability theory, also seen in applications in the philosophy of science, has also been used in the field of argumentation, as it includes processes in which existing beliefs about propositions can be changed by using reasons and evidence. This theory, which is very well developed, especially in the field of statistics, actually offers rules that can be used to think more about assumptions in argument analysis, to make assumptions more understandable, and, in other words, to alter probability estimates. The Bayesian approach, generally used for evidence-based arguments in argumentation, adds certain possibilities to each argument section (such as warrant, backing, rebuttal). It provides systematic analysis tools for students and researchers to evaluate arguments as strong and weak by enabling them to consider different alternative perspectives in argumentation and present supporting evidence. In education, the Bayesian argument framework has different applications for instruction and assessment, such as using Bayesian approaches to evaluate students' understanding of scientific concepts through problem-solving tasks (Dutilh Novaes, 2021; Hahn et al., 2009; Nussbaum, 2011).

In informal argument analysis, of the two alternative frameworks that deal with evaluating the content of arguments instead of identifying or counting parts of the argument as in the Toulmin model: Walton's dialogue theory is an approach focused on plausible reasoning and defeasibility; Bayesian probability theory is an approach focused on probabilistic reasoning and epistemology. However, the two theories are not technically inconsistent with the Toulmin model and even complement it in many different ways. In general, it can be said that the Bayesian approach can fit the Toulmin model, while Walton's approach is partially based on it. For example, in Walton's model, which has dialectical reasoning and plausible inference at its center, each argument has a conditional premise, equivalent to the warrant concept in Toulmin's model, which shows that it is based on the Toulmin model in part. However, while the applicability of the Toulmin model to ill-structured problems is very limited, Walton's dialogue theory is more advantageous with the many argumentation schemes it offers for practical reasoning for such problems. The Bayesian approach, the systematic way it provides to identify the strengths and weaknesses of informal arguments, makes it stronger than the Toulmin model (Nussbaum, 2011).

One of the other alternative contemporary philosophical frameworks for argumentation is the "critical discussion model" developed by van Eemeren and Grootendorst (2003), one of the theorists working in the dialectical tradition such as Walton, which has certain discourse rules and is preferred by education researchers (Dutilh Novaes, 2021; Eskin & Ogan-Bekiroğlu, 2013; Kim & Roth, 2018; Nussbaum, 2008; Nussbaum, 2011). The 'Critical Discussion Model' proposed by Frans H. van Eemeren and Rob Grootendorst is a framework for understanding argumentation that focuses on resolving disagreements by examining the validity of differing viewpoints. They introduce the concept of 'critical discussion,' which they describe as a structured dialogue aimed at analysis, evaluation, and construction of arguments. This model integrates pragmatic approaches with dialectical methods, treating argumentation as a procedural structured exchange of communicative acts between participants (van Eemeren & Grootendorst, 2003). Namely, this approach explores the dialectical aspect of dialogue in confronting and integrating diverse and conflicting ideas or beliefs in order to arrive at a shared understanding or conclusion (Kim & Roth, 2018). Additionally, it sees argumentative discourse as a complex speech act with specific communicative goals, combining both descriptive and normative elements for analyzing and evaluating arguments (Dutilh Novaes, 2021).

In summary, while the Toulmin model views arguments only as products and analyzes their structure, the 'critical discussion model' developed by van Eemeren and Grootendorst, Walton's 'dialogue theory,' and the 'Bayesian approach to argumentation' adopt a more dialectical perspective. These theories not only analyze the structure of arguments but also consider the interactive social processes involved in constructing and discussing them. Furthermore, these theories can be considered more pragmatic, as they evaluate arguments based on the type and purpose of the discourse (Duschl, 2008; Nussbaum, 2008; Nussbaum, 2011).

"The study of argumentation has so far not resulted in a universally accepted theory (van Eemeren et al., 1996, p. 24)." In conclusion, argumentation models have different purposes, such as analytical, normative, and descriptive. If the purpose of a model is analytical, with the help of that model, researchers can analyze the structure of an argument; that is, they can identify the components of the arguments and examine the relationships between these components. In contrast, if the purpose of a model is normative, with the help of that model, researchers can make a judgment about the strength and quality of an argument or its components. Finally, if the purpose of a model is descriptive, with the help of that model, researchers can make a descriptive explanatory judgment about a person's tendency to argue (Nussbaum, 2011). In short, argumentation models are instrumental for researchers in assessing the quality of the argumentation process and students' arguments. These models provide normative standards and analytical frameworks, enabling researchers to understand the depth of students' reasoning, the extent of their backing for claims, and how thoroughly they evaluate opposing viewpoints (Nussbaum, 2008). Consequently, it is crucial for researchers to identify which purposes—analytical, normative, or descriptive—a specific argumentation model serves (Nussbaum, 2011).

2.2 Analyses of the Argumentation Process in Science Education

Formal education should aim at train students in collaborative and rational reasoning. Research has shown that through prolonged implementations focusing on the teaching and practice of argumentative skills, students can indeed learn to argue effectively. Given this, it is no wonder that many global and national education initiatives, such as NGSS, NRC, AAAS, OECD, and 21st-Century Skills, have established new educational objectives, benchmarks, and standards for the contemporary world emphasizing the importance of argumentation (Asterhan & Schwarz, 2016). This growing emphasis on argumentation in the curriculum quickly necessitated the development of more comprehensive assessment methods (Pearson et al., 2015).

In argumentation research assessments, as Erduran (2007) pointed out, all researchers can articulate their shared concern using a single term: “methodology” (p.47). Within the field of science education, the adoption of argumentation theory as a theoretical foundation has led to the development of several methodological perspectives, techniques and tools. These include analytical frameworks and argument diagramming to assess and improve argumentative discussions (Driver et al., 2000; Erduran, 2007).

To achieve our educational objectives, it’s essential to have these methodological tools for guiding implementations that aim at the development of high-quality arguments; offering educators insights on which aspects to prioritize and strategies to guide students’ argument construction; assisting students in understanding the structure and nature of arguments and also providing educators a framework to evaluate students’ arguments for tracking their progress (Driver et al., 2000).

For science education, the prevailing trend in using analytical frameworks for studying argumentation has commonly highlighted the qualitative dimensions of both argument’s structure (claims, data, and warrants) and the argumentation procedures (Erduran, 2007; Sampson & Clark, 2008; Sandoval & Millwood, 2005).

When examining assessments of argumentation interventions, especially in relation to broader educational objectives like achievement, NOS, and the development of scientific skills, several terms come to the forefront. Often, the focus is on the “quality of arguments (argumentation)”. As well as terms like the “level of argumentative skill or ability”, “argumentativeness” and its various levels are frequently mentioned More recently, the discourse has expanded to encompass terms like “argument structures” and “argumentation profile.”

2.2.1 Analyzing the Quality of Argumentation

Several perspectives have been explored within argumentation theory in the previous section. Some of these approaches focus on to providing a detailed depiction of how arguments are naturally constructed. Meanwhile, other approaches focus on establishing criteria, definitions, characteristics, guidelines, and processes for the critique, assessment, and formation of arguments (Driver et al., 2000). Nussbaum (2011) critiqued the presentation and evaluation of arguments, emphasizing the importance of criteria, definitions, or characteristics to determine the quality of arguments.

Arguments can stem from students' reasoning and can be expressed in various forms, including dialogue, writing, and other formats. Through argumentation, a valuable perspective can be obtained. Consequently, it is possible to evaluate and analyze these spoken and written arguments (Driver et al., 2000; Nussbaum, 2011; Sandoval & Millwood, 2005).

"Quality includes judgments about the structure of arguments and their conceptual adequacy" (Sandoval & Millwood, 2005, p. 24). Thus "arguments can be judged as strong or weak along a continuum, with stronger arguments judged to be of better quality" (Nussbaum, 2011, p. 85-96).

Stating that "assessing the quality of arguments, either spoken or written, is not an easy task" (p.54), Knight and Grymonpré (2013) emphasized the challenges or difficulties of the assessing argument quality process. Many aspects of students' written arguments can be critiqued, but prioritizing the most vital aspects is a challenge. Assessing spoken arguments in the moment is even more challenging, given the immediate response required by evaluators.

On the other hand, these evaluations of high-quality arguments are not random. Studies discuss the complexity of this assessment process and provide definitions, criteria, and characteristics of quality arguments. This description is fairly detailed;

outlining what constitutes a high-quality argument. Effective evaluations often draw upon a range of criteria, ranging from the logical structure of the argument and scientific correctness or sufficiency of its content to the nature and type of justifications provided. Additionally, research on the characteristics of quality arguments highlights the importance of having multiple perspectives in justifications. Indeed, when considering the depth and relevancy of justifications, high-quality arguments have not only backing and rebuttals but are also grounded in justifications that value relevant, multiple insights and are based on scientifically accurate information. Therefore, arguments that are well-structured and supported by diverse and relevant justifications are often considered high-quality, whereas those with weak or unrelated justifications are often considered poor (Aydeniz & Gürçay, 2013; Bilican, 2018; Sampson & Clark, 2008; Zohar & Nemet, 2002). This is all based on a lot of research that has tried to better understand how students construct and present scientific arguments (McNeill et al., 2016).

In summary, many researchers study the theme of evaluating the quality of arguments, particularly in educational or scientific contexts, and address the complexities and challenges associated with assessing argument quality. Although arguments arise from individual reasoning and can be expressed in various ways, including speech and writing, the strength and quality of an argument largely depend on its structure, the scientific correctness of its content, and the nature of its justifications. Evaluating these arguments is a complex task, but generally recognizing high-quality arguments involves identifying those with a well-designed structure that encompasses both relevant, multiple, and scientifically accurate justifications. There are extensive research efforts dedicated to the evaluation and support of students' scientific argumentation.

As highlighted above, in line with these extensive research efforts, experts in argumentation and curriculum design are focused on nurturing classroom dialogues and evaluating students' capacity to reason with evidence and theory (Duschl, 2007, 2008). They explore issues such as the efficacy of students' arguments concerning various natural phenomena interpretations, the differences between the argumentative approaches of students and scientists, and the benefits students derive from argumentation exercises in classrooms (Sampson & Clark, 2008). Notably, since the 1990s, analytical frameworks and methodological approaches for argumentative discourse in educational settings have evolved and been refined (Duschl, 2007, 2008; Sampson & Clark, 2008). These analytical frameworks and methodological approaches have empowered researchers to describe and assess arguments, examining both their quality and nature (Sampson & Clark, 2008). Indeed, argumentation frameworks enable individuals to express and organize their thoughts, making their cognitive processes visible. This facilitates educators in assessing students' thinking and argumentative skills. Consequently, "herein lies the importance of locating robust argumentation frameworks" for guiding the development of students' argumentation practices (Duschl, 2007, p.160).

Similarly, in science learning contexts, there has been a significant increase in studies centered on the argumentative discourse analysis. This argumentative discourse plays a crucial role in understanding how students engage with scientific concepts. Alongside this trend, extensive research has been conducted to assess the quality and depth of students' scientific argumentation skills (Jiménez-Aleixandre & Erduran, 2007; McNeill et al., 2016) and "the making of the right kinds of arguments and that such arguments make sense" (Sandoval & Millwood, 2005, p.24).

There are two main perspectives guiding these assessment studies. The first perspective is rooted in science studies which emphasize the role of discourse in building scientific knowledge and its educational implications. The second, stemming from a sociocultural perspective, highlights the significance of social interaction in learning, suggesting that advanced thinking processes emerge from such social activities, especially through language (Jiménez-Aleixandre & Erduran, 2007).

Science educators have preferred some of these analytical frameworks mentioned above to examine both the nature and quality of established scientific arguments (Boğar, 2019b; Erduran, 2007; Sampson & Clark, 2008).

These analytical frameworks fall into two groups. The first group comprises domain-general frameworks whose applicability can be generalized to a wide variety of fields and purposes. They are not confined to science alone, and their generality might overlook important aspects of argumentation in specific disciplines. The most preferred examples of these in science education are TAP and the approach of Schwarz, Neuman, Gil and Ilya (2003) (Boğar, 2019b; Clark et al., 2007; Erduran, 2007; Sampson & Clark, 2008).

The second group includes domain-specific frameworks, which are tailored exclusively to science, incorporating science-specific criteria for argument analysis. The most widely used examples of these in science education are Zohar and Nemet's (2002), Kelly and Takao's (2002), Lawson's (2003), and Sandoval's (2003) approaches (Boğar, 2019b; Erduran, 2007; Sampson & Clark, 2008).

'Giere's (1991) approach', 'McNeill, Lizotte, Krajcik and Marx Model (2006)' (Boğar, 2019b) and also 'Erduran and colleagues' (2004) framework', 'Clark and Sampson's (2007) analytic framework', 'Kuhn and Udell (2003) framework' and 'Duschl's (2007) framework' (Clark et al., 2007) are other analytical frameworks favored in science education.

An overview of these analytical frameworks favored by science educators in the context of examining both the nature and quality of argumentation reveals that the majority of these frameworks, whether pertaining to a domain-general or domain-specific area, demonstrate an orientation towards the TAP.

Toulmin's ideas are valuable for crafting theoretical tools for both the analysis and evaluation of argumentation. TAP is often utilized to illuminate the structure of spoken and written discourse by providing transparency, acting as a foundation for further evaluation (van Eemeren et al., 1996).

On the subject of using TAP as a foundation for further evaluation, similarly Lee et al. (2014) stated that many of these analytical frameworks aligned with the taxonomy of TAP. Additionally, Lee and his colleagues (2014) provided an overview of these various approaches, frameworks, guidelines, methodologies and scales used in the assessment and analysis of scientific arguments. Their overview takes a detailed look at how students structure their arguments, the categories used for evaluating and coding, and how different components of the argument are scored and interpreted. They discussed that several analytical frameworks have examined scientific arguments by employing various coding categories that based on the taxonomy of TAP and have evaluated the occurrence frequency within these coding categories. This examination was conducted by categorizing and coding justifications and explanations, especially those associated with the alignment of data and theory. Different rubrics have been utilized to assess the validity of scientific justifications including distinctions between different types and numbers of justifications. Also, most coding for counterarguments or conditions of rebuttal were recorded as either absent or present. Multi-level ordinal scales have been developed to capture a student's scientific argumentation ability, to characterize the depth of argumentation or to measure dialogic argument situations. Besides, different scoring rubrics and composite scores have been developed to assess argumentation quality. In other rubrics that focus on more advanced argumentation skills, numbers of certain elements or the presence of counterarguments and rebuttals are seen as signals. Also, the difficulties in ranking the epistemic levels of argumentation have been cited in other rubrics. Thus, Lee et al. (2014) reveal a marked diversity in the methods and criteria used for assessing students' abilities in argumentation.

Another important review of these frameworks has been presented by Nussbaum (2011). Similarly, he stated that in addition to TAP as an analytical framework, which is widely used in the quality analysis of arguments, many researchers have sought to develop different methodological tools and frameworks to make judgments about the interventions applied in argumentation. During the development of these alternative approaches, many methods have emerged: determining the number of arguments, counter-arguments, rebuttals and amount of evidence; determining the soundness of arguments based on relevant and acceptable reasons; specifying more general criteria such as having sufficient data; suggesting a refutation of the premises of the opposing argument for a stronger rebuttal; proposing integrated arguments that evaluate and refute counter-arguments for stronger arguments that can withstand objections; and evaluating either the conceptual quality analyzed with normative criteria or the levels of opposition dimensions (Nussbaum, 2011).

However, while there have been several noteworthy review works on frameworks used to analyze argumentation in the field of science education, the most significant and impactful study has been conducted by Sampson and Clark (2008). Their comprehensive study stands like a cornerstone in the science education field, guiding science educators with precision and clarity. It serves as a reference point that illuminates the path for further research and practice, suggesting new directions in scientific argumentation.

Sampson and Clark (2008) conducted a detailed review of frameworks for argument analysis in science education by applying the analysis of a sample argument to each of the six analytical frameworks (mentioned above as domain general and domain specific). They noted that while there are important differences between these frameworks, which are based on different fundamental theoretical perspectives in science learning and serve different pedagogical scientific research objectives, these frameworks also have commonalities in three critical areas. These areas include an examination of the structure of a scientific argument where its components are analyzed; an examination of the content of that argument where the scientific validity of these components is analyzed; and an examination of the nature of the justification by analyzing how these components are supported in that argument. Their review, which aims to make a basic taxonomy about structure, content and justification is a synthesis study and shaped around the following questions: How do these six frameworks define and conceptualize ‘structure, content, and justification’? How much importance do they give to these three key aspects? What are they really focusing on? What are their affordances to science education and the limitations of these frameworks for science education?

To sum up, it is understood that in the field of science education, the application of these various analytical frameworks serves multiple purposes. These frameworks provide a systematic approach to both analyzing students' argumentation abilities and revealing insights into their capacity to produce arguments, present justifications, and establish connections within scientific contexts. For researchers and educators, these frameworks act as critical tools for assessing the quality and depth of students' arguments. They help in determining the quality of arguments based on relevant criteria, evaluating the sufficiency of data, and proposing more refined methods for argument evaluation. By highlighting strengths and weaknesses in students' abilities to argue scientifically, these frameworks not only guide instructional practices but also inspire new research directions. The use of these frameworks continues to shed light on understanding, assessing, and enhancing students' argumentation skills. In addition to the aforementioned aspects, as Sampson and Clark (2008) stated that, the data collected through these frameworks will make a significant contribution to the processes of developing materials, instructional applications, and learning environments. This is necessary for better positioning of classroom argumentation implementations in science education.

While the various analytical frameworks in science education offer invaluable insights and tools for understanding, assessment, and development of students' argumentation, analyzing argumentation in science education using these various analytical frameworks is not without its limitations and criticisms. The application of these frameworks introduces specific issues, critiques, challenges, and complexities that must be carefully considered, given their implications for both theory and practice in the field of science education. There are five key issues that stand out and require further inquiry and critique. These range from critiques about analytical frameworks to the recommendation of justification analysis.

One of these issues encountered in the application of frameworks for the analysis of argumentation in the field of science education pertains to the critiques related to a commonly used framework: Toulmin's Argument Pattern (TAP).

The argument structure of Toulmin, despite its wide acceptance and growing popularity as an applicable model and an assessment tool, especially for assessing the quality of arguments in science education research (Nussbaum, 2011; Sandoval & Millwood, 2005; van Eemeren et al., 1996), there has encountered various criticisms and complexities in its application.

Evagorou et al. (2012) emphasized a fundamental critique of TAP: the difficulty of differentiating between elements such as 'claims, data, warrants, and qualifiers.' The identification of these components often relies on the immediate context of prior dialogue, creating a situation where researchers must infer or make more explicit definitions. These challenges can impact interrater reliability, leading some to argue against the use of TAP in science education.

Even Toulmin personally acknowledges that making distinctions among components in a practical setting can often be complicated, given that the definitions of these components may at times be contradictory, and he further admits that it is unnecessary to engage in analytical evaluations to distinguish these components (Sandoval & Millwood, 2005; van Eemeren et al., 1996).

In a related vein, Kim & Roth (2018) also further pointed to TAP's linearity and technical nature and underscored challenges related to the vagueness of coding systems and the consistent assessment of argumentation levels.

On the other hand, van Eemeren et al. (1996) stated that Toulmin's ideas are valuable for crafting theoretical tools for both the analysis and evaluation of argumentation, but while Toulmin's model is widely recognized as a beneficial tool for analyzing argumentation, its application as an evaluative model is not as emphasized. Sandoval and Millwood (2005) elaborate on this as follows: Utilizing TAP for analysis has offered valuable insights into the ways students construct their arguments, and has assisted researchers in understanding these constructed arguments particularly in correlating the form of arguments to conceptual comprehension. However, it has failed to facilitate evaluations regarding the quality, validity, coherence, or logic of the arguments. That is to say, researchers could determine how students formed their arguments, but they could not evaluate whether these arguments were sensible, reasonable, or logically sound. As a result, the quality of these arguments and the students' understanding of the nature of scientific argumentation remain ambiguous. All existing applications of TAP are incapable of evaluating whether or not the structurally well-formed arguments are also logically coherent (Driver et al., 2000).

Furthermore, Kim & Roth (2018) emphasize that using TAP components in coding brings substantial difficulties in articulating the complex dynamics of argumentation's social and epistemic aspects and the multifaceted interactions in the classroom environment. Specifically, the challenges lie in grasping the abstract nature of ideas and uncertainty in assertions and in identifying how claims and evidence fit into the more extensive contexts of argumentation.

As can be seen, the widespread acceptance and use of TAP as a valuable tool for argument analysis do not diminish neither the fundamental challenges associated with its implementation, nor the various opinions and criticisms regarding its effectiveness and suitability in different contexts. The introduction of TAP in science education research has become both popular and controversial. These issues not only underscore the challenges in implementing the TAP but also necessitate a careful examination of the model's role and the potential limitations of its application within the field of science education.

Indeed, these issues are not specifically tied to the use of TAP. Sandoval and Millwood (2005) stated that this represents a constraint for any analysis, such as TAP, that is exclusively concerned with the structure, shape, or appearance of arguments. Additionally, according to Erduran (2007), contrary to common assertions and beliefs, the obstacles faced by science educators when dealing with

TAP-based analysis for classroom discussions are very similar to those encountered with any other analytical framework. “An analytical tool derived from whatever theoretical or grounded framework will have its limitations in application, and it will not answer many questions (p. 66).”

The second issue that has been revealed as a result of the overview of the frameworks is the challenges associated with frameworks other than TAP. Nussbaum (2011) argued that, since TAP lacks strong criteria for analyzing the quality of arguments, many educational researchers have sought to develop different methods, aiming to make judgments about the interventions applied in argumentation. However, criticism has also been directed at all these alternative methods for the following reasons: ignoring the content of the argument, counter-argument, and rebuttal; uncertainty of criteria for determining relevance and acceptability of a reason; not addressing critical questions when setting general evaluative criteria; the need for mechanisms to determine the amount of adequate supporting data; and disagreement among experts regarding normative criteria about the correctness of ideas.

Numerous critiques and research efforts have been conducted to understand and evaluate other different frameworks, thereby establishing a broader context for the examination of these frameworks within the field of argumentation. Duschl (2007, 2008) provided a foundational overview of different argumentation frameworks and outlined the diversity of theoretical approaches that belong to them, from Toulmin’s structural patterns to Perelman and Olbrechts-Tyteca’s rhetorical and persuasive focus to Walton’s dialectical view. Thus, he identified issues related to the level of detail in the information utilized. Also, Erduran (2007) stated that although frameworks like that of Walton are recognized as potential tools for methodology, the existing work is insufficient to firmly establish their impact on the study of argumentation within school science. Furthermore, Clark et al. (2007) conducted a comprehensive review, categorizing various frameworks by their primary focuses, opportunities, and limitations in the context of evaluating dialogic exchanges in argumentation. This examination leads to a significant observation: the multiplicity of viewpoints within these frameworks highlights that simply stating that the quality of argumentation has been assessed or supported is not enough. To enhance collaboration and enable comparisons with other studies in the discipline, researchers must detail the theoretical perspectives that guide their analysis methods.

Consequently, whether or not the Toulmin model is used or simply counting the number of arguments and counterarguments many researchers in the field of education have had difficulty assessing the quality of arguments, and there are uncertainties about this quality analysis. As a result, the nature of argument quality is multidimensional, and many approaches to this issue require the support of other different methods (Nussbaum, 2011).

Similarly, the uncertainties Nussbaum mentioned have been made them visible through the work of Sampson and Clark for science education. At the end of their studies, Sampson and Clark (2008) underlined that when these analytical frameworks are used, different answers are reached for the question of whether a scientific argument is of high quality, that is, the analysis of the same argument in different frameworks may be different, and even the frameworks that find (or not) the argument scientifically adequate, appropriate, and favorably even have different reasons for this. This is because frameworks define structure, content, and the nature of the justification of arguments differently and give them varying degrees of importance.

The first two issues, which are related to utilizing frameworks, reveal another issue: the importance of field-dependent criteria in argument analysis. According to Sampson and Clark (2008), no framework for argument analysis can be used interchangeably, as each is designed to address a unique research question and context and has a particular focus. This perspective emphasizes that both the type of argument constructed and the chosen analytic framework within which its quality is evaluated must align with the nature of the task (Sampson & Clark, 2008), thereby further highlighting the relevance of field dependence in argument analysis. Building on this notion, the concept of the field-specific nature of argumentation merits a closer examination, as it plays a vital role in determining the effectiveness and appropriateness of various analytical approaches.

Building upon the concept of field dependence, Toulmin emphasized the contextual nature of argumentation and posited that there are no one-size-fits-all criteria for logical thinking and debate. This concept of the field-specific nature of argumentation challenged the idea of universal logical standards, highlighting that different fields have unique epistemological norms. This means that the principles that govern the transition from evidence to conclusions must align with the prevailing understanding and methods of that particular field. For instance, the right approach to arguing in history or literature requires an understanding of the distinct criteria of these disciplines (van Eemeren et al., 1996). Similarly, Sandoval & Millwood (2005) highlighted that Toulmin's own observations emphasized that argument quality or strength arises less from its structured form and more from the judgments that are specific to the field, particularly regarding the alignment among claims, evidence, and warrants. They further argue that an evaluation of the conceptual soundness of scientific arguments should be an integral part of the analysis of the structure. Therefore, any analytical approach shaped by Toulmin's thinking must consider the field-specific nature of argumentation and examine the appropriateness of the justifications.

The acknowledgment that the standards for assessing argumentation depend on the specific field has increasingly found acceptance (van Eemeren et al., 1996). For instance, a significant insight into the analytical frameworks developed by Sandoval and his team is the recognition that the field-specific nature of criteria plays a crucial role in the evaluation of arguments (Erduran, 2007). Additionally, the assessment of quality and the criteria for quality are subject to variation among disciplines, based on the nature of the subjects being examined, the methodologies considered valid for investigation, and the theoretical aspects embedded in scientific practice (Sampson & Blanchard, 2012). Yet, in spite of extensive research, the precise definition, categorization of these criteria for quality, and distinctions in rationality standards across different disciplines remain somewhat ambiguous (van Eemeren et al., 1996).

The specific discipline, field, and even the focused area of research also determines the nature of the argument structure as well as the criteria for quality (Sampson & Blanchard, 2012). Similarly, according to Mendonça and Justi (2014), the importance of field-dependent criteria in argument analysis should be highlighted by focusing on the nature of the argument structure namely context-specific elements of arguments. Because the elements of an argument—claims, evidence, and justifications—cannot be fully understood without acknowledging the specific context and field in which they are produced, and in this analysis, an argument should be seen not only as a product but also as a process connected with the environment and the collective reasoning process. Thus, taking into account this dialogic discourse shaped by individual contributions and contextual factors allows us to determine which elements of the argument individuals value. Therefore, in other words, the strength, quality, and appropriateness of an argument are significantly influenced by the field-specific parameters, within which it is developed,

Additionally, Ludwig et al. (2021) discussed the variation in justifications of arguments depending on the academic field as well as the cultural or situational context. They illustrate this by noting that a student's justifications in a physics classroom can contrast with those given in a chemistry classroom. This contrast can occur even if the data types, such as anomalous results, are similar and the experiments in both scientific fields are of a comparable nature. This underlines the idea that the nature of justification in argumentation is not only field-dependent but also contextually sensitive, further reinforcing the concept that the evaluation of arguments and their quality varies across different academic disciplines and cultural settings.

Thus, another issue to be considered is the highlighting and recommendation of "justification analysis" within argumentation analysis. In their review of the epistemological criteria of analytical frameworks and methodologies, Sampson and Clark (2008) evaluated how existing frameworks may lack accuracy in assessing the alignment of students' arguments with these criteria. They emphasized the necessity for a more exact correlation between analytical frameworks and epistemic standards, thereby suggesting this as a direction for further research (as cited in Duschl, 2008, p.285).

According to Sampson and Clark (2008), very important and valuable findings have been obtained by examining the arguments established in science education from atomized aspects. However, there is a need for more holistic approaches that will provide a common examination in terms of structure, concept, epistemology, and social dynamics in order to evaluate the quality of arguments. In addition to the structural analysis of students' arguments, the patterns they belong to and the themes they contain, as well as why and how these patterns and themes emerged, should be investigated in new studies. When moving to new research areas such as argument-driven conceptual change in science education, it is necessary to focus more deeply on the 'content, logical coherence, relevance, and explanatory power of the claim and explanation,' as well as 'causal mechanisms and core concepts.' In the analysis of argument quality, it is now accepted in science education that it is necessary to focus not only on the structural issues of arguments but also on the content, adequacy, accuracy, and epistemic characteristics of justification. Namely, there is a need for analytical frameworks in science education that will enable "to analyze the overarching patterns of justification as related both to the content and the structure of arguments" in a broader and authentic way (as cited in Sampson & Clark, 2008, p. 467).

Why should we engage in a deep and authentic analysis of the nature or pattern of justification within scientific arguments? Uncovering the pattern of justification and understanding its nature can provide significant insights into the quality and essence of scientific argumentation. Ludwig et al. (2021) emphasize the importance of exploring justifications in depth, especially within the realm of laboratory work in science education. While acknowledging the significance of an argument's structure and content, they argue that examining justifications offers a unique perspective. This approach enables a clearer understanding of students' knowledge generation processes during scientific inquiries, with a specific focus on the epistemic aspects of the argumentation. Such an analysis reveals the methods students use to build their knowledge and the rationale behind their support or opposition to various claims. Furthermore, Ryu and Sandoval (2015) argue that for argument analysis, only examining the structure is insufficient to understand its quality fully. The judgments about justifications are a crucial aspect. Making such assessments involves a comprehensive analysis of the argument's substantive content within specific fields or disciplines. Iwuanyanwu (2022) also contributes to this viewpoint, stating that insights into understanding students' strategies in argumentation, especially in problem-solving contexts, mainly come from analyzing their justifications. This approach reveals the underlying reasoning processes students use while constructing their arguments. Similarly, Lee et al. (2014) emphasize that students' performance in scientific argumentation is largely based on their justifications. This suggests that assessing scientific argumentation effectively should concentrate on the scientific reasoning connecting theory and evidence and also it is predominantly seen in students' justifications.

As Bricker and Bell (2008) stated, "issue of justification is central to argumentation, and argumentation is understood only by examining justifications (p. 490). All of these perspectives collectively underscore the necessity of a thorough analysis of justifications in argumentation, highlighting its integral role in understanding and evaluating the quality of scientific reasoning in science education.

A key aspect of the students' argumentation discourse is the justification they provide for their expressed ideas. This process of justification occurs as students attempt to convince either themselves or others of the validity of their thoughts (Skoumios, 2013). "Justification analysis contributes to the understanding of the sensemaking and persuasion goals of an argumentative process" (Mendonça & Justi, 2014, p. 214). The highlighting and recommendation of the analysis of persuasion within argument analysis is also another important issue. Argumentation is a crucial component of scientific thinking and is used by students, teachers, or researchers to defend, refute, or change their ideas. However, this vital aspect of argumentation, namely the analysis of persuasion, can sometimes be overlooked.

Indeed, the strength of science is the capacity to build, activate, and merge different types of written symbols for constructing convincing arguments (Sandoval & Millwood, 2005), and as Allchin and Zemplén (2020) stated, “in popular culture, persuasion is a zero-sum game (win or lose), and as a result, students tend to treat argumentation politically rather than epistemically” (p. 918).

The diversity of available frameworks allows for the emphasis and examination of aspects such as general argument patterns, persuasion, and dialectical reasoning. This variety reflects the multifaceted nature of argumentation in supporting diverse learning outcomes (Duschl, 2007, 2008). Research reveals a marked diversity in the methods and criteria used for argument analysis. Additionally, it was demonstrated that scientific argumentation has a complex structure and requires a multifaceted approach to assessing students’ abilities (Lee et al., 2014). In the educational field, numerous researchers grapple with the task of assessing the quality of arguments, faced with ambiguities surrounding this qualitative analysis. Consequently, the nature of argument quality is multidimensional, necessitating the integration of various methods. These could include the evaluation of argument construction or the persuasiveness of arguments, counter-arguments, and rebuttals (Nussbaum, 2011). Similarly, Sandoval & Millwood (2005) stress the necessity of examining more than just the formation of arguments. Evaluating the structure or quality of an argument is pivotal, but it does not offer a complete insight into the quality of the argument. They propose that focusing only on the structural facets of an argument can leave a critical gap in the assessment process. They also highlight the need to evaluate how convincing the students’ arguments are. Consequently, a thorough comprehension of how students develop scientific arguments requires more than just an evaluation of the formation or structure. It needs an evaluation of the persuasiveness of the arguments.

To sum up, up to this point, a comprehensive exploration of both the process of analyzing argumentation and the available frameworks governing argument quality was undertaken. Clearly, while there's significant value in these frameworks for analyzing argumentation, they are not without challenges. To address these issues more effectively and align with the multidimensional nature of scientific argumentation analysis, many researchers have adapted existing frameworks or explored alternative new methods and approaches.

For example, to address the challenge of distinguishing between components and the validity and reliability problems of utilizing TAP, many researchers formulated 'the notion of justification' and preferred to analyze an argument simply by accepting it as its claim and its justification (Erduran et al., 2004; Evagorou et al., 2012; Kim & Roth, 2018; Sampson & Clark, 2008; Sandoval & Millwood, 2005; Zohar & Nemet, 2002).

Whether employing the TAP or not, a significant number of researchers in education encounter challenges in assessing argument quality, leading to uncertainties in the analysis process (Nussbaum, 2011), and these challenges encountered methodologically in argument analysis are also underlined by researchers (Erduran, 2007; Ludwig et al., 2021; Mendonça & Justi, 2014; Sampson & Clark, 2008). Specifically, significant challenges in methodological issues continue to exist, especially when dealing with the less-explored dimensions of argumentation in science classrooms (Erduran, 2007), such as the analysis of justification and persuasion.

Besides, using qualitative research methods in the study of argumentation is instrumental for understanding the social and cognitive dynamics that are active in educational settings (Nussbaum, 2008).

What is the focus of this study? In addressing this question, we have laid the groundwork by highlighting existing overviews and critiques related to the argumentation analysis process. This serves as an introduction to our central discussion on the important role that justification plays in enhancing the quality and effectiveness of an argument.

The field of argumentation studies lacks a "universally accepted theory" to date. Consequently, the current state of this field cannot be summarized by referencing a single dominant theoretical framework (van Eemeren et al., 1996, p. 24). Considering the evolution of argumentation theory, it becomes evident that elements of the argumentation process—whether termed 'claim', 'proposition', 'reasoning', 'warrant', 'justification', 'rebuttal', 'counterargument', 'reason', 'premise', 'source', 'scheme', 'plausibility', 'acceptable', 'sufficiency', 'relevance', or 'persuasive'—are all considered valuable and significant. Regardless of the varying purposes (be they analytical, normative, or descriptive) and focus (such as structure, content, quality, strength, or justification) of these theories, models, and frameworks, a common element that receives universal importance is the justification of the claim or proposition. In other words, despite its different definitions and terminologies across theories or frameworks, the concept of 'justification' remains universally significant.

Taking into account all these critiques mentioned in this section, a clear need is observed for a shift or transition from evaluating the quality of arguments to focusing on the analysis of the justifications behind them. Namely, there is a need for a change in perspective from examining the overall strength and effectiveness of arguments to analyzing the underlying justifications used to support those arguments. This change should involve a more detailed examination of the sources, data, warrants, and justifications contributing to the validity and persuasiveness of various claims. In general, a deeper and more nuanced look at the fundamentals of persuasive discourse is required.

It is clearly seen that after exploring the nuances of argument quality, it becomes important to more deeply investigate the underlying justification mechanisms. While a quality assessment provides a broad framework for assessing the strength and validity of an argument, understanding the sources of its justification can add a layer of depth to this quality assessment by uncovering the origins of the argument's persuasive power. Essentially, the sources of justification serve as the bedrock upon which the quality of an argument is built. Therefore, the focus of this study is to conduct an in-depth analysis of justification in the argumentation process.

In the following section, the investigation will shift its focus to the examination of justification analysis, a key component as indicated in the field of argument analysis literature.

2.2.2 The Justification Analysis

Justification is the rational assessment process of giving good reasons to show that a certain claim, idea, or statement should be believed or accepted (Ferreira et al., 2016). In the analytical frameworks developed for analyzing the argumentation process in science education, justification is defined in two ways. First, "thought processes such as hypothetical-deductive reasoning" or making connections between different epistemic levels; the second is defined as "information components such as data-warrants-backings-reasons" contained in the arguments (as cited in Sampson & Clark, 2008, p. 467).

As previously mentioned, the main reason for defining justification in terms of "information components" is to overcome several challenges. For example, to reduce the negative impact on the consistency between different raters due to the difficulty in distinguishing these information components (data, warrants, backings, and reasons) and to improve both validity and reliability across different scales in science education (Evagorou et al., 2012; Kim & Roth, 2018). To deal with these issues, numerous researchers have adapted pre-existing frameworks or explored new alternative techniques and strategies. Among these efforts, a significant contribution is the formulation of the concept of justification as a unified category that combines elements such as data, warrant, backings, explanations, reasons, and supports.

One of these significant contributions belongs to Erduran and her colleagues. As Erduran et al. (2004) stated, "there is little doubt that there is a claim and a justification." This formulation of justification removes much of the ambiguity about which information components are data, warrants, backings, and reasons. Consequently, the task of differentiating between these information components in the analysis of argumentation processes "becomes less problematic" for researchers (p. 919). Much like Erduran and her colleagues, Zohar and Nemet (2002) have also provided a significant contribution to the field of justification formulation in science education. They emphasized that "an argument consists of either assertions or conclusions and of their justifications, or of reasons or supports" (p. 38). In their efforts to refine the framework (TAP), they simplified the categories of data, backings, and warrants and reformulated them into a single concept of justification, and their approach successfully addressed many of the challenges in terms of validity and reliability (Erduran, 2007).

In accordance by these efforts to formulate data, backings, and warrants into a single concept of justification, many researchers have adopted a similar perspective. As Sampson and Clark (2008) stated, a significant number of researchers have both accepted and preferred to analyze an argument simply by accepting its essential elements as the claim and its justification. "To help students express their arguments, to simplify this complex practice by emphasizing the structure of an argument more simply, and thus to help a teacher quickly and effectively assess the arguments" (Knight & Grymonpré, 2013, p. 53-54) researchers have considered a scientific argument from an individual perspective, namely in terms of its structure, and they have preferred approaches to the analysis of the argumentation process that regard an argument as a 'justified claim'. This justified relationship involves the use of appropriate and sufficient information, evidence, and reasoning (Angeloudi, Papageorgiou, & Markos, 2018; Kolstø, 2006; D'Souza, 2017; Engelen & Budge, 2023; Erduran & Kaya, 2016; Evagorou et al., 2012; Kelly, Regev & Prothero, 2007; Knight & Grymonpré, 2013; Ludwig et al., 2021; McNeill & Knight, 2013; McNeill & Krajcik, 2012; McNeill et al., 2006; Mendonça & Justi, 2014; Namdar, 2017; Osborne et al., 2016; Pearson et al., 2015).

Also, the term "justification" used in this study aligns with the above-unified definition.

This collective approach to redefining data, backings, and warrants under the unified concept of justification not only aligns with ongoing research efforts but also enriches existing frameworks for assessing argumentation through justification analysis.

In current science education and related disciplines, a significant amount of research has been conducted to investigate diverse aspects of argumentative practice. These aspects range from the formation of arguments to their justification and justification analysis (Chen, Benus, & Hernandez, 2019).

In light of the importance given to the role of justification in argumentation for science education, it is not surprising that a significant amount of work needs to be done in this area. Because, as Ludwig et al. (2021) stated, especially in science and science education, the construction of knowledge is closely connected with its justification. This process includes linking scientific assertions to relevant data. This means that justifications act as integral information components of any argument (Ludwig et al., 2021; Skoumios, 2013).

So, argumentation, explanation, and justification are recognized as fundamental aspects of practices in classroom instruction (Brigandt, 2016), and these instructional practices commonly depend on reasoning, particularly through justifications that build up argumentation and explanation (Vieira et al., 2016). Also, for participants in collaborative teaching activities to engage constructively, justification and argumentation are required (Salminen et al., 2012). Moreover, the objective of argumentation is to formulate justifications for solving problems or answering questions (Nussbaum & Bendixen, 2003), namely, "In the production of an argument, one key factor is the justification of why given information or data support a certain claim" (Ludwig et al., 2021, p. 820). The ability to argue effectively, with a particular emphasis on competences in justification, is reflected in various science standards (Ludwig et al., 2021), reinforcing the notion emphasized by Erduran et al. (2004) that the strength and quality of argumentation in science are closely connected to the effective application of justifications. In the context of argumentation, students actively participate in discussions (by engaging and primarily interacting with their peers). A key aspect of this communicative exchange is their justification of the claims they make. The process of justification occurs as students attempt to convince themselves, other students, and the instructor of the accuracy and validity of their justified ideas (Skoumios, 2013).

As mentioned above, Bricker and Bell (2008, p. 490) emphasize that the essence of argumentation lies in critically examining both criticisms and justifications, suggesting that a proper understanding of argumentation comes from exploring these two aspects. Complementing this viewpoint, Ludwig et al. (2021) highlight the 'central role of justifications in argumentation,' especially in the context of school science. They underscore the necessity of analyzing the various types of justifications employed by learners during scientific argumentation, indicating the integral part these justifications play in developing of scientific understanding and discourse (p. 820).

Therefore, the research related to the justification analysis not only have deserved considerable attention and importance in science education but also continue to be crucial for advancing our understanding of effective scientific discourse and reasoning, shaping future educational practices and standards.

When reviewing the studies focused on the analysis of justification within the related literature, it becomes clear that these research efforts exhibit diverse perspectives.

This diversity reflects the multifaceted nature of justification as a concept, with researchers approaching the topic from different theoretical frameworks and methodological backgrounds. This diversity also highlights how justification is interpreted and approached differently across various academic fields in science.

Among these diverse perspectives in the analysis of justification, studies conducted from an epistemological standpoint hold a significant place. *These studies approach the justification process from an epistemological perspective,* focusing on the nature of knowledge and the ways of acquiring it. These studies primarily focus on epistemological constructs such as personal epistemology, epistemic beliefs, epistemic criteria, and epistemic cognition, analyzing how these components influence the formation, structure, and evaluation of justification. One of these studies belongs to Krist (2020). She focused on using two epistemic criteria, "Nature of Account and Justification," by students in classroom communities over three years, highlighting how their approach to scientific idea formation evolved. The context of the study involved observing and video-recording classroom lessons in nine content areas, with 94 6th to 8th grade students. The research aimed to understand how stabilizations and dynamic changes occurred using these criteria for building scientific ideas in group discourse over 12 weeks in three content areas each year. The results showed that by 8th grade, students were using these epistemic criteria more effectively. They began interpreting sources with greater complexity and articulating their scientific ideas more coherently and causally. This study highlighted both the growth in students' ability to effectively justify their ideas and the evolving role of justification in constructing scientific knowledge. Moreover, Bråten et al.'s (2013) study focused on 65 Norwegian 10th-grade students' perceptions of how scientific knowledge claims are justified. The study first assessed the students' beliefs on three types of justifications: personal justification, justification by authority, and justification by multiple sources. The findings revealed a tendency to believe in justifications provided by authority first, followed by those from multiple sources and personal justification. The second part of the study investigated if these justification beliefs uniquely influenced the students' ability to comprehend conflicting scientific documents. The analysis showed that personal justification and justification by multiple sources were significant predictors of document comprehension, even after controlling for topic knowledge. The study found a negative correlation between relying on personal opinion for justifying scientific claims and comprehension, whereas relying on multiple sources for justification had a positive effect. This research contributes to understanding the connection between epistemic beliefs and emerging skills crucial for an information-rich society, notably in justifying claims by synthesizing various conflicting information sources. Bråten et al. conducted a similar study also in 2014. This study focused on how students' epistemic cognition regarding the justification of scientific knowledge claims influences their skills in sourcing and argumentation among undergraduate students. Central to the study were two questions: how do students' beliefs about justification affect their ability to source information and their argumentative reasoning, considering their prior knowledge. The research involved 51 Norwegian undergraduate students and adopted an innovative approach, using online think-aloud sessions instead of offline questionnaires to assess students' epistemic cognition. Students read six documents presenting conflicting views on "cell phone radiation and health risks." The students' approaches to the justification of knowledge claims were categorized as authority-based, personal, or based on multiple sources. The results showed that after considering prior knowledge, using multiple sources for justification uniquely improved students' ability to source and argue effectively in their essays, leading to more accurate source citations and coherent, well-supported arguments. In summary, this study demonstrates that understanding students' justification methods can predict their capabilities in sourcing and argumentative writing, emphasizing the importance of epistemic cognition in science literacy.

This approach mentioned above, which belongs to justification studies conducted from an epistemological perspective, is crucial in understanding the foundational aspects of how knowledge is justified and validated in various scientific fields. These studies investigate the critical relationship between the nature of justification and the underlying epistemological beliefs that shape it. By exploring this relation between epistemic beliefs and justification, these studies shed light on the underlying principles that guide scientific reasoning and argumentation. This not only enriches our comprehension of the concept of justification but also highlights the importance of epistemological considerations in shaping scientific discourse.

Another approach within the justification analysis literature investigates the criteria individuals or groups use to justify scientific knowledge claims. This research perspective focuses on how these criteria are selected and their impact on the structure of justification, highlighting the decision-making and evaluative aspects inherent in this process. For example, Skoumios (2013) conducted a study from this perspective. The study aimed to explore how a 'computer-assisted teaching method,' which integrated simulation techniques and 'socio-cognitive conflict' strategies, impacts the types of criteria secondary school students use in their justifications for their scientific claims about the buoyancy of objects. Implemented with 21 students, the context of the study involved a teaching approach that used computer simulations to explore their understanding of sinking and floating. In the end, students' comments made in group discussion orally and individually were analyzed. Two types of justification criteria were identified: 'rigorous criteria,' common in scientific reasoning, and 'informal criteria,' more typical in everyday reasoning. The findings showed that the 'computer-assisted teaching method' influenced the students' preference for types of justifying criteria. There was a significant shift in students' justifications towards 'rigorous criteria' over informal ones, suggesting that the instructional method effectively enhanced their scientific reasoning and dialogic argumentation skills.

While the first approach in justification analysis studies analyzes the epistemological components, the second perspective explores the criteria individuals or groups use to justify claims in scientific contexts. *Alongside these two approaches, there is* *another significant perspective in justification analysis studies: the determination and categorization of types of justifications.* This perspective shifts the focus towards the determining and categorizing various types of justifications, bridging the gap between theoretical understanding and practical application in the diverse areas of scientific knowledge justification.

One of the studies exemplifying this perspective was carried out by Beniermann et al. in 2021. They explored how individuals informally reason about 'Controversial Scientific Issues (CSIs)' by using an online survey with 398 participants. The study focused on understanding the underlying attitudes and justifications in their reasoning. It aimed to categorize the types of justifications individuals use toward selected CSIs, including 'evolution, climate change, genetically modified foods (GMF), vaccination, and SARS-CoV-2'. Participants' open-ended responses were qualitatively analyzed to identify the types of justifications. Using a deductive-inductive approach, the justifications were categorized into five main types, further divided into 25 subcategories. This classification included 'subjective (normative) justifications' and 'intersubjective justifications,' the latter of which was split into 'evidential (empirical and theoretical)' and 'deferential (body of knowledge and lack of knowledge)' subcategories. 'Subjective justifications' were based on personal beliefs or logical fallacies. The categorization of 'Intersubjective justifications' distinguished them based on whether they cited an authoritative source ('deferential') or the content of the CSI itself ('evidential'). Within 'evidential justifications,' distinctions were made between 'empirical justifications', relying on concrete data, and 'theoretical justifications,' based on reasoning. 'Deferential justifications' referred to either a recognized 'body of knowledge' or an acknowledged 'lack of knowledge. The study found that, 'Subjective, Empirical, and Theoretical justifications' often varied by topic, whereas 'Deferential justifications' appeared more consistently across different CSIs. Also, 'Empirical justifications' were more frequent than theoretical ones. References to 'a body of knowledge' were the most common, and 'Subjective justifications' were the least common.

Another study to determine types of justifications was conducted in mathematics by Makowski (2021). She focused on the types of justifications used by pre-service middle school mathematics teachers, particularly concerning a unit on 'patterns.' Also, the study aimed to determine if the types of justifications varied depending on the presentation format of tackled pattern problems (diagrams versus numeric lists) and to explore the range of justifications employed both orally and in writing. These justifications were analyzed using TAP, which was enhanced with an adapted hybrid coding system designed for categorizing justification types. The study identified three main types of justifications in mathematical problem-solving: 'Inductive, Structural-Intuitive, and Deductive' justifications. 'Inductive justifications': This type predominantly relies on empirical evidence, using quantitative data to support mathematical claims. 'Structural-intuitive justifications': These are characterized by using familiar mathematical properties to form conclusions. Unlike other types, these justifications do not involve a systematic, thorough investigation. 'Deductive justifications': In this category, conclusions are drawn by systematically applying established mathematical principles and theorems. The research revealed a strong preference among participants for 'Inductive justifications', often at various levels and incorporating counterexamples in complex problem-solving. In written responses, participants predominantly chose 'Inductive justifications' when they used a single type of justification. Interestingly, when participants employed 'non-inductive justifications,' they frequently supported these with 'inductive evidence.' Additionally, it was common for participants to combine 'Inductive justifications' with 'Structural-intuitive' or 'deductive reasoning' in both oral and written forms, typically starting with 'inductive evidence' and gradually integrating more 'Deductive and Structural-intuitive justifications.' Makowski's (2021) study highlights the importance of understanding the diverse use of justification types by pre-service teachers in mathematics across different contexts. In this way, the study provides valuable insights into pre-service teachers' mathematical reasoning, offering valuable information for educators. This insight is crucial for enhancing the quality of mathematics education and preparing PSTs for effective teaching practices.

Similarly, Maciejewski and Star (2019) analyzed the justifications used by university students during procedural mathematical tasks with a specific focus on 'the row reduction of matrices.' The research aimed to categorize justifications emerging in these contexts, enhancing understanding of students' knowledge of procedure and decision-making processes. A key aspect of the study was exploring why students prefer certain procedural approaches over others, how they justify these preferences, and how they assess the appropriateness of their strategies in solving tasks. Using a 'phenomenographical approach,' the study analyzed verbal and written responses provided by students while solving mathematical tasks. The data, comprising audio recordings of students' problem-solving processes and written work, were thoroughly analyzed to construct a framework for categorizing justifications. The analysis revealed two distinct categories of justifications with three descriptive subcategories based on the nature of the justifications, each emerging for student decision-making in row-reduction mathematical tasks: 'Algorithmic and Anticipatory justifications.' 'Algorithmic justifications' represent a generalized approach where the reasoning, although possibly related to the specific task, is applicable across a range of similar problems. This category is further divided into Conforming to Established Procedures (justifying steps by aligning with established previously learned methods), Relying on Authoritative Guidance (justifying steps based on instructions or methods validated by external authoritative figures, such as teachers or textbooks), and Focusing on the Problem State Alteration (justifying steps by making decisions focused on the immediate step, typically following the broader algorithmic process without considering forward planning or future implications). On the other hand, 'Anticipatory justifications' are tailored to the specific context of the task and demonstrate students' foresight in their problem-solving process. These include Aiming for a Future Outcome (Students identify and aim for a desired future outcome in the task, guiding their actions to achieve this specific goal), Avoiding Undesirable States (Students recognize clear of actions that might lead to undesirable future scenarios or complications in the task and avoid these actions), and Enhancing Efficiency (Students focus on actions that either by choosing steps that shorten the overall process or by performing actions that simplify future steps, thus optimizing the problem-solving process). Maciejewski and Star (2019) argued that these six sub-categories provide a nuanced understanding of students' reasoning processes, and this wide variety of justifications observed suggests that effective instruction in mathematical procedures can significantly enhance students' conceptual understanding of mathematics.

Moreover, Premo et al. (2019) conducted an initial investigation to understand how physical alterations in question prompts could affect students' use of different types of justifications in their comprehension of 'Inheritance' and 'Evolution' concepts. Specifically, the study examined how these types of justifications differed based on the students' learning methods. The study involved 314 middle school students taught using either 'Category Construction' or a 'Traditional Worksheet Control' method. Their responses to two scenarios presented three days later, particularly one involving a physical change, were analyzed and categorized in two different types of justifications: 'Intuitive justifications' and 'Science-aligned justifications.' 'Science-aligned justifications' were characterized by their consistency with evolutionary theory and included a variety of justifications based on lack of impact, behaviors acquired through learning, increased chances of survival, genetic factors, or non-heritability. Conversely, 'Intuitive justifications' typically involved anticipating major effects on subsequent generations, directly or indirectly referencing inheritance. For example, they might include justifications asserting that offspring would inherit traits and suggesting generational enhancement of traits. This category also included justifications addressing the acquisition of new physical traits as a result of the scenario presented. The findings indicated a higher inclination for participants to use intuitive reasoning in scenarios featuring physical changes compared to those with behavioral ones. Furthermore, students engaging in the ‘Category Construction’ task exhibited more ‘Science-aligned justifications’ and fewer ‘Intuitive justifications’ compared to the control group. Moreover, the effectiveness of the ‘Category Construction’ task in promoting scientific reasoning was enhanced when feedback was provided. In general, two key conclusions were drawn. Firstly, students demonstrated a capacity to apply both ‘Science-aligned justifications’ and ‘Intuitive justifications’ when interpreting inheritance, influenced by the type of physical change presented. Secondly, engagement in the ‘Category Construction’ task significantly influenced the application of ‘Science-aligned justifications’ over Intuitive justifications.’ In the end, Premo et al. (2019) suggested that ‘Category Construction’ tasks, especially when supported by relevant feedback and scientifically accurate scenarios, can encourage students to use more ‘Science-aligned justifications’ than ‘Intuitive justifications.’

As seen above, these studies, along with others focusing on identifying types of justifications, involve a complex and detailed examination of the various forms and structures in which justifications are formulated and presented. This approach offers a comprehensive perspective, aiming to understand the diverse methods and reasoning styles used in the justification process, whether in everyday reasoning or scientific discourse, thereby facilitating the classification of different types of justifications.

Consequently, up to this point, in justification analysis studies, we have observed multifaceted perspectives. Firstly, there is an approach to justification analysis studies conducted from an epistemological perspective. This perspective primarily focuses on understanding the foundations and validity of knowledge, elaborating on how justifications align with or diverge from established epistemological theories. Secondly, another perspective investigates the criteria individuals or groups use to justify scientific knowledge claims. This perspective focuses on understanding how social, cultural, and personal factors influence the criteria in the process of justification within scientific contexts, and it is closely related to the sociology of knowledge. Another approach involves the determination and categorization of types of justifications. This perspective focuses on analyzing different types of justifications, exploring their roles in scientific discourse and thought processes. It also offers insights into the various ways justification is employed and the implications of these different types. Alongside these three approaches, there is another significant perspective in justification analysis studies: the determination and categorization of sources of justification. In the following section, the focus will shift to examining sources of justification.

2.2.2.1 Analysis of Sources of Justification

The recent scholarly focus on the role of argumentation in learning processes, particularly in relation to inquiry, marks a notable shift towards exploring epistemological dimensions. This shift is based on two key assumptions: firstly, that child inherently develops implicit understandings about knowledge through daily life experiences, and secondly, these understandings might not align with their comprehension of scientific knowledge and methodology. This acknowledgment underlines the universal acceptance that learning involves assimilating new information with pre-existing knowledge, and effective teaching, particularly in the field of science, should facilitate students in connecting new concepts to their existing knowledge. Accordingly, there is a growing need for research that accurately investigates the epistemological approaches students employ when reasoning about scientific issues (Sandoval & Çam, 2011). Building on this, Allchin and Zemplén (2020) emphasize that involvement in argumentation research typically focuses on analyzing arguments, their sources, and justifications in science education.

This perspective is further supported by McNeill et al. (2016). They emphasized the importance of understanding how scientific arguments are constructed and “the types of justification sources are valued within the scientific community (p.264)." As Sandoval and Çam (2011) stated "whether we want to attend to them or not, children not only have ideas about the world when they come to science instruction, but they also have ideas about how they know what they know (p.402)." Therefore, educators should elicit and address students' sources of justification for their causal beliefs (Sandoval & Çam, 2011). In scientific discourse, there are different sources of justification for a claim, including "empirical evidence, science ideas, appeals to authority, plausible mechanisms, and prior experiences," each holding varied epistemological value (Knight, 2015, p.35).

For instance, as Aguiar (2016) stated, conversations within the class can be seen as a specific form of discursive practice that enables the integration of the student's culture, which is rooted in everyday knowledge, with the academic culture of science that centers around scientific knowledge. Moreover, as Rudsberg, Östman, and Östman (2017) stated, the discursive practices students engage in are inseparably connected to their personal experiences. Namely, a person's experience and discursive practices are mutually dependent and shape each other, meaning that understanding one requires considering the other. The findings from their study showed "how an individual's earlier experiences, knowledge, and thinking contribute to the collective meaning-making in the classroom (p. 709)." Furthermore, Knight (2015) highlights the concept of 'productive resources.' This approach emphasizes that knowledge, being context-specific, leads students to apply their cognitive resources in scenarios they perceive as relevant. Specifically, when a type of knowledge has been activated and proved to be useful in a past experience, it is then seen as 'productive' and it is likely to be utilized in future similar situations. This is evident in how students often argue in everyday life, using personal experiences as justifications. This familiarity with using personal experience in arguments is then extended to their approach in scientific discussions, as they have previously found it to be 'productive.'

Similar to the importance of experience, prior content knowledge is an important source to consider for effective scientific discussion. Lee et al. (2014) highlight the dependency of students' abilities to construct scientific arguments on their existing content knowledge. This aspect is supported by Jiménez-Aleixandre and Erduran (2007); who point out that argumentation serves as a window into students' prior knowledge, enabling a deeper analysis of their arguments. Furthermore, McDonald (2013) underscores the importance of considering learners' background in science and integrating into discussions to enhance engagement in argumentation.

Therefore, prior knowledge and experience are important sources for classroom discourse and argumentation activities. To create effective learning environments for these types of discussions, it is crucial to recognize and acknowledge the pre-existing knowledge and life experiences that students carry into the classroom from their home environments and communities (Huff & Bybee, 2013). This is because, as stated by NRC (2012, p. 284). "When people enter into the practices of science or engineering, they do not leave their cultural worldviews at the door, and instruction that fails to recognize this reality can adversely affect student engagement in science."

Efficient science teaching takes into account the "prior knowledge, experiences, and beliefs" of students to ensure a fair and inclusive science learning experience for everyone (Huff & Bybee, 2013, p. 34).

This consideration is important because, for instance, students' background and content knowledge serve as a foundation for them to use evidence in backing scientific claims (Cheuk, 2016), significantly influencing students' engagement in argumentation (Ogan-Bekiroğlu & Eskin, 2012). It is a key factor in assessing the quality of their argumentation within that particular domain (Asterhan & Schwarz, 2016).

Moreover, for effective science teaching, the role of personal experience is also important. Gültepe and Kılıç (2021) emphasize that the experiences people gain from daily life are significantly important in the context of education and influence how they acquire knowledge and develop skills. This notion is supported by McNeill and Berland (2017), who assert that individual experiences are crucial in the context of classroom teaching. They highlight that personal and social aspects of students' lives can greatly enhance their engagement. According to Cheuk (2016) the social aspect of argumentation considers the backgrounds and experiences of those involved. This is evident as students often utilize their thoughts and lived experiences when engaged in scientific argumentation (Angeloudi et al., 2018; Cheuk, 2016; Knight, 2015; McNeill & Pimentel, 2010; Ryu & Sandoval, 2015; Sandoval & Çam, 2011). Perloff (2003) further supports this idea by defining “a good argument is one that is organized, elaborated, and supported by evidence or personal experience” (as cited in Nussbaum & Schraw, 2007, p.59).

Additionally, for effective science teaching, daily life observation is as important a source of justification as prior knowledge and personal experience. For example, many elementary students frequently use observations from their daily lives, such as noticing a puddle drying up over the course of a day, as scientific evidence to support their understanding of natural phenomena. This situation demonstrates how daily observations can serve as valuable scientific evidence in the learning process. Additionally, in the process of evaluating scientific claims, people, even scientists, rely on diverse types of information sources. Often, they learn about the natural world through their personal observations rather than just through accepted established facts. This type of learning underscores that personal experiences and observations can be as informative as traditional scientific knowledge (McNeill & Berland, 2017). Similarly, Sampson and Clark (2008) stated that in the context of the arguments, students generally prefer explanations that simply describe their daily life observations rather than mentioning the causality issues. Also, Skoumios (2013) underlined that when individuals use empirical consistency, they support their claims by showing that these claims or the data backing them align with empirical evidence gathered from scientific experiments or observations in daily life.

In summary, students' background knowledge, personal experiences, and observations from daily life play a critical role in their engagement with scientific argumentation as sources. These sources are not only fundamental in helping students make sense of scientific concepts but also vital in their active participation in scientific discourse. Also, there is a necessity for educational approaches that recognize and integrate these essential aspects of student life into the learning process. Therefore, these sources need to be analyzed more deeply in scientific argumentation.

Another perspective in justification analysis studies focuses on the sources of justification. These studies explore the diversity of sources used in the justification process and assess their impact on the quality of justification. They highlight the significance of the origin and nature of information and evidence in shaping justification.

For example, there are many different analytical frameworks favored by science educators in the context of examining both the nature and quality of argumentation related to three critical areas: 'structure,' 'content,' and 'nature of the justification.' One of these frameworks was developed according to the approach of Schwarz et al. (2003). It is used for evaluating argument quality, focusing on the appropriateness and acceptability of the reasons. Schwarz et al. (2003) found that the abstract and consequential reasons underlined as "the highest quality reasons" involving inferences drawn from "background knowledge, personal experiences, and the claims of others." They also observed that students' arguments are generally one-sided, featuring a single reason often vague or considered a 'make sense' reason. These make-sense reasons are "generally accepted beliefs or truisms, those based on authority, or reasons arising from personal experience" (as cited in Sampson & Clark, 2008, p. 454). Additionally, Sampson and Clark (2008) conducted a detailed review of frameworks for argument analysis in science education. They stated that as a result of the analysis of the justification of the arguments made by the students in terms of information components, it was determined that the students preferred to use “inferences, personal experiences, authority figures, insufficient or inappropriate information while justifying their data (p. 468).

One of the important studies analyzing justification, which exemplifies this perspective on the sources of justification, was conducted by Ludwig et al. in 2021. Their analysis is centered on how students individually justify their decisions in the physics lab, rather than on whether these choices reflect a change in their understanding or beliefs about physics concepts. The study does not measure the proficiency or quality of the justifications or structure but rather explores their nature and sources. The research is mainly concerned with how students react to experimental data that conflicts with their existing beliefs or hypotheses, offering insights into their cognitive processes in such scenarios. So, they present two distinct studies. The first study focuses on eliciting, identifying, and categorizing the range of situation-specific justifications students use both based on anomalous experimental data collected by themselves and from quantitative physics experiments while supporting or rejecting scientific hypotheses. Study 1 follows a methodology where students initially hypothesize (presenting with a brief explanation), test these hypotheses experimentally, and collect data. Tasks in mechanics and thermodynamics were chosen, specifically focusing on ‘the simple pendulum’ and ‘temperature in solid bodies.’ These topics were chosen because of their potential to prompt incorrect initial hypotheses from students and their suitability for being easily testable by students and could also end with anomalous data. For the first study, 129 students from 8th to 10th grades were selected and randomly divided among three experimental activities in mechanics and thermodynamics. Data gathering through semi-structured interviews took place promptly following the completion of these experiments, and the primary question asked during interviews was whether they chose to support or reject their first justifications. The studies collectively identified a comprehensive range of justifications used by students. These ten types of justifications include “appeal to an authority, data as evidence, experimental competence (technical/skills), experimental competence (self-concept), ignorance, intuition, measurement uncertainties (explicit), measurement uncertainties (implicit), suitability of the experimental setup, and use of theoretical concepts" (p. 819). Furthermore, the second study aims to develop and present a methodology for quantitatively and empirically measuring four specific types of justifications among the ten identified. These selected justification types, including 'appeal to authority,' 'data as evidence,' 'experimental competence,' and 'use of theoretical concepts,' are measured using a questionnaire that employs a Likert-type scale for responses. The questionnaire can be completed in 5-10 minutes. This measurement tool also offers a new way to efficiently facilitate the study of factors influencing students' justification types and how these justifications affect their scientific reasoning in a laboratory context.

Another study, conducted by Bilican in 2018, aimed to identify the sources of justifications in science education, particularly in relation to SSI. This research was designed to examine how a course on science teaching methods, which included explicit reflective instruction on NOS, influences the understanding of NOS and justifications in socio-scientific decision-making. This case study, which involved five students enrolled in a program for elementary science education, primarily aimed to assess how their perspectives on NOS evolved, the changes in the sources of their justifications, and their understanding of NOS correlate with their justification in socio-scientific decision-making. Participants took part in a semester-long course featuring explicit NOS instruction. Data were collected through pre- and post-administration of two key instruments: 'the Decision-Making Questionnaire (DMQ)' and 'the Views of Nature of Science Questionnaire'. The DMQ presented real-world scenarios, such as environmental issues and health-related dilemmas ('fetal tissue implantation, global warming, and the relationship between cigarette smoking and cancer'), requiring participants to make and justify decisions. Both tools were instrumental in assessing changes in the participants' views on NOS and their justification processes. The study tracked changes in justification sources through DMQ responses. The analysis identified justification sources in participants' responses, using an open-coding approach for categorization. It also involved searching for patterns within these justifications. Results identified ten justification sources: "Ethics Humanity, Ethics Social responsibility, Religion, Pedagogical, Legality, Science Conservation of Nature, Science Empirical, Social Rights, Social Economy and Personal (p. 429)." The study found diverse individual changes in justifications among participants, lacking a clear, uniform pattern. Participants utilized various sources for their justifications before and after the NOS instruction, with only minor changes observed in these sources post-instruction. Participants primarily based their justifications on "personal values, ethical/moral beliefs, and social factors (p.432)." Notably, in the global warming scenario, several participants showed an increase in the number of justifications post-instruction. The study also found that personal experiences and familiarity with SSIs played a role in shaping the range and sources of justifications. No clear correlation was found between enhanced NOS understanding and changes in the sources of justifications for socio-scientific decision-making. This study shows how pre-service science teachers approach and justify socio-scientific issues after receiving explicit NOS instruction. The research highlights that NOS instruction does influence their understanding of science, but its effect on how they justify decisions in socio-scientific situations is not straightforward.

Bråten et al. (2016) aimed to examine how clear source presentation and risk highlighting within texts might affect readers' attention to and utilization of source information. This was specifically examined in the context of readers making decisions about health-related controversial topics from single documents. The research included 259 university students enrolled in various undergraduate programs. Participants read documents concerning "artificial sweeteners and cell phone use" and then indicated if these influenced their behavioral intentions on a three-point scale. They also provided justifications for their decisions. The sources of these justifications were categorized as references to "primary and embedded sources, personal opinions, personal experiences, other sources, and document content (p. 1612-1613).” The research primarily focused on how participants attributed the conclusions drawn in the documents to various sources, their recall of these source details, and the nature of their justifications for behavioral decisions. In making decisions about health-related issues, participants predominantly overlooked the information about sources presented in the texts. This trend was evident regardless of how the text was structured or the sources were highlighted. The study found a noticeable trend where participants placed greater reliance on their own personal experiences and beliefs than the sources directly cited or indirectly mentioned in the documents. Overall, there was a limited inclination among participants to modify their behaviors based on the document content. Notably, the document on ‘artificial sweeteners’ had a greater impact on influencing behavioral intentions compared to the document on ‘cell phone use.’ In contrast, when providing justifications for their decisions, participants consistently avoided referencing the primary or embedded sources from the documents. The documents' content was also rarely used as a basis for decision-making. Instead, personal experiences, especially those related to ‘artificial sweeteners’ or ‘cell phone use,’ were the dominant factors in their decision-making process. Personal opinions about these issues also significantly influenced whether participants considered altering their behaviors. The study observed a variation in the justifications across the two different topics, with a stronger reliance on personal opinions particularly evident in responses to the document about ‘artificial sweeteners.’ The critical insight from this study is that university students mainly ignored source information in documents when making decisions about controversial issues like ‘artificial sweeteners and cell phone radiation.’ They did not significantly distinguish between embedded source information and the main content of the documents in their justifications. The study highlights a general tendency among participants to ignore source information when making decisions on controversial health-related topics. Personal experiences and opinions were given more weight than the documented sources or content. To explain this general tendency, Bråten et al. (2016) suggest that pre-existing beliefs about the topics (e.g., health risks) may have influenced the participants’ responses more than the actual content or sources of the documents.

In her dissertation, Knight (2015) investigates how middle school students understand, use, evaluate, and critique two key constructs: various sources (forms) of justification and scientific evidence in the context of writing and reading scientific arguments. The research specifically focuses on the comparative analysis of students' abilities to construct and critique arguments using different sources of justifications, emphasizing the quality of evidence and the epistemic status of these justifications in their arguments across reading and writing modalities. The research also focuses on understanding the criteria students use for these critiques and how they discriminate the quality of evidence in scientific discussions. Additionally, this dissertation aims to explore students' preferences for different types of scientific evidence and to determine if these abilities in critiquing and constructing arguments represent distinct skills or a single overarching ability. In summary, the analysis focus of the study is different sources of justifications: “empirical evidence, science ideas, appeals to authority, and prior experiences (p.35)” and “four constructs: reading sources of justifications, writing sources of justification, reading empirical evidence, and writing empirical evidence (p.13)”. The comprehensive methodology of research involves 125 students from 6th and 7th grades and employs card sorting, cognitive interviews, and various assessments to evaluate the student’s abilities and criteria for these four constructs. To reveal the students' preferences in both the nature of justification and empirical evidence, students participated in a core activity: a card sort task in which they were presented with nine various justifications for one scientific claim, each combining different sources of justifications and types of evidence. This sorting task required students to select and rationalize the most convincing justifications. The students' responses were then evaluated using Rasch models to understand further their capacity to assess scientific evidence critically. This involved examining their ability to critique the evidence across the different sources of justification and types of empirical evidence: “relevant-supporting, relevant-contradictory, or irrelevant (p.48).” Additionally, cognitive interviews were conducted with a selected group of students (n=28) to gain deeper insights into the criteria they used in their critiques. These participants were instructed to select the top three justifications and describe the reasoning behind their selections. Consequently, these students had to determine and explain whether the nature of the empirical evidence or the sources of justification held more significance for them. Then, a dimensionality analysis was conducted to investigate whether the identified four constructs constituted separate skills or a singular, overarching ability. Furthermore, the study classified students’ abilities into levels based on their skill in identifying and critiquing justifications, ranging from basic recognition to complex analysis of argument quality. The findings illustrate that a scientific claim can be justified through various sources: “empirical evidence, scientific concepts, appeals to authority, and personal experiences (p.6-7)” Each source provides a unique approach to justifying a claim, with empirical evidence relying on observable and measurable data, while scientific ideas utilize theoretical concepts and principles without direct evidence. Appeals to authority draw on expert opinions, and prior experiences represent experiential reasoning based on personal or known or anecdotal experiences. The study also finds that students showed a strong preference for justifications based on empirical data over other forms: authority statements and personal experiences. Despite the overall preference for empirical data, the study notes that some students also chose justifications based on authority opinions and prior experiences, highlighting their recognition of diverse evidence sources. Besides this, the research also highlights that it was difficult to ascertain a clear preference between authority statements and personal experiences due to varying responses. The card sorting activity also revealed key themes, including the prioritization of the type of empirical evidence over the sources of justification and a preference for relevant-supporting justifications over others (contradictory or irrelevant). Knight (2015) concludes that while middle school students predominantly favor empirical evidence, they also recognize and occasionally use other sources such as ‘authority statements’ or ‘personal experiences’ and these less favored sources of justification are not inherently unacceptable in scientific arguments. According to Knight (2015), it is important to recognize that forms of evidence less commonly accepted in epistemology can still be valid. This dissertation is significant in the context of middle school education, as it suggests that students at this stage are developing a nuanced understanding of scientific argumentation and the various sources of evidence that can be used to support scientific claims.

In their research, McNeill and Pimentel (2010) analyzed how arguments are formed by students discussing climate change in high school settings. They focused on the dynamics of classroom discussions about climate change. The researchers analyzed transcripts from three high school teachers' classes, paying close attention to both the structure of arguments presented by students and the dialogic interactions among them. The intent was to understand how students construct arguments and how teachers facilitate this process in the context of scientific argumentation. The study was set in classrooms with 11th and 12th-grade students participating in a 'climate change module,' structured over 11 lessons and scheduled to cover 16 to 19 class periods. This module was part of a broader curriculum comprising eight units, each lasting two to four weeks. The analysis categorized the sources used in student justifications into three groups: 'Scientific' (e.g., melting glaciers, rising sea levels), 'Personal' (e.g., personal experiences with weather), and 'Other Types (External)' (e.g., information from external sources) (p. 211). The research found a diverse use of source types across these three different classrooms. In one classroom, the focus on sources of justifications was mainly 'Scientific' with little use of 'Personal' or 'External'. In contrast, especially when the use of scientific evidence was not strictly required, the second classroom saw more frequent use of personal experiences, such as discussing unusual weather patterns. The third classroom saw a wider variety of source types, including 'Personal,' 'Scientific,' and 'External' sources. This diversity in source usage revealed that students, when not directed to use only scientific evidence, tended to draw from a variety of sources for their justifications. This variation in source usage highlights the significant role teachers play in shaping how students approach and understand scientific topics, especially in science areas where their prior content knowledge is limited. Additionally, the study also highlighted that teachers varied in how much they emphasized and supported the use of students' personal experiences in discussions about climate change. At the end of the research, it was concluded that when teachers were flexible in allowing diverse source types, students more frequently used daily experiences, such as personal weather experiences, and external sources like media reports and anecdotes from others.

Moreover, the research conducted by Sandoval and Çam in 2011 investigated how children aged 8-10 assess the validity of different sources of justifications for causal claims. The primary focus identifying the epistemic criteria these children use in evaluating various sources of these justifications. The study aimed to understand the conditions and reasons that influence children's preference for certain justifications, with a particular focus on how evidence clarity affects their choices. Additionally, it sought to explore whether children's preferences for specific types of justifications were consistent or varied depending on the available evidence. A group of 26 children participated in an exercise involving decision-making based on different sources of justifications. The children were presented with story scenarios where they assisted two characters in choosing the most convincing reason for believing a certain claim. The justifications provided to the children for evaluation included three sources: 'appeals to an authority, plausible causal mechanisms, and data-based evidence.' In these story scenarios, the justifications based on authority and plausible mechanisms consistently supported the causal claim. These were paired with data that either clearly supported the claim or were ambiguous, offering no clear support and thus providing a basis for the children to evaluate the strengths of different justifications. The analysis of interviews, in which students were asked to select the most convincing justification and to explain their choices, provided a comprehensive view of their reasoning processes. This was achieved by examining the collective trends in the children's responses and individual differences in the two stories. The study found that children generally preferred evidence-based justifications over those based on authority or plausible mechanisms. This preference was stronger in comparison to authority-based justifications. However, when the justification was a plausible mechanism, children's preference for evidence was not as marked, especially when data were ambiguous. Thus, this preference varied based on the nature of the justification sources and the clarity of the evidentiary data. This finding suggests that children value both evidence and plausible mechanisms, depending on the clarity of the information provided. The analysis of children's consistency in choosing justifications showed that many children (15 of the 26) predominantly chose evidence-based justifications across different scenarios, indicating a strong tendency towards preferring empirical reasoning. Additionally, the study noted that children's choices were influenced by a range of factors, including their personal experiences and the perceived credibility of the justifications. Often, children cited personal experience to support non-evidentiary justifications or used alternative causal mechanisms. When choosing evidentiary justifications, they typically demonstrated an understanding of the presented data, valuing its credibility over other types of justification. Interestingly, their beliefs in the story's claim did not majorly impact their preference for a particular type of justification source. In the study's conclusion, it was found that children generally rank sources of justifications in a loose order, with a preference for data, followed by plausible mechanisms, and least favorably, authority. Their main criterion for preferring any justification was its credibility, especially valuing personal experience. In scenarios where both data and plausible mechanisms supported the claim, children often chose the plausible mechanism (personal experience), suggesting that their preference for plausible explanations may increase when data do not align with these mechanisms. This research contributes to the field of science education by extending our understanding of how young children evaluate and prioritize different sources of justifications. It also suggests that understanding children's observed preferences for different types of justification sources can enhance science education.

Similarly, Salmerón et al. (2016) conducted a study to explore how students of various educational levels (primary, secondary, and undergraduate) assess the credibility of information in online forums. Specifically, it focused on two factors: the identity of the author and the nature of the evidence supporting the author's statements. Two controlled experiments were conducted involving online discussions on everyday topics. In these discussions, the authorship of the advice varied (either a self-declared expert or an anonymous user), as did the type of evidence provided (external sources or personal experience). The experiments aimed to understand how students judge the reliability of advice in different scenarios: a single piece of advice (Experiment 1) and multiple conflicting pieces of advice (Experiment 2). Students also provided justifications for their judgments. In scenarios with just one piece of advice (in the First Experiment), students did not significantly consider the author's identity or the nature of evidence when evaluating the advice's credibility. In the Second Experiment, where multiple pieces of advice were available, students showed a preference for advice from self-declared experts over anonymous users. This trend was more evident among undergraduate students compared to younger ones. Additionally, there was a developmental trend: primary students favored personal experience, whereas undergraduates preferred advice supported by external sources. Younger students tend to use source cues more superficially, while undergraduate students demonstrate a deeper appreciation and understanding of source credibility, combining author identity and evidence type effectively. These findings indicate that the presence of various perspectives in forum discussions enhances students' focus on the characteristics of information sources.

Consequently, the studies mentioned above were conducted from the perspective of analyzing justification sources. They adopted a categorization approach to analyze the sources of justifications and how these processes are constructed and perceived in different contexts. This perspective has enabled us to bridge a significant gap between theoretical knowledge and the practical applications of justification in real-world scenarios, establishing connections between abstract theories of knowledge and the practical challenges encountered in real-life situations. The categorization achieved by this analysis is fundamental in enhancing our understanding of the mechanisms behind justification construction and perception across different contexts. Consequently, these studies represent a significant step in understanding the multifaceted nature of knowledge and justification processes and how they are shaped in various situations and contexts.

Additionally, the investigation into the nature of justifications in student arguments is notably rare. Beniermann et al. (2021) observe that there are only a few studies that have focused on the types and content of justifications. This lack of research highlights a crucial gap in our understanding of how students construct and justify their arguments, underscoring the need for more detailed studies in this area. Nevertheless, the existing research concerning the criteria utilized by students to justify their claims is notably constrained in scope and depth (Skoumios, 2013). Similarly, Cheng et al. (2021) highlight that in science education, there is a significant lack of research on understanding how students transfer and apply their schooled knowledge and justification skills to unschooled contexts, like online environments, and this presents a critical challenge. Therefore, there is a significant gap in science education research regarding the analysis of justification, both in and out of formal educational contexts, and studies related to "justification analysis" are needed within argumentation analysis for science education.

It is also evident that there is a notable gap in the research surrounding 'sources of justification analysis,' particularly in the context of science education. Knight (2015) highlights this gap across various aspects of scientific argumentation, stating, "The scientific argumentation research has tended not to address how students construct and critique sources of justification—the research around this construct is limited" (p.36). This gap becomes more evident as Knight (2015) points out the challenges students face in constructing arguments and the lack of focus on the mechanisms behind justifications, as well as on "what sources of justification students value (p.37)," despite more attention being given to the structure of arguments and the inclusion of scientific evidence.

Similarly, Sandoval and Çam (2011) expand this discussion to include developmental psychology and science education, focusing particularly on children's understanding of justifications. They underscore the importance of 'practical epistemological ideas' in constructing children's justifications and highlight the disconnection between these ideas and the nature of scientific knowledge. They emphasize that these 'practical epistemological ideas' are "important to science educators as they can provide valuable insights into the cognitive sources that children can bring to bear on their own science learning and possibly even suggest instructional strategies to promote such learning" (p.384). However, there is still a need for research that effectively connects children's epistemological ideas they actually employ and instructional strategies.

In summary, both Knight (2015) and Sandoval and Çam (2011) emphasize the urgent need for more research on the sources of justification. This research is crucial for a better understanding how justifications are formed, critiqued, and perceived, especially in science education. This gap in the literature affects our theoretical understanding of the mechanisms behind justification processes but also has practical implications for educational strategies and the development of students' critical thinking and reasoning skills. This limitation in studies becomes increasingly significant when considering this important role of justification.

Therefore, the focus of this study is to conduct an in-depth analysis of justification within the argumentation process, primarily by investigating and categorizing the different sources of justifications.

Additionally, we focus on the changes experienced in these justifications during the argumentation process as a persuasion discourse. This approach also aligns with one of the critiques discussed and recommended earlier in the '2.3.1. Analyzing the Quality of Argumentation' section: the importance of including persuasion analysis, namely in determining the most convincing justifications. As Ludwig et al. (2021) discussed, "it seems especially important to investigate the relationship between persuasion and the use of different justifications (p. 839)."

Thus, integrating this element is crucial for a thorough understanding and comprehensive analysis of argumentation. In other words, a significant part of our focus is to understand how sources of justification change within an argumentative discourse. This aspect is important for a complete analysis of argumentation, ensuring that we address not only the structure and content of arguments but also how justifications are constructed individually and interact during the discussion and change at the end. By doing this, we aim to provide a clearer understanding of the argumentation process, capturing how arguments are constructed and challenged in real-world scenarios.

Besides, it is unclear whether and how different types of justification sources play a role in the argumentation process, that is, how they influence the argumentation as a social process. In other words, this area has not been extensively studied.

To the best of our knowledge, no study has yet simultaneously categorized types of justification sources and monitored the changes in these sources within the argumentation process.

Consequently, the purpose of this study was to conduct the analysis of justification as a key component of constructed arguments. More precisely, the research investigated students' justifications for their claims in the realm of physics and categorized the diverse types of sources used to support these justifications. This study does not focus on changes in epistemological ideas and beliefs or understanding of concepts in physics. It explores the change in these sources during argumentation practice in an authentic way.

CHAPTER 3

METHODOLOGY AND PROCEDURES

The review of related literature and the rationale for the study have been presented in previous chapters. As mentioned, the primary purpose of this research is to elaborate on and classify the emerging types of justification sources, as well as to examine the interactions among them and their changes. This examination occurs when students face debatable inquiry tasks with counter-intuitive physics problems in an argumentation process formed by the 'Predict-Observe-Explain' (POE) instructional strategy. For this purpose, eight debatable inquiry tasks, each with six phases, were prepared. This study seeks answers to the following research questions:

1. What types of justification sources emerged during the argumentation process?
2. How do the types of justification sources vary across the six phases of the argumentation process?
3. How do the types of justification sources vary across the eight tasks?
4. How do participants' justification source types change after Group Discussion 1 (before the demonstration)?
   4.1. How do participants' justification source types change after Group Discussion 1 (before the demonstration) across eight tasks?
   4.2. How do participants' justification source types change after Group Discussion 1 (before the demonstration) in terms of being relevant or irrelevant?
5. How do participants' justification source types change after Group Discussion 2 (after the demonstration)?
   5.1. How do participants' justification source types change after Group Discussion 2 (after the demonstration) across eight tasks?

5.2. How do participants' justification source types change after Group Discussion 2 (after the demonstration) in terms of being relevant or irrelevant?

This chapter focuses on the methodology, covering various aspects essential to the research. It starts with the research design, explaining how the study was conducted. The descriptions then move to the participants and research context, detailing the setting of the study, including the course design, steps in the POE instructional strategy, the development of debatable inquiry tasks, the selection of counter-intuitive physics problems, and the experimental setups used. Following this, the data collection process is outlined, explaining the timing and sources of data collection, which include argumentation worksheets as data collection sources. The data analysis procedure is described next, detailing how the data were coded and analyzed concerning the research questions. The chapter also addresses the study's trustworthiness, the researcher's role, and ethical considerations taken into account during the research. It concludes by discussing the assumptions made, the limitations faced, and the strategies employed to control potential threats. All these methodological issues are explained in detail in the following sections.

3.1 Research Design

This section explains the rationale for selecting a case study, one of the qualitative research types, for the study. Case studies enable researchers to describe "the object of their research—cases—and focus their investigations on the study of these cases" (Fraenkel & Wallen, 2003, p. 439). Stake (1997) defined a *case study* as an in-depth exploration of a program, event, activity, process, or one or more individuals bounded by time and activity, as cited in Creswell (2003).

This study aims to categorize the various types of justification sources that arise and to explore how these sources interact with each other and change. This exploration is conducted as students engage with controversial inquiry tasks that involve counter-intuitive physics problems within an argumentation process shaped by the POE instructional strategy.

Therefore, the case study approach was selected for this study, and among the various classifications of case study designs, it was decided to conduct an ‘instrumental case study.’ This decision was made because the current research analysis focuses on the phenomenon, not the case itself. Specifically, the phenomenon of interest is argumentation, namely the emergence and evolution of justification source types in our case, rather than focusing on people or instructions. Thus, the case serves as an instrument for analyzing the elements and the processes of argumentation.

An ‘instrumental case study’ is employed when the primary interest extends beyond the characteristics of the case itself, such as a specific individual, class, school, program, educational setting, and event, which are considered of secondary importance. This approach serves as an ‘instrument’ or a vehicle to provide deeper insights into broader issues, questions, or phenomena, focusing on understanding implications beyond the case. Researchers utilizing this method are less concerned with the details or complexities of the individual case and more focused on generating findings that have broader applicability and relevance. Therefore, the essence of an instrumental case study lies in its utility in achieving a broader understanding that goes beyond the immediate case, aiming for conclusions that are generalizable beyond the specific instances being analyzed. Namely, researchers conducting these instrumental case studies seek insights that can apply to more than just the one case they are studying. They are more interested in lessons that can be applied in other situations, not just the characteristics of the single case (Fraenkel & Wallen, 2003).

The design of the instrumental case study is coherent and well-aligned with the specific aims of this study. The current research focuses on a very specific phenomenon: the nature and dynamics of justification source types within the context of scientific argumentation involving counter-intuitive physics problems and using the POE instructional strategy. The main concern is not necessarily the people involved or the broader educational framework but rather the particular phenomenon of how justification source types emerge and interact in such an educational context. The case in the current study involves students' experiences with the argumentation process formed by the POE instructional strategy in the 'General Physics Laboratory 1' course. This process of argumentation is the subject of our analysis. The study examines eight weeks of the argumentation process, defining the time boundaries of the case being studied. The data source is the argumentation worksheets filled out by the students, which serve as self-written reports. The unit of analysis is 'each student's justifications.' To clarify, these justifications are written explanations of students' claims that reflect their reasoning process. Thus, the unit of analysis encompasses every meaningful word, phrase, and sentence used to support a claim in these justifications.

3.2 Research Context and Participants

This section presents the participants and the research context involved, which are crucial to understanding the methodology employed in this study. It starts with descriptions of the participants, detailing the process of forming both pilot and main study groups. Then, it explains the setting in which the research was conducted, detailing the course design. The discussion then moves on to describe the steps in the POE instructional strategy, which is central to our approach. Next, the development of debatable inquiry tasks is presented, which includes the selection of counter-intuitive physics problems and the description of the experimental setups for demonstrations used in the study.

3.2.1 Participants

This study was conducted with 25 first-year university students seeking a degree to become science teachers and enrolled in the 'Elementary Science Teaching

Undergraduate Program' at a university in Northern Turkey in the 2016-2017 academic year. They participated in the 'General Physics Laboratory 1' course as part of their curriculum. This course is critical for students to gain practical experience in science education and acquire in-depth knowledge of fundamental physics concepts. Through this course, the students had the opportunity to apply theoretical knowledge in a laboratory setting and begin developing key skills relevant to teaching science.

The researcher, serving as a research assistant at a university in Northern Turkey, faced the challenge of requiring significant time and in-depth investigation for this study. The accessibility of students was a crucial factor in the research design; thus, the university where the researcher is employed was chosen for the study. This selection effectively addressed potential constraints related to time and workforce, enabling a more efficient and manageable research process. The researcher could use existing relationships and logistical advantages by conducting the study within their institution, significantly reducing the limitations that often complicate academic research.

The 'General Physics Laboratory 1' course offers a uniquely suitable environment for implementing the argumentation process structured by the POE instructional strategy. This course aligns closely with the research content, providing distinct advantages for facilitating the argumentation process. Its laboratory setting and hands-on approach stand out compared to other science courses in the science teaching program, making it particularly effective for this study's objectives. Moreover, the conceptual physics topics related to the counter-intuitive physics problems selected for this research are simultaneously taught to the students through the 'General Physics 1' course. This course focuses on the theoretical aspects complementary to the practical sessions encountered in the 'General Physics Laboratory 1' course. This dual approach ensures that students receive a comprehensive understanding of physics concepts, allowing them to connect theoretical knowledge with practical laboratory experiences more effectively.

Additionally, this integration of theory and practice enhances the learning experience, making it conducive to exploring and understanding complex physics concepts through argumentation.

Therefore, the main study's participants are first-year university students majoring in the 'Elementary Science Teaching Education' department at a university in Northern Turkey. This cohort includes 25 individuals, with a demographic breakdown of four males (16%) and 21 females (84%). 10 students were 19 years old (40%), eight students were 18 years old (32%), and seven students were 20 years old (28%). Out of the students, 17 (68%) graduated from 'Anatolian High School,'4 (16%) from 'Multi-Program High School,' and the remaining 4 (16%) from high schools of various other types. All students were placed in this undergraduate program by getting a minimum of 249.2 and a maximum of 296.6 points in the university entrance exam. They were all enrolled in the compulsory 'General Physics Laboratory 1' course during the fall semester of the 2016-2017 academic year, and for each of them, it was their first experience with this laboratory course. Each student was assigned a pseudonym, ranging from letters A to Z, to maintain confidentiality and avoid using students' real names.

Additionally, a pilot study group has been determined for the processes of 'Selection of the Counter-Intuitive Physics Problems' and 'Development of the Argumentation Worksheet as the Primary Data Collection Instrument,' which will be addressed in following sections.

This pilot study group involved first-year university students majoring in the 'Elementary Science Teaching Undergraduate Program,' totaling 48 students. These students were not only enrolled in a compulsory 'General Physics Laboratory I' course during the fall semester of the 2015-2016 academic year, as part of the 'Elementary Science Teaching Undergraduate Program' at the same university located in northern Turkey, but they were also from the same cohort as the 25 students who would participate in the main study, ensuring a consistent educational background and level of expertise. This alignment was crucial for maintaining uniformity in the participant pool, as all were registered for the same course within the same department at the university, reflecting the conditions set for the main study's participants.

3.2.2 Research Context

The Research Context explains where and how we conducted our study. It first presents the design process of the ‘General Physics Laboratory 1’ course, in which the current study was applied and which served as a background for the study. Afterward, the phases of the argumentation process, formed by the POE instructional strategy and carried out within the scope of this course, are explained in detail. These detailed descriptions show how this strategy was integrated into the course design to engage students deeply in the subjects they were studying. Finally, the creation of debatable inquiry tasks is explored, demonstrating how these tasks were designed to encourage critical thinking and active participation among the participants. The selection of counter-intuitive physics problems is also highlighted, specifically for their potential to challenge preconceptions, their ability to question usual thinking, and their effectiveness in encouraging a deeper examination of physics concepts. Additionally, the experimental setups used for POE in the study are described, providing a view into the hands-on parts of the research and how these setups were designed to facilitate the investigation.

3.2.2.1 Course Design

‘The Elementary Science Teaching Undergraduate Program’ at the university where the study was conducted includes physics laboratory courses, one of which is the ‘General Physics Laboratory 1’ course, designed to engage students in practical learning experiences. According to the course content in ‘Elementary Science Teaching Undergraduate Program,’ students typically perform experiments as part of this course and prepare laboratory worksheets (reports). Furthermore, this process usually follows a ‘cookbook approach.’ In line with the course design principles, the ‘General Physics Laboratory 1’ course was selected for the current study to examine the argumentation process, guided by the POE instructional strategy. The course's structure, aiming to foster a deeper understanding of physical concepts through active engagement, was designed by the researcher, who also served as the instructor. This course is scheduled for meetings with students twice a week, totaling four hours weekly.

At the beginning of the fall semester of the 2016-2017 academic year, one week was dedicated to informing students about the procedures and goals of the ‘General Physics Laboratory 1’ course. Specifically, students were briefed on the purpose of the methodologies applied in this course, including the significance of collecting and analyzing data, which would be shared with them after the study. Additionally, the researcher outlined the course syllabus, providing detailed explanations to ensure clarity and set expectations. Furthermore, detailed instructions were given on how the course would be conducted, emphasizing the innovative use of argumentation worksheets. Students were guided on effectively completing these worksheets, a crucial component of the course designed to enhance their understanding and application of scientific concepts through structured argumentation. This preparatory phase was instrumental in providing the students with the needed knowledge and skills, ensuring they were ready to start the learning process. This comprehensive orientation covered not only the course content and schedule but also highlighted the pedagogical strategies that would be used. This approach aimed to support the main goal of creating an engaging and interactive learning atmosphere.

The argumentation process was carried out over eight weeks in the ‘General Physics Laboratory 1’ course. Each week, for two hours, students completed eight distinct tasks and filled out argumentation worksheets designed for each task. During the other two hours of the course each week, correct answers to eight counter-intuitive physics problems for the tasks were presented. Furthermore, during these sessions, the accuracy and errors in the justifications provided by the students throughout the six phases of the argumentation process were reviewed, and feedback was shared with them. This feedback was provided before they started on the next task, facilitating a continuous learning and improvement cycle. Additionally, this feedback also motivated the students to continue writing their justifications throughout the six phases for the task in the following week.

At the end of the fall semester of the 2016-2017 academic year, one week in this laboratory course was dedicated to presenting the current research findings to the students.

The argumentation process we designed in this course aims to examine the sources of justifications and to observe any changes in these sources of justifications throughout their interactions in discussion parts. To facilitate the emergence of diverse and varied justifications, we designed a natural and free discussion environment where no interventions were made. This approach ensures that students can freely express their justifications and engage in debates, thus enriching the argumentation process with a wide range of perspectives. The goal was to create a setting that encourages critical thinking and the development of well-supported arguments.

In the next section, we will detail what students are expected to do in each phase of the argumentation worksheet. Specifically, the contents of the six phases of the argumentation process, which are based on the POE instructional strategy, will be explained thoroughly.

3.2.2.2 Steps in Argumentation Process

The instructional strategy used to create an argumentative environment for this study is the POE. The POE instructional strategy is rooted in 'Posner's conceptual change model' which facilitates the change of students' existing erroneous conceptions. This approach begins with students making predictions about a problem, topic, or experiment and justifying their claims with reasons. Next, they move on to the observation phase, enabling students to test their predictions empirically. Finally, they reevaluate their initial predictions and explanations by comparing them, looking for consistency or discrepancies, and then provide their final explanations (Ha & Kim, 2018; White & Gunstone, 1992).

Within the scope of this study, students were presented with eight tasks, each comprising six distinct phases, during the argumentation process formed by the POE instructional strategy. Table 3.1 details these six phases, outlining the activities students were expected to perform in each phase and giving average time durations. The pictures of each of the six phases of the argumentation process are given in Appendix A.

Table 3.1 Six Phases of Argumentation Process Formed by POE Instructional Strategy

Phases	Detailed Phase Activities
Phase 1: Initial Justifications	- Step 1: Participants presented their claims and justifications regarding the question provided in the given task. - Step 2: Simultaneously, participants indicated their justifications' sources and origins. - During Step 2, the researcher formed heterogeneous argumentation groups of 4-5 participants based on the diversity of claims presented in Step 1. (Average time duration: 10-15 dk)
Phase 2: Group Discussion 1 - Before the Demonstration	- In groups of 4-5, participants shared their initial claims and justifications related to the given question. - They also generated counter-justifications to refute the opponent's justifications when necessary. - Group members recorded on argumentation worksheets which justifications they found to be logical and persuasive and which ones they considered to be illogical and unpersuasive. (Average time duration: 25-30 dk)

Table 3.1 (continued)

Phase 3: Revised Justifications After Group Discussion 1 - Before the Demonstration	- Following the group discussion, participants re-evaluated their initial justifications, considering all justifications discussed: o They made appropriate changes if necessary. o If not, they repeated their initial justifications unchanged. o If participants changed their justifications after the group discussion, they additionally specified which participant in the group the new justification belonged to. (Average time duration: 5-10 dk)
Demonstration	- Participants observed a demonstration; a teacher experiment testing the predictions of the question and a slow-motion video illustrating the detailed results of the experiment. - Students who had objections about the observed results tried the experiments themselves. For instance, they measured the durations from what was reflected on the slow-motion videos, especially in problems involving time. (Average time duration: 10-15 dk)
Phase 4: Revised Justifications After the Demonstration	- After observing the demonstration, participants reviewed their justifications and made any necessary changes. - Additionally, participants were asked to write clear justifications when providing new justifications, ensuring they did not only repeat the result of the demonstration. (Average time duration: 5-10 dk)
Phase 5: Group Discussion 2 - After the Demonstration	- Participants, in groups of 4-5, discussed their observations from the demonstration and generated new justifications, if any, that emerged. - They also generated counter-claim and justifications to refute the opponent's claims and justifications when necessary. - Group members recorded on argumentation worksheets which justifications they found to be logical and persuasive and which ones they considered to be illogical and unpersuasive. (Average time duration: 10-15 dk)

Table 3.1 (continued)

Phase-6: Final Justifications After Group Discussion 2 - After the Demonstration	- Participants reviewed their justifications one last time, made any necessary changes, and provided the final version of their justifications. - If participants changed their justifications after the group discussion, they additionally specified which participant in the group the new justification belonged to. (Average time duration: 5-10 dk)

3.2.2.3 Development of Debatable Inquiry Tasks

The research aims to examine and classify the various types of justification sources that emerge during the argumentation process within the physics laboratory, facilitated by the POE instructional strategy. Moreover, it seeks to examine the interactions among these sources of justifications. To this end, creating an argumentative science classroom environment that supports such exploration is crucial. The tasks integrated into this argumentation process must align with the nature of this argumentative environment. In other words, these tasks should be designed to promote a rich diversity of claims and justifications produced by the students during the argumentation.

Therefore, to encourage students to present diverse claims and justifications, selecting problems with a counter-intuitive nature is crucial as they lead to cognitive conflict as well as diverse claims. As some studies have highlighted, this cognitive conflict is often triggered by encountering anomalous data, playing a vital role in maintaining an engaged and dynamic discussion environment. Within such an environment, characterized by a diversity of claims and justifications, the observation step of the POE instructional strategy becomes particularly significant. In this observation phase, students are presented opportunities to test their claims for these counter-intuitive problems; namely, they confront anomalous data that leads to cognitive conflict and challenges their preconceptions, thus ensuring the continuity of the argumentative environment. Given these considerations, integrating counter-intuitive physics problems into the debatable tasks emerges as a strategic approach to achieving these educational objectives.

The following sections will present the criteria for selecting and preparing these 'counter-intuitive physics problems' and outline experimental setup design for students' observations.

3.2.2.4 Selection of the Counter-Intuitive Physics Problems

In the selection of the counter-intuitive problems, an extensive review of related literature on 'Counter-Intuitive Physics Problems,' including resources such as the 'Force Concept Inventory (FCI)' test, relevant books, and scholarly articles, was conducted. This evaluation resulted in the initial choice of 25 'Counter-Intuitive Physics Problems.'

Subsequently, these selected 25 problems were presented to three experts in Physics Education for evaluation. These experts evaluated these problems for several criteria: their alignment with the inherent nature of counter-intuitive problems, their appropriateness for the students' level of understanding, their relevance to the physics concepts outlined in the theoretical framework of the designed course, and the clarity of their statements.

Experts made corrections to some questions in terms of clarity of statements. Furthermore, three questions were considered not to align with the nature of counter-intuitive problems, one question was considered inappropriate for the student's level of understanding, and one question was thought to be unrelated to the physics concepts outlined in the content of the course were excluded from the pilot study.

Based on the experts' feedback, a final set of 20 'Counter-Intuitive Physics Problems' was chosen to conduct a pilot study.

The main goal of this preliminary investigation through a pilot study was to uncover the diversity of claims and justifications that students could produce. Additionally, a significant objective was also to determine the rate of correct responses to the presented counter-intuitive physics problems. This was crucial for measuring how accurately students could approach these types of problems, thus assessing the depth of their understanding of the subject matter. Indeed, the ability or inability of students to provide correct answers also serves as an indicator of the counter-intuitive nature of these problems. This relationship suggests that the extent to which students struggle with these problems not only reflects their understanding but also highlights the inherent challenge posed by counter-intuitive physics problems. Therefore, analyzing the rate of correct responses is not only about assessing students' knowledge but also about understanding of the complexity and counter-intuitive aspects of the tested physics concepts. It was essential to involve students in this phase to select the counter-intuitive physics problems for integration into eight debatable inquiry tasks.

The pilot study involved 48 students as a pilot study group, as mentioned before. These 20 'Counter-Intuitive Physics Problems' developed for the pilot study were presented to these 48 students in an open-ended format. Students were requested to write down their claims regarding these problems and to provide justifications to support their claims explicitly. The choice of an open-ended format was deliberate to avoid the limitations associated with multiple-choice problems, as our goal was to observe the broadest possible diversity of claims and justifications that students could generate. Therefore, responses were collected face-to-face, and students were given one hour to complete this task.

After analyzing the results of the 20 problems from the pilot study in terms of the diversity of claims and justifications, as well as the rate of correct responses, we aimed to ensure a broad thematic range within the subject matter. Specifically, we aimed to include a wide array of topics from the mechanics unit, covering problems on inclined planes, dynamometers, pulleys, circular motion, and scales. Additionally, we prioritized selecting problems that would facilitate demonstrations during the observation phase of the POE instructional strategy, leading to the choice of eight

‘Counter-Intuitive Physics Problems.’ The selected eight problems, which encompass a diverse range of topics and provide opportunities for the application of the demonstration phase of the POE model, are listed in Table 3.2.

Table 3.2 Eight Counter-Intuitive Physics Problems

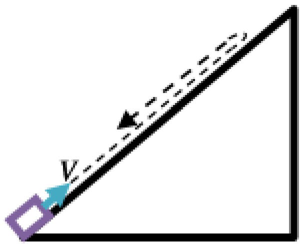
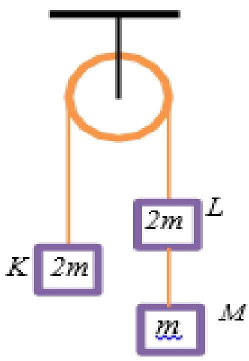
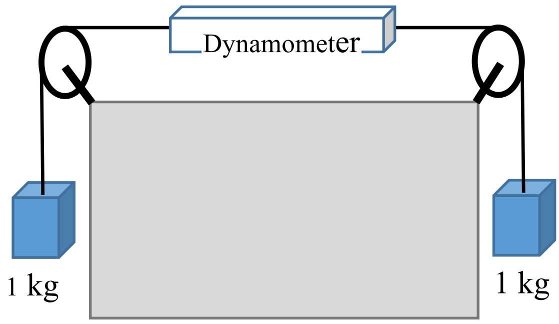
1. question for Task 1: Weighing	A man is standing still on scales showing his weight $P_{initial}$. Suddenly, the man squats with an acceleration a. What weight, (P'), will the scales read while the man is squatting? (Campanario, 1998)  *(Correct answer: $P' < P_{initial}$)*
2. question for Task 2: Inclined Plane 1	A block is set in motion up a rough inclined plane with an initial speed V as shown in the figure. The block comes to its initial position after traveling a certain distance up along the plane. For this motion, what is the relationship between the time it takes to move up (t_{rise}) and the time to come back ($t_{descend}$)? (Balta & Eryılmaz, 2015)  *(Correct answer:* $t_{rise} < t_{descent}$)
3. question for Task 3: Pulley KLM	Three objects of masses 2m, 2m, and m are hung vertically over a frictionless pulley of negligible mass as shown in the figure. After the system is set in motion, the rope between L and M is cut. What can be said about the motion of K after the rope is cut? (The mass of the rope is negligible.) (Balta & Eryılmaz, 2015)  *(Correct answer: Object K will move with constant velocity)*

Table 3.2 (continued)

4. question for Task 4: Dynamometer

Two identical masses of 1kg each are hung from the ends of a string that passes over two identical pulleys fixed to a table as shown in the figure.



What is the value shown by the dynamometer placed in between?

(Neglect the friction, the masses of the pulleys, and that of ropes. Take $g = 10\ m/s^2$)
(Balta & Eryılmaz, 2015)

(*Correct answer:* The dynamometer shows a force of 10 N.)

5. question for Task 5: Pulley XY

Two objects X and Y of equal masses are hung vertically over a frictionless pulley of negligible mass as shown in Figure 1. Initially, they are situated at equal heights. Now object X is pulled down, as shown in Figure 2, stopped, and then released.

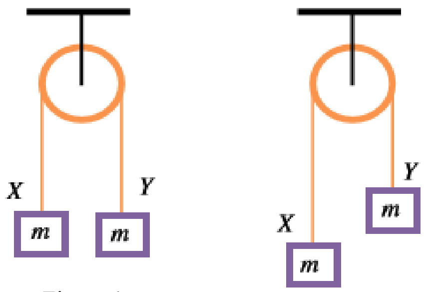
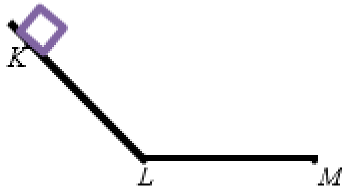
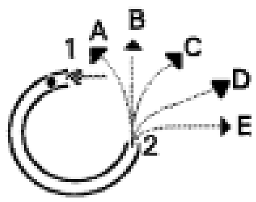
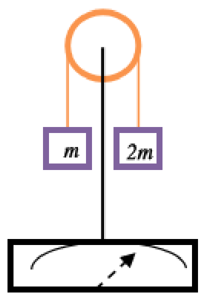


Figure 1 Figure 2

What can be said about the motion of X after it is released?
(Neglect the mass of the rope)
(Balta & Eryılmaz, 2015)

(Correct answer: It will stay where it was stopped)

Table 3.2 (continued)

6. question for Task 6: Inclined Plane 2	An object is released from point K on an inclined plane. The time it takes for the object to move between points K and L is t_1, and the time it takes the object to move between points L and M is t_2.  What is the relation between t_1 and t_2? (|KL|=|LM| and friction can be neglected.) (Balta & Eryılmaz, 2015) *(correct answer: $t_2 < t_1$)*
7. question for Task 7: Circular Motion	A tube with a circular shape is horizontally fixed to a table. A steel ball is launched from end 1 of the tube, and the steel ball exits from end 2 of the tube.  Which of the options in the figure shows the path the steel ball will follow on the table after it exits the tube? (Neglect friction) (Çataloğlu, 1996; Hestenes, Wells, & Swachhamer, 1992; Temizkan, 2003) *(correct answer: It follows path B (moves straight))*
8. question for Task 8: Atwood Machine	An Atwood machine of negligible mass, a support, and a rope are put on scale as shown in the figure. When the system is released what value will the scale reads? (Balta & Eryılmaz, 2015)  *(correct answer: between 2mg and 3mg)*

3.2.2.5 Experimental Setups for Problems

In Table 3.2, we detailed eight counter-intuitive physics problems for which experimental setups were constructed. These setups were designed specifically for the demonstration phases of the argumentation process within the physics laboratory, utilizing the POE instructional strategy.

Furthermore, for these experimental setups corresponding to the eight tasks, slow-motion videos were pre-recorded. These videos were then presented to the students in the observation phase, following the live demonstration of the experiment. This strategic use of slow-motion videos allows students to closely analyze and understand the details of the experiments that might be missed or overlooked in real time. By incorporating this visual aid, students are better equipped to grasp the underlying principles of the physics concepts demonstrated, enhancing their learning experience and fostering a deeper comprehension of the material.

Additionally, these experimental setups are designed to be both practical and easily accessible, ensuring that every student has the chance to engage in hands-on experimentation. This accessibility ensures that students can directly engage with the materials, fostering a more inclusive and hands-on learning environment. In other words, these experimental setups not only facilitate a hands-on learning experience but also directly engage students in the discovery process of complex physics phenomena. They are particularly effective when students encounter anomalous data that challenge their preconceptions, leading to cognitive conflict. When faced with counter-intuitive physics problems, students who had objections often tried the experimental setups themselves. For instance, in demonstrations that involved measuring time, students referred to slow-motion videos for accurate durations and thus were convinced of the results. Similarly, for problems related to weighing in Task 1, circular motion in Task 7, inclined planes in Task 2 and Task 6, and using a dynamometer in Task 4, they actively engaged with the setups to conduct experiments on their own. This direct involvement not only reinforces their understanding but also resolves their doubts effectively.

It should also be noted that these observation setups were arranged to enable the most accurate and closest observations possible. In some setups, measurements could be taken precisely, and students could test their predictions successfully. The following tasks are examples of such tasks: Task 1: Weighing,' 'Task 2: Inclined Plane 1,' 'Task 4: Dynamometer,' 'Task 5: Pulley XY,' 'Task 6: Inclined Plane 2,' and 'Task 7: Circular Motion,' However, in some cases, it was not possible to achieve perfect accuracy in taking measurements. These setups did not work well when obtaining precise measurements, especially in scenarios like 'Task 8: Atwood Machine,' where weights rapidly strike the scale, and 'Task 3: Pulley KLM,' where a string between moving objects is cut. However, in these cases, slow-motion videos taken during preliminary trials of the setups before implementation facilitated the observations.

Appendix B provides a comprehensive collection of visuals, including photographs of the experimental setups for tasks. This array of materials serves as a valuable resource for understanding the specifics of each experimental setup and the dynamics involved in the physics concepts being demonstrated.

3.3 Data Collection Process

In this section, which details the data collection procedures, we first outline the procedural steps and a comprehensive time schedule for the data collection process. Additionally, in the 'data collection source' subsection, we explain the development stages of the argumentation worksheet. This worksheet, specifically designed as a data collection instrument, is discussed in detail to provide insights into its design rationale, development process, and intended use in gathering data.

3.3.1 Time Schedule of Data Collection Procedures

The data collection process for this study started at the beginning of 2016 and lasted for about a year. This whole process is detailed in Table 3.3.

This table outlines the chronological progression of the data collection process, highlighting the continuous refinement of the argumentation worksheet. This emphasizes the crucial role of expert feedback and pilot studies in refining the data collection instruments.

Table 3.3 Time Schedule of the Data Collection Procedures

Steps of the data collection procedures	Time (intervals)
Preparation of the first draft of the argumentation worksheet	January- February
Collection of feedback from experts on the argumentation worksheet	March
Refinement of the argumentation worksheet through pilot studies	March-June
Determining the experimental counter-intuitive physics problems	April-June
Pilot study for the selection of eight counter-intuitive physics problems	June
Revision of the argumentation worksheet based on the findings from pilot studies	June-September
Submission of the argumentation worksheet to experts for final comments	September
Design of 'General Physics Laboratory 1' course	September
Finalization of the argumentation worksheet based on experts' feedback	October
Construction of experimental setups for eight counter-intuitive physics problems	October
Implementation over eight weeks	November-December

As can be seen from Table 3.3, which outlines the data collection process, our initial objective was the preparation of the argumentation worksheet. This initial phase, drafting the worksheet's first version, extended over two months. Following this and the integration of expert feedback, we conducted a series of five pilot studies to test and refine the worksheet.

During this period, we also began the process of selecting the experimental 'Counter-Intuitive Physics Problems' to be included in the debatable inquiry-based tasks. A pilot study, detailed earlier in Section 3.2.1.4, was conducted to choose these problems. As previously explained, this led to the selection of eight particular problems to be incorporated into the study based on the findings of our analysis of this pilot study.

Following that, additional changes to the argumentation worksheet were done and submitted for expert review, taking into account the findings from the pilot studies. Simultaneously, we began designing the 'General Physics Laboratory 1' course. This phase was followed by preparing the final version of the argumentation worksheet, informed by the final feedback from experts, and the construction of the experimental setups for the eight chosen 'Counter-Intuitive Physics Problems.' With these preparations complete, we moved into the implementation phase.

The eight debatable inquiry-based tasks associated with the eight 'Counter-Intuitive Physics Problems' were implemented over eight weeks. This phase constituted the final stage of the data collection process for our study, thus effectively concluding it.

3.3.2 Data Collection Source

The qualitative data of this study were collected from the students' self-written reports on argumentation worksheets completed during the eight tasks. These worksheets, filled out by the students, serve as a primary data source. The upcoming section will provide details on the argumentation worksheet, essential for collecting data.

3.3.2.1 Argumentation Worksheet

At the end of each task within the study, students were required to complete argumentation worksheets specifically designed as the primary data collection instrument. These worksheets were structured around a six-phase argumentation process developed based on the POE model. Each phase of the argumentation process required students to fill out these worksheets, thus providing self-written reports that documented their reasoning. The argumentation worksheets, collected as separate sheets for each phase, ensured comprehensive data collection on the students' claims and justifications, reflecting their thought processes. This methodological approach facilitated a detailed examination of the students' written justifications for all six phases of the argumentation process.

As outlined in Table 3.3, the initial draft was first prepared and then submitted to four experts for their review and evaluation for the development and preparation stages of the argumentation worksheet as a data collection instrument. This draft was examined by one professor and three associate professors, all specializing in 'Physics Education' and working at different universities. The expert evaluation form prepared for this examination was given to these four experts. The experts were specifically requested to assess the compatibility of the questions within the data collection tool with the study's research questions. They were asked to check whether the questions developed for seeking answers and collecting data aligned with the research questions and objectives of the study. Additionally, they were invited to provide suggestions and opinions on any potential improvements, which could be noted in a designated section of the evaluation form.

Feedback received on the argumentation worksheet led to several significant adjustments. Specific questions in the argumentation worksheet were revised to enhance the clarity of statements and their comprehensibility and relevance to the research questions and objectives of the study. Additionally, more precise instructions were added to some questions to ensure consistent understanding and application among students. Issues identified in the flow and clarity of some questions in the group discussion sections were corrected.

Finally, the argumentation worksheet was tested in five tasks following the feedback from these four experts. These pilot studies not only ensured that the adjustments and recommendations provided by the experts were effectively integrated into the worksheet but also allowed us to verify if data could be collected productively, thereby enhancing its relevance and efficacy as a data collection instrument.

These five pilot studies for the development process of the argumentation worksheet were further enriched by involving pilot study group who were participated in determining the 'Counter-Intuitive Physics Problems' process. The participants of this pilot study group were first-year university students majoring in the 'Elementary Science Teaching Undergraduate Program,' totaling 48 students. This diverse group of students contributed to the pilot studies by providing various perspectives and feedback, which was instrumental in refining the argumentation worksheets.

Furthermore, these five pilot studies were conducted on various topics, such as 'Electrostatic,' 'Lightning,' 'the Brightness of the Lamps,' 'Boiling," and 'Scale.' This diverse selection of subjects allowed for a comprehensive evaluation of the argumentation worksheet across different scientific concepts and phenomena. Conducting the pilot studies on such varied topics ensured that the worksheet's effectiveness in facilitating argumentative analysis and data collection was thoroughly tested, providing valuable insights for further refinement.

Through these pilot studies, the researcher obtained crucial feedback regarding the time duration required for each phase of the argumentation process. This information was particularly valuable for optimizing the design of the argumentation worksheets, ensuring that students could effectively engage with each phase without feeling rushed or constrained by time. The feedback on timing was essential for adjusting the worksheets, making them easier to use and better at collecting high-quality data from the students' writings.

Another crucial feedback emerged from the pilot studies regarding Phase 1 of the argumentation process. It was recognized that the researcher needed sufficient time to bring together students with varying claims within each group to foster heterogeneous argumentation discussion groups. This approach was vital for enhancing the diversity and quality of the discussions, ensuring a wide range of perspectives and justifications were represented. To achieve this without disrupting the flow of the argumentation process, it was decided to split Phase 1 into two steps, as explained in Section 3.2.1.2 (Steps in the Argumentation Process.) This modification allowed students in Step 2 to indicate their justifications' sources and origins on the pages provided to them while simultaneously enabling the researcher to quickly form heterogeneous argumentation discussion groups based on the different initial claims written by students in Step 1. This strategic adjustment ensured that the grouping process was conducted efficiently, minimizing delays and maintaining the momentum of the argumentation activity. Additionally, this adjustment helped reveal the broadest possible range of justifications, making the argumentation discussions richer with different perspectives and insights.

Finally, from the feedback of these five pilot studies, the researcher identified a need to simplify the distribution and collection of the argumentation worksheets across the six phases of the argumentation process, designed to be completed within two hours. To prevent any confusion and facilitate easy use and quick monitoring of the process, including the ability to quickly identify and assist groups that may be falling behind in any phase, it was decided to design the pages representing each phase in different colors. This color-coding of phases not only enhanced the organizational efficiency but also significantly improved the ease of use during the implementation. Additionally, boxes of different colors were created for each group for further convenience, ease of application, and time-saving. These boxes were used to store the color-coded argumentation worksheets, ensuring each group's argumentation worksheets were easily identifiable, accessible, and could be collected efficiently. These colorful interventions also drew students' interest in the process, making it more enjoyable and motivating. The use of varied colors not only simplified the logistical aspects of the study but also enhanced engagement by adding a visual and interactive element to the learning environment. This approach likely fostered a more dynamic and inclusive atmosphere, encouraging active participation and deeper involvement in the argumentation tasks. This thoughtful organization greatly aided in the efficient management of the implementation of argumentation.

Consequently, pilot studies served as a practical test to evaluate the refined argumentation worksheet in real research scenarios, allowing for further adjustments and validation of its design and content before its final application in the study.

Following the insights gained from these five pilot studies, necessary corrections were applied to the argumentation worksheet. Subsequently, this revised version was submitted to six experts for final review. This step ensured that the worksheet not only benefited from the initial feedback but also received an additional expert review, aiming for a more refined and effective instrument for data collection. The revised version of the argumentation worksheet was reviewed for a comprehensive review by a group of experts comprising three professors, one associate professor specializing in 'Physics Education,' and one professor specializing in 'Elementary Science Education' from four different universities. Additionally, an associate professor in 'Turkish Education' also examined the argumentation worksheet for language and grammar accuracy.

This final process of expert reviews mirrored the initial evaluation process, where the prepared evaluation form was distributed among other experts. They were asked to evaluate the relevance and alignment of the worksheet's questions with the study's research questions and objectives. This included assessing the coherence between the questions designed for data collection and the study's goals. The experts were also requested to suggest improvements, ensuring the worksheet's effectiveness and clarity. Their feedback was integrated, further refining the worksheet for its final use in the study.

Finally, considering the feedback from these six experts, the final version of the argumentation worksheet was completed. This version, consisting of six phases, includes pages distinctly colored for each phase to facilitate ease of use and comprehension. The completed worksheet is provided in Appendix C for reference. Each phase is presented on separate pages, ensuring a structured and clear progression through the six phases.

3.4 Data Analysis Procedure

The study required students to complete argumentation worksheets for eight tasks. These tasks were designed to cover six distinct phases. This structured approach not only encouraged a deep engagement with the course material but also provided a rich data source for analysis.

After the eight-week intervention period, the argumentation worksheets completed by the 25 students were collected. The next crucial step involved transferring the data contained within these worksheets into a computerized environment in a digital format. This digital transcription was a vital process, ensuring that the data was preserved accurately and was readily accessible for the comprehensive data analysis phase that followed.

In the following subsections of this section, we will explore the detailed procedures used for both data coding and the analysis process. These sections are designed to provide a clear and comprehensive overview of the methodologies and techniques used to interpret and analyze the collected data, with the goal of addressing the research questions outlined at the beginning of this study. Through this detailed analysis process, we aim to gain valuable insights into the types of justification sources, the interactions among these different types of justification sources, and their changes within the argumentation process.

3.4.1 Data Coding

The primary objective of this case study is to analyze and classify the diverse types of justification sources that emerge and examine the interactions among these various sources during students' participation in debatable inquiry tasks involving counter-intuitive physics problems within an argumentation process facilitated by the POE instructional strategy.

The case in this current study involves students' experiences with this argumentation process. This process of argumentation is the subject of our analysis. The primary data source consists of the students' argumentation worksheets, which function as self-written reports. These worksheets are crucial in capturing the students' reasoning and justifications within the argumentation process. As mentioned before, in this study, the unit of analysis is defined as 'each student's justifications,' explicitly referring to the written explanations provided by students to support their claims, reflecting their reasoning process. To clarify, the unit of analysis covers every meaningful word, phrase, and sentence that contributes to supporting a claim in these justifications.

For data coding, we first analyzed the students' written justifications for their claims, focusing on the sources of these justifications. A qualitative content analysis was conducted on these identified semantic units, serving as the foundation of our analysis, to develop a categorization system for the types of justification sources. This categorization system was developed through an open-coding process of the students' writings, aiming to search for patterns related to types of justification sources. The researcher carefully read through the raw data multiple times, closely examining and comparing it for similarities and differences. This detailed and systematic examination led to the identification of the initial categories. Each category, created during this first coding phase, represented a specific type of justification source. The process was iterative and involved continuous comparison, revising and changing some initial categories, merging some others, or splitting them into different subcategories. This evolution of categories continued until the emerging categorization efficiently reflected the dataset. Ultimately, this process of open-coding and adjustment not only resulted in the development of a set of justification source types, categorizing the various sources used in justifications but also assessed these justifications for whether they led to the correct solution of the given problem, thereby determining their relevance or irrelevance within the coding process.

The set of justification source type categories developed through our analysis was then compared with other categories found in the literature, as shown in Table 3.4.

Table 3.4 Categories in the Related Literature

Personal (Albe 2008; Bilican, 2018; McNeill & Pimentel, 2010)
Personal Experiences (Bråten et al., 2016; McNeill & Pimentel, 2010; Salmerón et al., 2016; Schwarz et al., 2003)
Prior Experiences (Knight, 2015)
Personal Opinions (Bråten et al., 2016)
Plausible Causal Mechanisms-personal experiences (Sandoval & Çam, 2010)
Background Knowledge (Schwarz et al., 2003)
Use Of Theoretical Concepts (Ludwig et al., 2021)
Authority (Schwarz et al., 2003)
Appeal To an Authority (Knight, 2015; Ludwig et al., 2021; Sandoval & Çam, 2010)
Science Empirical (Bilican, 2018)
Data As Evidence (Ludwig et al., 2021)
Science Ideas (Knight, 2015)
Scientific (McNeill & Pimentel, 2010)
Data-Based Evidence (Sandoval & Çam, 2010)
External Sources (Salmerón et al., 2016)
Other Types (External) (McNeill & Pimentel, 2010)

This comparison allowed us to contextualize our findings within the related literature, highlighting similarities and differences. This step was crucial for validating the uniqueness and relevance of our categorization system, ensuring it contributes meaningfully to existing knowledge and provides a foundation for further research.

We implemented several measures to ensure our data coding was reliable and our category system was accurate, valid, complete, objective, and transferable. Two raters, both specialists in physics education, independently performed a second phase of coding on a portion of the data, which comprised 30% of the total dataset, amounting to 126 codes for justification source type categories. These raters then engaged in discussions about the appropriateness of the sources used in the justifications and the corresponding categories. This second coding process aimed at reaching a consensus on the set of justification source type categories. In this process, several loose definitions were sharpened, merged, or divided to maximize the agreement. Ultimately, starting from an agreement rate of 84%, a consensus was reached with a finishing rate of 95%, achieving an agreement rate of over 90%. Following a similar procedure, a second coding round was also conducted to determine the relevance or irrelevance of justifications. This time, two different raters, both specialists in physics education, were provided with all the relevant and irrelevant codings created for eight tasks. They were asked to assess the appropriateness of these justifications being classified as relevant or irrelevant. Through mutual discussions, a full agreement was reached once again. Finally, the consensus achieved with these four raters demonstrates a high level of inter-rater reliability, further emphasizing the strength of our categorization system. Table 3.5 shows the final category list and definitions for justifications based on these categories used for the study. Description and examples of these categories will be presented in the results section.

Table 3.5 Emerged Categories and Definitions

Categories	Definitions
Daily Life Experiences:	
a) Real-Experiences:	Real-Experiences are students' personal experiences in their daily lives. When students encountered problems that appeared similar to, or the same as, their own life experiences, they often used sources of justifications of this kind.

Table 3.5 (continued)

b) Illusive-Experiences:	Illusive experiences refer to those assumed but not real, as they are physically impossible to experience in the way the students' have described them.
Daily Life Observations:	
c) Real-Observations:	Real-Observations refer to students' observations of their daily life situations. These observations differ from the experiences in that during the experiences, students interact with the environment; however, during the observations, students do not interact; they just observe the phenomena as outsiders. Typically, students developed this type of justification source when encountering a problem perceived as similar to, or the same as, their previous observations.
d) Illusive-Observations:	Illusive observations are considered assumptions rather than actual experiences since they are physically impossible to observe in the manner described by the students.
e) Observations from Media:	These observations refer to students' observations from watching movies, cartoons, simulations, animations, games, sports events, or documentaries on television or the internet.
School:	
f) Teacher	'Teacher' refers to sources of justification used by students based on knowledge acquired from their teachers.
g) Textbook	'Textbook' refers to sources of justification used by students based on knowledge gained from school textbooks.
h) Experiments or Demonstrations in class	These refer to sources of justification used by students based on experiments or demonstrations conducted in school.
i) School Life	'School Life' refers to sources of justification used by students based on their knowledge from courses or school life (primary, secondary, high school, and university). Specifically, these sources are based on the student's general experiences in school life without an explicit reference to a particular subject, teacher, textbook, or other materials.
Implicit	'Implicit' refers to situations where students justify their claims without explicitly referencing a specific source.

Additionally, it is important to remember that some justifications can contain multiple sources, meaning they can be coded as 'multiple source.' This aspect should not be overlooked and considered during the coding process. However, these multiple sources were used only for the analysis of change of justification sources because their role would be of importance in their persuasiveness during argumentation process.

Therefore, the data coding conducted for the analyses was based on the justifications provided for students' claims rather than on the students themselves. In other words, the types of justification sources in the encodings and the result tables presented in the upcoming 'Chapter 4: Results' should be considered independently of the students. This approach ensures that the analysis focuses on the sources of justifications. By abstracting the justifications from the individuals, we aim to identify patterns and themes in justification sources that go beyond personal perspectives, thus facilitating a more objective and comprehensive understanding of the argumentation process. This methodology emphasizes the argumentative content as the primary object of analysis, aligning with our objective to categorize and assess the various types of justification sources emerging from student interactions within the argumentation.

The following sections outline the comprehensive data analysis procedures used to address the study's research questions.

3.4.2 Data Analysis for the Research Question 1, 2 and 3

The main purpose of this case study is to analyze and classify the emerging types of justification sources. The first three research questions prepared for this purpose are as follows:

1. What types of justification sources emerged during the argumentation process?
2. How do the types of justification sources vary across the six phases of the argumentation process?
3. How do the types of justification sources vary across the eight tasks?

To capture patterns related to justification sources and effectively analyze the variation in types of justification sources, the data analysis for these three research questions was focused on examining the justifications that students articulated for their claims, with a particular emphasis on the sources of these justifications. Then, based on the diverse sources of these justifications, justifications were further examined, categorized, and systematically coded for the eight tasks and each of their six phases. Subsequently, the data coding performed for the eight tasks and each of their six phases was transformed into tables that display number and percentage values for each task (Appendix D) and each phase (Appendix E), respectively, utilizing of the distributions in terms of percentage values to provide a comprehensive and clear visual representation of the findings. This approach facilitates a deeper understanding of the distribution and prevalence of different justification sources across the tasks and phases.

Therefore, we successfully identified the types of justifications based on the various sources we examined, capturing their variations across the six argumentation phases formed by the POE instructional strategy and the eight debatable inquiry tasks. This comprehensive analysis not only reveals the dynamic nature of justification sources but also highlights the impact of the instructional strategy and task complexity on the types of justifications employed.

3.4.3 Data Analysis for the Research Question 4 and 5

The other purpose of this research is to examine the interactions of these different justification source types with each other when students confront debatable inquiry tasks with 'counter-intuitive physics problems' in an argumentation process formed by the POE instructional strategy. The last two research questions prepared for this purpose are as follows:

4. How do participants' justification source types change after Group Discussion 1 (before the demonstration)?

4.1. How do participants’ justification source types change after Group Discussion 1 (before the demonstration) across eight tasks?

4.2. How do participants’ justification source types change after Group Discussion 1 (before the demonstration) in terms of being relevant or irrelevant?

5. How do participants’ justification source types change after Group Discussion 2 (after the demonstration)?

5.1. How do participants’ justification source types change after Group Discussion 2 (after the demonstration) across eight tasks?

5.2. How do participants’ justification source types change after Group Discussion 2 (after the demonstration) in terms of being relevant or irrelevant?

Specifically, the research sought to identify which types of justification sources had greater influence in persuading others or demonstrated a higher susceptibility to change during the argumentation process and their mutual effects. To this end, the focus was placed on tracking the evolution of the types of justification sources that emerged and subsequently transformed, particularly after their interplay, throughout all stages of the argumentation process, starting from Phase 1. This approach involved a detailed examination of the justification sources themselves rather than the students, thereby enabling a deeper insight into how justifications develop and affect each other within a collaborative discourse environment.

Figure 3.1 illustrates the methodology employed to track the evolution of justification source types across the six phases of the argumentation process for a group of four students. This figure serves as a visual representation of how the various sources of justification were coded and monitored for changes throughout the discussion.

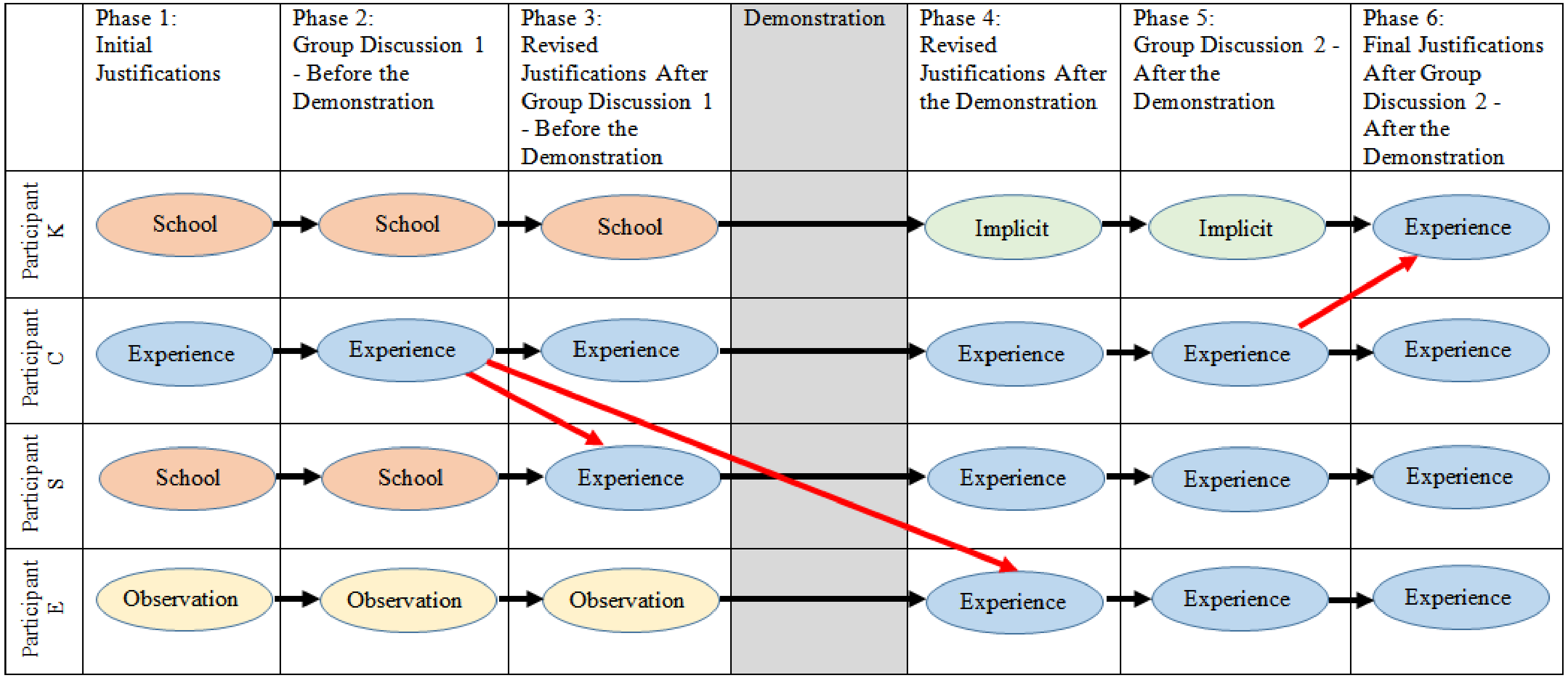


Figure 3.1 The Change of the Justification Source Types Across Six Phases of the Argumentation Process for a Group of Four Participants

During the individual revision phases that followed the group discussions and demonstration phases, attention was given to students who were persuaded by the justifications of others. Specifically, when students acknowledged being convinced by another's justifications and adopted them as their own in their revised justifications, a unique coding process was applied. The justifications that convinced students were identified, and their codes were attributed to the adopting students' justifications. This coding strategy was consistently applied throughout the study to trace ideas' flow and transformation carefully.

Subsequently, the data coding performed to capture the variation in justification source types between phases 1 and 3, as well as between phases 4 and 6 for each of the eight tasks was transformed into tables that display both number and percentage values for each task (Appendix F).

This utilized descriptive statistics to provide a comprehensive and clear visual representation of the findings. This method enables a more comprehensive insight into how various sources of justification evolve throughout the phases.

To summarize, the data analysis for the fourth and fifth research questions was thoroughly focused on tracking the dynamics of change among justification source types throughout the argumentation process. As shown in Figure 3.1, this detailed examination covered six distinct phases, enabling the identification of patterns in how justification sources evolved and influenced each other. The analysis aimed to identify the specific sources of justification that served as catalysts for change, illuminating the complex interplay of ideas and the persuasive power of different justification sources within group discussions.

3.5 Trustworthiness of the Study

In the realm of qualitative research, ensuring the credibility of a study is significant. To achieve this, researchers employ various techniques, including 'triangulation,' ‘peer examination’ (also known as peer review), ‘member checks’ (or respondent validation), ensuring ‘adequate engagement’ in data collection, and maintaining a ‘long-term engagement’ between the researcher and the students. Additionally, the researcher's position, often referred to as reflexivity, plays a critical role in enhancing the study’s credibility.

For the current case study, the technique of peer examination was applied to analyze the process. The iterative nature of data collection and analysis facilitated the identification of emergent categories, ensuring a comprehensive exploration of the research questions. Peer debriefing sessions, facilitated by my advisor and another associate professor, were instrumental in enhancing the rigor and trustworthiness of the study, as they engaged in critical discussions regarding the research process, potential biases, and interpretations of findings. Their feedback and insights served as valuable checks against researcher subjectivity, contributing to the overall validity and credibility of the study’s findings. Additionally, peer debriefing fostered reflexivity and encouraged me to remain mindful of their positionality throughout every stage of the research process. This collaborative approach not only strengthened the methodological integrity of the study but also enriched the depth and nuance of the research outcomes, ultimately advancing my understanding of sources of justifications and their dynamic nature.

Furthermore, this included an evaluation of the types of justifications based on sources, as well as distinguishing between relevant and irrelevant justifications. To thoroughly analyze the types of justifications based on sources, one associate professor and one assistant professor, all specializing in physics education and represented by two distinct universities, were engaged as a second coder. To assess the relevancy of the justifications, one professor and one associate professor, both experts in physics education and representing two different universities, participated as second coders.

To ensure adequate engagement in data collection, a comprehensive eight-week argumentation process was implemented with the study's 25 students. Throughout this period, there was a high level of participation, with an average of 23 students actively involved each week. This engagement facilitated the completion of a total of six phases within the self-written format argumentation worksheets. The consistent participation and motivated completion of these worksheets underscore the effective involvement and significant data collection efforts undertaken in this study.

Additionally, the study ensured credibility through long-term engagement between the researchers and the students. Specifically, the researcher was an instructor for the courses 'FBO 103 - General Physics Laboratory 1' and 'FBO 104 - General Physics Laboratory 2' during the 2016-2017 academic year. This prolonged engagement provided a deep insight into the students' perspectives and enhanced the trustworthiness of the findings.

Moreover, in the methodology chapter, special emphasis was placed on detailing the data collection and analysis processes. This was done to enhance the 'Transferability' of the study. By providing a comprehensive account of the methods employed, the study aims to enable other researchers to apply the findings in different contexts, thus broadening the impact and applicability of the research.

3.6 Researcher Role in the Study

In this study, the role of the researcher was important in ensuring the success of the research by effectively managing and engaging with students. The researcher was instrumental in establishing an environment where students felt comfortable sharing their insights and experiences openly. By fostering a supportive and encouraging atmosphere, the researcher enabled students to engage in learning thoroughly. This approach facilitated a deeper exchange of information and significantly improved the quality of data collected.

During this study, the researcher paid special attention to facilitating group discussions in a manner that allowed for uninhibited interaction among students. Specifically, during these discussions, students were encouraged to freely express their thoughts and engage in dialogue without any interference from the researcher. This approach was carefully implemented across different study phases, ensuring students could openly discuss and share their perspectives. By adopting this non-interventionist stance, the researcher not only preserved the authenticity of the students' contributions but also fostered a sense of trust and safety, which are crucial for the depth and quality of the discussions. This methodology enabled the collection of rich, unfiltered data, providing invaluable insights into the study's subject matter.

The researcher carefully maintained neutrality throughout the interactions, preventing biases from affecting the study's outcomes. By clearly communicating the study's objectives and boundaries, managing students' expectations, and making them feel valued, the researcher significantly enhanced students' involvement and commitment to the research process.

3.7 Ethical Considerations

Within the scope of the research, the ethical approval process was undertaken with the Applied Ethics Research Center at Middle East Technical University (METU). Research proposals, along with ethical considerations specific to the current study (such as confidentiality, informed consent, and potential risks to students) were submitted during this process. Official permission from the Applied Ethics Research Center at METU was obtained, and this permission is documented in Appendix G.

Students were informed about the study's purpose through the informed consent process. Additionally, details regarding what their participation entailed, the voluntary nature of their participation, and how their data would be used and protected were thoroughly explained to them.

For privacy, each of the 25 students was assigned a letter as a pseudonym to avoid using their real names, and their faces were hidden in photographs and visuals of the argumentation process in the laboratory. Beyond these measures, data protection and privacy were ensured by the researcher through secure data storage and establishing data retention. Access to the data was restricted only to the researcher.

An important aspect of ethical research involves sharing findings or feedback with students, when applicable, as it acknowledges their contributions and potentially enhances the value of the research for those involved. How our findings were shared with the 25 students is detailed in Section '3.2.1.1 Course Design.' This section explains that during two hours of the course, students submitted correct solutions to eight counter-intuitive physics problems each week. Additionally, the accuracy and errors in their justifications, provided throughout the six phases of the argumentation process, were systematically reviewed. Feedback was shared before implementing the next task, thus fostering a cycle of continuous learning and improvement. This approach not only facilitated their understanding and correction of mistakes but also motivated students to persist in providing their justifications across the tasks. This methodology underscores our commitment to an ethically grounded research process where student engagement and learning are significantly valued.

3.8 Assumptions

The assumptions of the current study are outlined to ensure clarity and transparency in the methodology, as they are foundational to the integrity and interpretation of the research findings. These assumptions of the study are as follows:

- It is assumed that students engaged with each of the six phases of the argumentation worksheet honestly and seriously. Therefore, their justifications are expected to reflect the genuine cognitive processes engaged during the argumentation tasks.

- It is presumed that all students had a consistent understanding of the instructions and the content of the argumentation worksheets, ensuring uniform comprehension essential for the comparability of their justifications.

3.9 Limitations

The emerging results are limited to a case framed by POE instruction, the mechanics concepts, specific tasks generated by 'Counter-Intuitive Problems,' and 25 students. Therefore, using alternative cases has the potential to extend the results by providing varied patterns in the sources and nature of students' justifications.

CHAPTER 4

RESULTS

In this chapter, the findings of the study are presented in five main sections, each of which presents the findings of the following research questions:

1. What types of justification sources emerged during the argumentation process?
2. How do the types of justification sources vary across the six phases of the argumentation process?
3. How do the types of justification sources vary across the eight tasks?
4. How do participants' justification source types change after Group Discussion 1 (before the demonstration)?
   4.1. How do participants' justification source types change after Group Discussion 1 (before the demonstration) across eight tasks?
   4.2. How do participants' justification source types change after Group Discussion 1 (before the demonstration) in terms of being relevant or irrelevant?
5. How do participants' justification source types change after Group Discussion 2 (after the demonstration)?
   5.1. How do participants' justification source types change after Group Discussion 2 (after the demonstration) across eight tasks?
   5.2. How do participants' justification source types change after Group Discussion 2 (after the demonstration) in terms of being relevant or irrelevant?

4.1 Findings for Research Question 1: Types of Justification Sources

The first research question of the study was, 'What types of justification sources emerged during the argumentation process?' In Phase 1 of the argumentation process, where students are asked to justify their claims and indicate the sources of their justifications, the responses to these questions have been analyzed. When considering the sources used in the students' justifications, a total of 10 different sources of justification under four main categories emerged. These categories and their specific types include the 'Daily Life Experience,' which encompasses 'Real-Experiences' drawn from actual life events, and 'Illusive-Experiences,' which are imagined. The 'Daily Life Observation' includes 'Real-Observations' from personal daily life observations, 'Illusive-Observations' which are imagined, and 'Observations from Media' derived from media sources. The 'School' related sources involve information or concepts learned from 'Teachers,' 'Textbooks,' 'Experiments or Demonstrations' conducted in the classroom, and general learning from 'School Life' without referring to any specific source other than school. Lastly, there are 'Implicit' sources, which are not explicitly stated by the students. These diverse sources of justification are illustrated in Figure 4.1.

The primary focus of this study is not analyzing whether the justifications provided by the students produce a solution to the given task or whether they are scientifically correct or incorrect. Instead, it analyzes the types of sources students use for their justifications during the argumentation process. Therefore, it cannot be said that justifications involving these 10 different source types, whose definitions and examples are presented below, always produce a correct or appropriate solution for the given problem. These justifications may be scientifically correct or incorrect.

Furthermore, in this study, while the primary focus is on analyzing the sources of justification rather than their scientific correctness, the relevance of these justifications is also coded for further analysis. However, a detailed examination of whether these justifications are relevant or irrelevant will be the subject of another study.

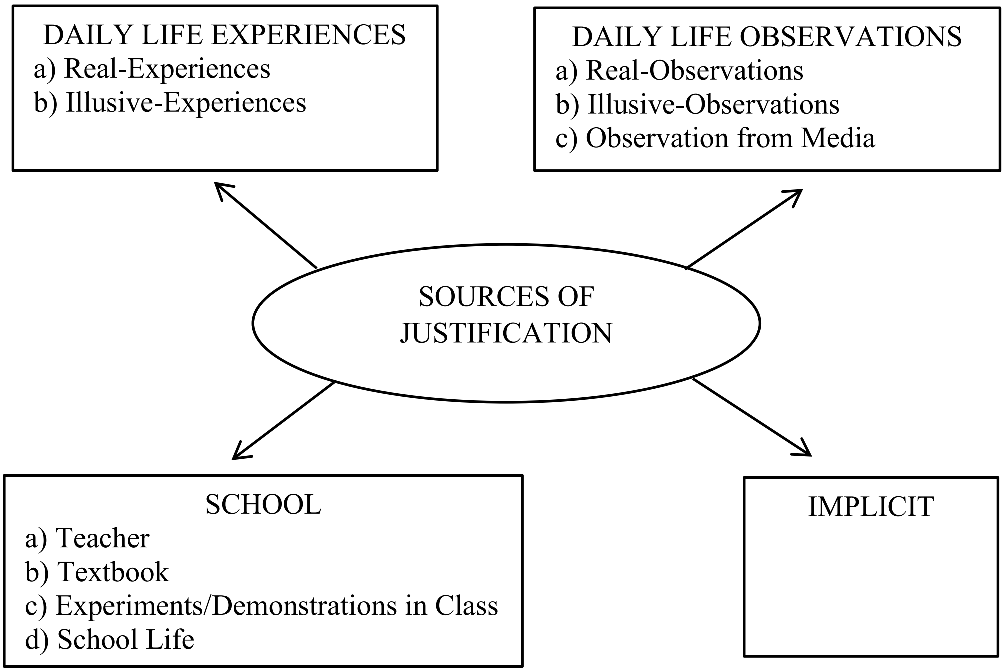


Figure 4.1 The Sources of Justifications

This study observed a variation in how students formulated their justifications. Some relied on a single source to answer the question, while others integrated multiple sources into their justifications, especially during the group discussions. Additionally, during group discussions, it was observed that some students failed to produce a justification to refute and persuade those with different views. Instead, they simply expressed disagreement without being convinced by the opposing justifications. Furthermore, some students only restated the results of the demonstration parts rather than producing a justification to explain these results. Such occurrences were classified under the category of 'None (No justifications).'

Definitions, related codes and examples for the 10 different sources of justification, as shown in Figure 4.1 above, are provided below.

4.1.1 Justifications Based on Daily Life Experiences

Justifications based on 'Daily Life Experiences' are categorized into two main types: those grounded in 'Real-Experiences' and those based on 'Illusive-Experiences'; both types are detailed in the following subsections.

4.1.1.1 Justifications Based on Real-Experiences (Real-Exper)

This type of justification originates from the students' personal experiences in their daily lives. When students encountered problems that appeared similar to, or the same as, their own life experiences, they often produced justifications of this kind. Below, several examples are provided to illustrate how these justifications were produced.

In the following example, Student Z explicitly refers to his/her personal experiences related to "going up or down hills" to justify his/her claim about motion dynamics on an inclined plane.

Example 1:
Task 2: Inclined Plane 1, Group 3, Phase 1, Student Z:

- $t_{descent} < t_{rise}$. *Since it is a system with friction, it will move upwards more slowly. However, it will descend faster. For example, Ayşe moves upwards on a hill at a certain speed 'v' and it takes her 20 minutes. Ayşe will take less than 20 minutes to descend this hill. While we struggle to move up a hill, it is much easier to descend.*

Similarly, in the following example, Student T is explicitly referring to his/her personal experiences related to 'sliding on ice or snow from a height' to justify his/her claim about an object's acceleration and constant velocity on an inclined plane.

Example 2:

Task 6: Inclined Plane 2, Group 2, Phase 3, Student T:

- $t_{KL} > t_{LM}$, $t_1 > t_2$. *When we release the object at point K, it gains speed downward. When reaching point L, it travels between L and M at a constant speed. Let's assume it starts from Vo = 0 and reaches a velocity of v = 50 at point L, continuing at this speed between L and M. Consequently, travel along the LM path is completed more quickly. While answering the question, I related it to my daily life experiences, such as sliding on ice or snow from a height.*

The following examples also exemplify how the students referred to their experiences to justify their claims.

Example 3:

Task 2: Inclined Plane 1, Group 6, Phase 1, Student F:

- $t_{descent} < t_{rise}$. *When a car moves upwards at speed V, it struggles due to the frictional surface and takes a longer time to move upwards. However, even though the frictional surface still affects it, the descent is quicker since the direction of motion is downward. When traveling in our car, we took longer to move up a steep ramp, facing some difficulty. But descending was quicker. It was not as challenging as moving upwards.*

Example 4:

Task 7: Circular Motion, Group 2, Phase 1, Student G:

- *It follows path B (goes straight). This is because once the steel ball gains speed, its velocity changes from v=0. When it leaves from point 2, it is free and thus continues on a straight trajectory, exiting through B. After point 2, since the steel ball doesn't have a specific trajectory, it shoots straight out. While answering the question, the memory that came to mind and that I shared is about my toy cars from childhood. They had multiple, varied tracks, and when I released my car, it would circle around a certain trajectory and then shoot straight out from the given end. This memory is the source of my knowledge in this instance.*

Example 5:

Task 7: Circular Motion, Group 6, Phase 1, Student V:

- It follows path B (goes straight). It will exit from B at a certain speed and continue straight. The reason I think this way is because when we spin something in a circle and then release it, it will move straight. The moment I release the ball, it will follow path B. This is how I thought about this experiment on the table, and it will exit from B. While answering the question, what brought to my mind the idea of the ball's straight exit was something I had observed before: when I spin something in a circle and let it go, it moves straight. I think the same logic applies here, and it will come with a certain speed and then exit straight at that speed.

4.1.1.2 Justifications Based on Illusive-Experiences (Illusi-Exper)

These are the justifications that students develop based on their assumed experiences. Illusive experiences refer to those assumed but not real, as they are physically impossible to experience in the way the students have described them. Several examples are provided below to demonstrate how students produce these types of justifications.

In the following example, Student F explicitly refers to his/her illusive experience, such as "when I squatted on the scale before, I saw my mass increase," to justify his/her claim that the mass appears greater during this action. This experience was coded as illusive because, in reality, he cannot see an increase in his mass measured on the scale.

Example 1:

Task 1: Weighing, Group 2, Phase 1, Student F:

-$P' > P_{initial}$. I think the mass measured while standing at $P_{initial}$ is smaller than at P'. I guess the mass will appear greater when squatting, and I believe this is because of the pressure exerted on the scale. I remember observing an increase in mass when I performed this movement while weighing with a scale before. (correct answer: $P' < P_{initial}$)

The following example also exemplifies how the students referred to their illusive experiences to justify their claims.

Example 2:
Task 7: Circular Motion, Group 4, Phase 1, Student A:

- *It follows path C (continues in the opposite direction of circular motion). Since we throw the steel ball with a certain speed from point 1, it will stick to and move along the circle. When it quickly reaches the empty space at point 2, it will want to continue moving but will try to exit the circle because it sticks to it. This is because we applied force and increased its speed at point 1, enhancing its tendency to exit. After point 2, due to its speed, it moves a bit further and then shoots out. Path E is not possible because it has an initial speed, so it moves a bit further. At point E, as soon as the circle ends, the direction changes immediately; such a thing can't happen. It can't just change direction immediately as soon as the circle ends at E. I thought it would tend to exit because the steel ball was thrown through the circle and had some speed. My brother had a toy. It looked like this question. That toy also had a round ball, and when I launched it in that system, it exited and then moved in a circular motion in the opposite direction.*
(Correct answer: It follows path B, goes straight)

4.1.2 Justifications Based on Daily Life Observations

Justifications based on 'Daily Life Observations' are categorized into three main types: those grounded in 'Real-Observations,' those based on 'Illusive-Observations,' and those based on 'Observations from Media'; all three types are detailed in the following subsections.

4.1.2.1 Justifications Based on Real-Observations (Real-Obser)

Justifications Based on Real-Observations were developed by students based on their observations from their daily life situations. Observations differ from the experiences in a way that during the experiences, students interact with the environment;

however, during the observations, students do not interact; they just observe the phenomena as outsiders. Typically, students developed this type of justification when encountering a problem perceived as similar to, or the same as, their previous observations.

Several examples are provided below to demonstrate how students produce these types of justifications.

In the following example, Student S explains the behavior of objects in a pulley system, referring explicitly to real-life systems observed in constructions, such as those used to lift bricks.

Example 1:
Task 3: Pulley KLM, Group 4, Phase 1, Student S:

-The object K moves downward with constant velocity. Objects L and K stay at the same level, as they will be balanced with object L. When the system is released, objects L and M are on one side, and the system moves to the right, as it will be heavier than object K. If the rope between objects M and L is later cut, object K, remaining above, moves downward as the weights become equalized. I developed these ideas by drawing on examples from daily life, such as systems used in construction to lift bricks.

The following examples also exemplify how the students referred to their observations to justify their claims.

Example 2:
Task 4: Dynamometer, Group 1, Phase 1, Student D:

The dynamometer shows 20 N. Object A will pull the dynamometer down 10 N. Since it is only attached to its hook, this causes the spring to lengthen (due to the pulley). Object B will also pull the dynamometer down by 10 N. The total will be 20 N. A long time ago, I think 10 years ago, a neighbor had a big garden, and he was selling his cherries; he had something like a dynamometer when he was selling them. He would hang the bag on the end of it and give it accordingly. In this question, I thought the forces should be summed up because each object exerts a force of 10 N downwards.

Example 3:

Task 6: Inclined Plane 2, Group 2, Phase 1, Student R:

- $t_{KL} = t_{LM}$, $t_1 = t_2$. The object takes the KL and LM paths in equal time. When released from point K, it will accelerate to point L and come to a stop there. Even on frictionless ground, there will be a slight deceleration at the end. This deceleration will balance the object's initial stationary state at point K so it takes the KL and LM paths in equal time. Since the path from K to L is a descent, it will make an accelerating movement. Since there is a smooth path between LM, the object will eventually stop, but due to the path's short length, there will be a very small slowdown between LM, and this minimal deceleration will compensate for the object's stationary start at K. The object takes the KL and LM paths in equal time. Although we do not often examine the working mechanisms of the items and tools we use in our daily lives, our ideas are formed by observing how they function. For instance, observing how a wheel moves on a straight road, downhill, and uphill has left a lasting impression in our minds.

4.1.2.2 Justifications Based on Illusive-Observations (Illusi-Obser)

The justifications supported with illusive observations are based on the students' assumed observations. These illusive observations are considered assumptions rather than actual experiences since they are physically impossible to observe in the manner described by the students.

Several examples are provided below to demonstrate how students produce these types of justifications.

In the following example, Student A explicitly refers to his/her illusive observation, based on witnessing their brother experiment with a scale at the pharmacy, to justify his/her claim about the change in mass value on a scale. This observation was coded as illusive because, in reality, he cannot observe an increase in his brother's mass measured on the scale.

Example 1:

Task 1: Weighing, Group 1, Phase 1, Student A:

- *$P' > P_{\text{initial}}$. The mass value momentarily increases when squatting or when exerting standing pressure on the scale. I remember observing this while my brother was playing with a scale at the pharmacy.*

(correct answer: $P' < P_{\text{initial}}$.)

The following example also exemplifies how the students referred to their illusive observations to justify their claims.

Example 2:

Task 6: Inclined Plane 2, Group 4, Phase 1, Student F:

- *$t_{KL} = t_{LM}$, $t_1 = t_2$, since the distance between KL-LM is equal and the motion of the object accelerates in the inclined plane in KL. Also, it continues its accelerated motion equally between the LM. That's why $t_1 = t_2$. There was a toy with such a mechanism. I saw it there. I had observed the movement of a train.*

(correct answer: $t_{LM} < t_{KL}$)

4.1.2.3 Justifications Based on Observations from Media (Media-Obser)

These justifications are formed by students based on their observations from watching movies, cartoons, simulations, animations, games, sports events, or documentaries on television or the internet. Several examples are provided below to demonstrate how students produce these types of justifications.

In the following example, Student G justifies the trajectory of a steel ball in a circular motion by explicitly referring to observations from the sport of hammer throwing seen in the Olympics and other televised sports events.

Example 1:
Task 7: Circular Motion, Group 2, Phase 1, Student G:

- *It follows path B (goes straight). This is because once the steel ball gains speed, its velocity changes from v=0. When it leaves from point 2, it is free and thus continues on a straight trajectory, exiting through B. After point 2, since the steel ball doesn't have a specific trajectory, it shoots straight out. I remember this from regularly watching the Olympics and other sports events. The sport of hammer throwing uses a logic similar to this steel ball scenario. We can compare this to hammer-throwing events, where the hammer starts swinging from one point and always moves straight when the exit area is clear.*

Similarly, in the following example, Student C justifies the motion dynamics on an inclined plane, referring explicitly to watching animations about inclined planes on the internet.

Example 2:
Task 6: Inclined Plane 2, Group 3, Phase 1, Student C:

- $t_{LM} > t_{KL}$ *;* $t_2 > t_1$*.. This is because an object accelerates downwards on an inclined plane. Therefore, it takes the path KL in a shorter time. So, I think an object will descend faster on a ramp. The moment the object is released from point K, it has a certain speed and moves faster with this speed. I remember this from animations about the inclined planes I watched on the internet.*

The following example also exemplifies how the students referred to their observations from the media to justify their claims.

Example 3:
Task 7: Circular Motion, Group 2, Phase 1, Student D:

-*It follows path C (continues in the opposite direction of circular motion). Since the ball makes a circular motion, there is centrifugal force acting on it. As soon as it leaves the trajectory, it will be thrown out. Since centrifugal force is in the direction as in the figure, it cannot follow the A and B paths. Since it is thrown at high speed, it cannot follow the E and D paths, it follows the C path. I remember this from watching amusement park accidents on* *television, where people were flung outwards and killed due to the breakage of swings spinning at high speed.*

4.1.3 Justifications Based on School

Justifications based on 'School' are categorized into four main types: those grounded in 'Teacher,' those based on 'Textbook,' those based on 'Experiments or Demonstrations' conducted in the classroom, and those based on 'School Life'; all four types are detailed in the following subsections.

4.1.3.1 Justifications Based on Teacher (Teacher)

These justifications formed by students are based on knowledge acquired from their teachers. Several examples are provided below to demonstrate how students produce this type of justification.

In the following example, Student D justifies the motion dynamics on an inclined plane, referring explicitly to his/her physics teacher's explanations, such as "after accelerating for a certain period, an object reaches a constant speed."

Example 1:

Task 2: Inclined Plane 1, Group 4, Phase 1, Student D:

- $t_{rise}=2t_{descent}$. *After a car goes up at a certain speed, it starts accelerating while coming down. After a while, due to constant mass and gravity, it reaches a constant speed. That's why* $t_{rise}=2t_{descent}$. *I remember my teacher saying in physics class that after accelerating for a certain period, an object reaches a constant speed.*

The following example also exemplifies how the students referred to their teachers to justify their claims.

Example 2:

Task 5: Pulley XY, Group 3, Phase 1, Student W:

- *Object X stays where it was stopped. It doesn't move. It remains the same and does not change. The net force is zero. Because the net forces are equal, Object X does not move. Objects X and Y stay as they are. There is no moving force. The length of the rope doesn't matter. Here, the force is the motion m and g. The length of the rope doesn't matter. Since the net forces are equal here, they maintain the position as shown in the figure. I remember hearing from my physics teacher that if the net forces are zero if there are no forces affecting each other, the object will keep its current state.*

4.1.3.2 Justifications Based on Textbook (Book)

These justifications formed by students are based on knowledge gained from school textbooks. Several examples are provided below to demonstrate how students produce these types of justifications.

In the following example, Student W justifies the behavior of objects in a pulley system, referring explicitly to textbooks.

Example 1:

Task 5: Pulley XY, Group 3, Phase 1, Student W:

- *Object X stays where it was stopped. It doesn't move. It remains the same and does not change. The net force is zero. Because the net forces are equal, Object X does not move. Objects X and Y stay as they are. There is no moving force. The length of the rope doesn't matter. Here, the force is the motion m and g. The length of the rope doesn't matter. Since the net forces are equal here, they maintain the position as shown in the figure. I remember the answer to this question from my past high school books.*

The following examples also exemplify how the students referred to textbooks to justify their claims.

Example 2:

Task 2: Inclined Plane 1, Group 1, Phase 1, Student R:

- $t_{descent} < t_{rise}$. $t_{descent}$ is faster. While the car is going uphill, it will make a slower movement due to the effect of friction and the effect of the slope, and it will be forced. But even if there is friction on the descent, there will be a little faster movement because the descent is downward. I remember the answer to this question from the textbooks I studied in high school.

Example 3:

Task 6: Inclined Plane 2, Group 2, Phase 1, Student W:

- $t_{KL} = t_{LM}$, $t_1 = t_2$. Because it will continue to move with a speed of mgcosα, and this speed will be constant since there is no friction force. Again, the velocity mgcosα will continue, and the v's and x's will be equal. And since they are equal, the times t_1 and t_2 are also equal. It is mgcosα that provides horizontal movement. There is no downward effect of mg, as it acts vertically. Since this force does not act vertically, it has no effect. I learned the answer to this question from my high school textbooks and from the extraction of inferences and the resulting questions in some physics books, and I remember it from there.

4.1.3.3 Justifications Based on Experiments/Demonstrations in Class (Exper-Demo)

These justifications students form are based on experiments or demonstrations conducted in school. Several examples are provided below to demonstrate how students produce these types of justifications. In the following example, Student I explicitly refers to an experiment conducted in his/her middle school science laboratory to justify his/her claim about the change in mass value on a scale.

Example 1:

Task 8: Atwood Machine, Group 3, Phase 1, Student I:

-The scale shows 3mg. When the system is released, the scale shows m+2m=3m. The system is pulled down with a weight of 2mg, but since there is also a weight of mg on the left, the

scale sums up all the values to itself. That's why the scale shows 3m. There was a reel experiment we conducted in a middle school lab. This is my source.

The following example also exemplifies how the students referred to experiments or demonstrations conducted in their classrooms to justify their claims.

Example 2:
Task 2: Inclined Plane 1, Group 4, Phase 1, Student X

- $t_{descent} = t_{rise}$. $t_{descent}$ *and* t_{rise} *are equal. Since the car moves on a frictional surface, the speeds going up and down are equal, as it is the same surface. A force is applied during the upward movement, and gravitational force acts during the descent. I wrote these based on simple experiments we conducted in primary school science lesson.*

4.1.3.4 Justifications Based on School Life (School-Life)

These justifications, formed by the students, are based on their knowledge from courses or school life (primary, secondary, high school, and university). Specifically, these justifications are based on the students' general experiences in courses without an explicit reference to a particular subject, teacher, textbook, or other materials.

Several examples are provided below to demonstrate how the students produce this type of justification. In the following example, Student C explicitly refers to his/her secondary to high school life to justify his/her claim about the change in mass value on a scale.

Example 1:
Task 1: Weighing, Group 4, Phase 1, Student C:

- $P' = P_{initial}$. *In my opinion, the P' value and the* $P_{initial}$ *value are the same. Because mass is the amount of matter that does not change. I do not think that the mass changes with every stance of a person. I remember learning this during my secondary and high school education. In both middle school and high school, I learned that mass is the amount of matter that does not change. And I think it is correct.*

The following examples also exemplify how the students referred to their school lives to justify their claims.

Example 2:

Task 5: Pulley XY, Group 6, Phase 1, Student P:

-X object goes down. The X object, with mass m, moves downwards. (The student redrew the two provided figures: In figure 1, labeled 'A,' the student marked 'T' to represent tension. In Figure 2, labeled 'B,' the student drew a downward arrow for 'X' and an upward arrow for 'Y' and labeled the distance between them as 'h'). In A, it can be said that X and Y are in balance. When X and Y are equal, the object is in equilibrium. In B, the object remains in equilibrium in terms of action and reaction, but the Y object possesses energy due to its height. The X object seeks to balance this energy. Thus, when the Y object is left up, the X object moves downwards to counterbalance the energy created by the height of the Y object. I remember learning about this from the subjects of action-reaction and inertia laws in high school and university, as well as the unit on work, power, and energy in high school.

Example 3:

Task 8: Atwood Machine, Group 1, Phase 1, Student P:

- The scale shows 3mg. Before the system starts to move, it exerts a force on the scale due to the weight of the objects with a total mass of 3m on both the right and left parts of the figure, resulting in a displayed value. When the system is released, it will move in the direction of the object with a 2m mass. However, since the total mass and the net force applied on the scale do not change, no change in the value displayed by the system is observed. If the system shows a force of 3mg before starting to move, the value displayed while the system is in motion and at the end will also be 3mg. This is because the total mass in the mechanism does not change, and consequently, neither does the force. I remember learning this concept from Newton's Laws in high school.

4.1.4 Implicit Justifications (Implicit)

These are justifications that the students develop without an explicit reference to a specific source. Several examples are provided below to demonstrate how the students produce this type of justification.

Example 1:
Task 4: Dynamometer, Group 2, Phase 1, Student Q:

-*The dynamometer shows 20 N. When 10 N of force pulls the system downwards, the system goes backward until the dynamometer shows 10 N. The other 10 N force pulls the system downwards, adding 10 N there. In total, the dynamometer shows 20 N. I answered based on my own thoughts.*

Example 2:
Task 7: Circular Motion, Group 1, Phase 1, Student F:

-*It follows path B (goes straight). When the ball in the figure starts moving at high speed on the circular path, it follows path B straight across due to the acceleration it gains after passing point 2, as there is no continuation of the circular path. I have never encountered a mechanism like this before. I reasoned only based on my own opinion.*

Example 3:
Task 8: Atwood Machine, Group 2, Phase 1, Student A:

- *The scale reads 3mg. The scale is dependent on gravity, and its value changes according to gravity. As a result, I added the masses together and then multiplied by the gravitational acceleration, which is 10. (m+2m).10 = 30m (On the given figure, the student showed m upward and 2m downward). I had never seen this information about the experiment anywhere and just gave this answer. Since it was a scale, gravity came to my mind, and that's why I responded this way. I gave my response, and this explanation is entirely based on my own thoughts without any specific knowledge.*

4.2 Findings for Research Question 2: Variation of Justification Sources Across the Phases of Argumentation

The second research question of this study is, ‘How do the types of justification sources vary across the six phases of the argumentation process?’ To illustrate the variation of justification source types across the six phases in all tasks, eight tables have been created, one for each task (see Appendix D). These tables demonstrate the variation of justification source types across each of the six phases and across all phases for all tasks. Then, by compiling the number and percentage of justification source type values for each phase of each of the eight tasks from the eight tables in Appendix D, six tables were created, one for each phase. These tables illustrate the variation of justification source types across each of the six phases for each of the eight tasks, as well as for all tasks collectively (see Appendix E). Finally, Table 4.1 has been created by compiling the number and percentage values of justification source types for all tasks in each phase, as presented in the six tables of Appendix E. This table, which shows the variation of justification source types across the six phases for all tasks, is presented in Table 4.1.

When Table 4.1 is examined, 25 students produced a total of 1,366 justifications, consisting of four different types, for their claims across the six phases of the eight tasks. When examining the total number of justification source types in Table 4.1, the highest number (n=304) occurred during ‘Phase 2: Group Discussion 1 - Before the Demonstration,’ which is the first group discussion before the demonstration. In contrast, the lowest number (n=192) was recorded in ‘Phase 4: Revised Justifications after the Demonstration,’ where students revised and rewrote their justifications following the demonstration.

When examining the percentages of justification source types for all phases in all tasks as presented in Table 4.1, ‘Justifications Based on School’ are the most frequently used, accounting for 44.95% of the total; ‘Justifications Based on Daily Life Observation’ are the least frequently used, accounting only 3.73%.

Table 4.1 Variation in Types of Justification Sources across the Six Phases for All Tasks

	All Tasks															
	Phase 1: Initial		Phase 2: Discussion 1		Phase 3: Revised		Demo	Phase 4: Revised		Phase 5: Discussion 2		Phase 6: Final		All Phases	
Justification Source Types	n	%	n	%	n	%		n	%	n	%	n	%	n	%
Daily Life Experiences	42	18	45	15	52	24		31	16	37	18	38	18	245	18
Real-Exper-R	11	5	13	4	18	8		30	16	32	15	33	16	137	10
Real-Exper-I	24	11	23	8	20	9		1	1	1	0	1	0	70	5
Illusi-Exper-I	7	3	9	3	14	6		0	0	4	2	4	2	38	3
Daily Life Observations	13	6	15	5	9	4		6	3	4	2	4	2	51	4
Real-Obser-R	0	0	0	0	0	0		0	0	0	0	0	0	0	0
Real-Obser-I	4	2	5	2	4	2		0	0	0	0	0	0	13	1
Illusi-Obser-I	3	1	4	1	1	0		0	0	0	0	0	0	8	1
Media-Obser-R	2	1	3	1	3	1		6	3	4	2	4	2	22	2
Media-Obser-I	4	2	3	1	1	0		0	0	0	0	0	0	8	1
School	153	67	152	50	138	63		56	29	58	27	57	27	614	45
Teacher-R	5	2	6	2	5	2		10	5	9	4	9	4	44	3
Teacher-I	17	7	15	5	12	5		5	3	7	3	7	3	63	5
Book-R	2	1	3	1	2	1		4	2	5	2	5	2	21	2
Book-I	7	3	7	2	5	2		0	0	0	0	0	0	19	1
School-Life-R	7	3	7	2	7	3		13	7	12	6	12	6	58	4
School-Life-I	89	39	87	29	79	36		5	3	6	3	6	3	272	20
Experiment-Demo-R	4	2	4	1	4	2		9	5	9	4	8	4	38	3
Experiment-Demo-I	22	10	23	8	24	11		10	5	10	5	10	5	99	7
Implicit	20	9	92	30	21	10		99	52	112	53	112	53	456	33
Implicit-R	3	1	56	18	4	2		40	21	51	24	57	27	211	15
Implicit-I	17	7	36	12	17	8		59	31	61	29	55	26	245	18
Total	228	100	304	100	220	100		192	100	211	100	211	100	1366	100
None (No Justifications)			41	12				17	8	30	12	2	1	90	6

When examining each phase of the argumentation process in Table 4.1, it is observed that in the first three phases, 'Justifications Based on School' were the most frequently used justifications with around 60%, and 'Justifications Based on Daily Life Observations' were the least frequently used ones with around 5%. In the last three phases after the demonstrations, 'Implicit Justifications' became the most frequently used justification, while 'Justifications Based on Daily Life Observations' became the least frequently used ones.

When examining the justification sources through each phase of argumentation, as presented in Table 4.1, it is clear that the variation of each source type distinctly shifts between phases. For example, 'Daily Life Experience' sources reach their highest point in 'Phase 3: Revised Justifications after Group Discussion 1 - Before the Demonstration,' showing a common use of personal experiences at that time. On the other hand, 'Daily Life Observation' sources are most frequently seen in 'Phase 1: Initial Justifications' and become least frequent by 'Phase 5: Group Discussion 2 - after the Demonstration' and 'Phase 6: Final Justifications after Group Discussion 2 - after the Demonstration.' This indicates an initial reliance on personal observations from daily life, which then diminishes in the later stages. Similarly, 'School' sources appear most frequently in 'Phase 1: Initial Justifications' and least frequently in 'Phase 5: Group Discussion 2,' showing an initial preference for what is learned in formal education that then reduces after further discussions and demonstrations. However, 'Implicit' sources become more common after the demonstrations, appearing most frequently in both Phase 5 and Phase 6. This evolution in justification sources across phases highlights a dynamic interaction where the nature of group discussions and observed demonstrations notably influences how people argue.

Additionally, this study also wondered whether students could provide the correct claim and relevant justification for the question asked of them upon reaching the demonstration part, where the correct claim is presented to them. Therefore, Tables 4.2 and 4.3 are created.

Table 4.2 Distribution of Students' Correct Claims, Wrong Claims, Relevant Justifications, Irrelevant Justifications, and No Answers in Phase 1 across Each of the Eight Tasks and All Tasks

	Task 1		Task 2		Task 3		Task 4		Task 5		Task 6		Task 7		Task 8		All Tasks	
Students':	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Correct Claims	0	0	1	4	0	0	10	43	5	21	10	45	11	44	4	17	41	22,2
Wrong Claims	21	100	23	96	22	100	13	57	19	79	12	55	14	56	20	83	144	77,8
Relevant Justifications	0	0	1	4	0	0	6	26	5	21	7	32	7	28		0	26	14,1
Irrelevant Justifications	21	100	23	96	22	100	17	74	19	79	15	68	18	72	24	100	159	85,9
No answers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number	21		24		22		23		24		22		25		24		185	

Table 4.3 Distribution of Students' Correct Claims, Wrong Claims, Relevant Justifications, Irrelevant Justifications, and No Answers in Phase 1 across Each of the Eight Tasks and All Tasks

	Task 1		Task 2		Task 3		Task 4		Task 5		Task 6		Task 7		Task 8		All Tasks	
Students':	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Correct Claims	0	0	2	8	0	0	10	43	5	21	13	59	13	52	7	29	50	27
Wrong Claims	21	100	22	92	22	100	13	57	19	79	9	41	12	48	17	71	135	73
Relevant Justifications	0	0	2	8	0	0	6	26	5	21	12	55	9	36	0	0	34	18
Irrelevant Justifications	21	100	22	92	22	100	17	74	19	79	10	45	16	64	24	100	151	82
No answers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number	21		24		22		23		24		22		25		24		185	

Tables 4.2 and 4.3 show the distribution of students' correct claims, wrong claims, relevant justifications, irrelevant justifications, and no responses, along with their numbers for each of the eight tasks and across all tasks in 'Phase 1: Initial Justifications' and 'Phase 3: Revised Justifications After Group Discussion 1 - Before the Demonstration.'

An examination of Tables 4.2 and 4.3 reveals that 78% of students did not reach a correct claim, and 86% of them did not provide a relevant justification in 'Phase 1: Initial Justifications.' Similarly, in 'Phase 3: Revised Justifications after Group Discussion 1 - Before the Demonstration,' 73% of students failed to reach a correct claim, and 82% did not provide a relevant justification.

These low rates of students being able to reach correct claims and provide relevant justifications by the end of 'Phase 1: Initial Justifications' and 'Phase 3: Revised Justifications' suggest that the surprise experienced during the demonstration part may lead to their difficulties in providing relevant justifications during this phase. This situation explains why the lowest total number of justification source types was recorded in 'Phase 4: Revised Justifications after the Demonstration,' as shown in Table 4.1.

4.3 Findings for Research Question 3: Variation of Justification Sources across the Tasks

To answer Research Question 3, which investigates how the types of justification sources vary across the eight tasks, Table 4.4 has been created. This table compiles the number and percentage of justification source types for all phases of each task, as detailed in the eight tables of Appendix D. Consequently, Table 4.4 demonstrates the variation in types of justification sources across the eight tasks for all phases.

Table 4.4 Variation in Types of Justification Sources across the Eight Tasks for All Phases

	Task 1: Weighing		Task 2: Inclined Plane 1		Task 3: Pulley KLM		Task 4: Dynamometer		Task 5: Pulley XY		Task 6: Inclined Plane 2		Task 7: Circular Motion		Task 8: Atwood Machine	
Justification Source Types	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Daily Life Experiences	37	30	41	24	3	2	24	13	4	2	57	35	79	38	0	0
Real-Exper-R	0	0	15	9	0	0	9	5	0	0	51	32	62	30	0	0
Real-Exper-I	2	2	26	15	3	2	15	8	4	2	6	4	14	7	0	0
Illusi-Exper-I	35	29	0	0	0	0	0	0	0	0	0	0	3	1	0	0
Daily Life Observations	3	2	0	0	12	8	9	5	0	0	10	6	17	8	0	0
Real-Obser-R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Real-Obser-I	0	0	0	0	7	5	1	1	0	0	5	3	0	0	0	0
Illusi-Obser-I	2	2	0	0	2	1	0	0	0	0	3	2	1	0	0	0
Media-Obser-R	0	0	0	0	0	0	8	4	0	0	0	0	14	7	0	0
Media-Obser-I	1	1	0	0	3	2	0	0	0	0	2	1	2	1	0	0
School	35	29	68	39	56	38	86	46	110	63	76	47	67	32	116	61
Teacher-R	0	0	0	0	0	0	24	13	14	8	6	4	0	0	0	0
Teacher-I	4	3	5	3	8	5	0	0	3	2	6	4	32	15	5	3
Book-R	0	0	0	0	0	0	7	4	14	8	0	0	0	0	0	0
Book-I	0	0	5	3	6	4	0	0	0	0	3	2	3	1	2	1
School-Life-R	0	0	0	0	0	0	18	10	12	7	18	11	10	5	0	0
School-Life-I	31	25	53	30	42	29	27	14	33	19	16	10	22	10	48	25
Experiment-Demo-R	0	0	0	0	0	0	6	3	23	13	9	6	0	0	0	0
Experiment-Demo-I	0	0	5	3	0	0	4	2	11	6	18	11	0	0	61	32
Implicit	47	39	65	37	75	51	69	37	62	35	18	11	47	22	73	39
Implicit-R	6	5	41	24	22	15	37	20	50	28	17	11	27	13	11	6
Implicit-I	41	34	24	14	53	36	32	17	12	7	1	1	20	10	62	33
Total	122	100	174	100	146	100	188	100	176	100	161	100	210	100	189	100
None (No Justifications)	30	20	2	1	34	19	10	5	1	1	3	2	0	0	8	4

When examining the total number of justification source types in Table 4.4, it is observed that the highest frequency of justification source types (n=210) occurred in ‘Task 7: Circular Motion.’ Additionally, according to Table 4.4, ‘Task 7: Circular Motion’ has the highest usage rates for both ‘Justifications Based on Daily Life Experiences’ (38%) and ‘Justifications Based on Daily Life Observations’ (8%).

Along with these findings from Table 4.4, it is also insightful to examine Table 4.2. Reviewing Table 4.2, it is observed that in ‘Task 7: Circular Motion’, the proportion of students who initially presented a correct claim is the second highest among the eight tasks at 44%. Similarly, the proportion of students who produced relevant justifications for a correct claim is also the second highest among the eight tasks at 28%.

In contrast, according to the total number of justification source types in Table 4.4, the lowest frequency of justification source types (n=122) was recorded in ‘Task 1: Weighing.’ Reviewing Table 4.2, it is noted that ‘Task 1: Weighing’ is one of only two tasks in which no student initially presented a correct claim among the eight tasks. Similarly, it is one of the three tasks where no student produced relevant justifications for a correct claim among the eight tasks given.

When examining each task based on Table 4.4, it is observed that in ‘Task 1: Weighing,’ ‘Justifications Based on Daily Life Experiences’ are the most frequently used with 30%; ‘Justifications Based on Daily Life Observations’ are the least frequently used with 2%. In ‘Task 2: Inclined Plane 1,’ ‘Justifications Based on School’ are the most frequently used with 39%; ‘Justifications Based on Daily Life Observations’ are not used. In ‘Task 3: Pulley KLM,’ ‘‘Implicit Justifications’ are the most frequently used with 51%; ‘Justifications Based on Daily Life Experiences’ are the least frequently used with 2%. In ‘Task 4: Dynamometer,’ ‘Justifications Based on School’ are the most frequently used with 46%; ‘Justifications Based on Daily Life Observations’ are the least frequently used with 5%. In ‘Task 5: Pulley XY,’ ‘Justifications Based on School’ are the most frequently used, with 63%;

‘Justifications Based on Daily Life Observations’ are not used. In ‘Task 6: Inclined Plane 2,’ ‘Justifications Based on School’ are the most frequently used with 47%; ‘Justifications Based on Daily Life Observations’ are the least frequently used with 6%. In ‘Task 7: Circular Motion,’ ‘Justifications Based on Daily Life Experiences’ are the most frequently used with 38%; ‘Justifications Based on Daily Life Observations’ are the least frequently used with 8%. In ‘Task 8: Atwood Machine,’ ‘Justifications Based on School’ are the most frequently used with 61%; both ‘Justifications Based on Daily Life Experiences’ and ‘Justifications Based on Daily Life Observations’ are not used.

When examining each type of justification source based on Table 4.4, it is observed that ‘Daily Life Experience’ was most frequently used in ‘Task 7: Circular Motion’ at 38% and was not used in ‘Task 8: Atwood Machine.’ Additionally, the rate of using ‘Daily Life Experience’ was 35% in ‘Task 6: Inclined Plane 2’, 30% in ‘Task 1: Weighing’, and 24% in ‘Task 2: Inclined Plane 1’, but relatively low, at 2%, in both ‘Task 3: Pulley KLM’ and ‘Task 5: Pulley XY.’ ‘Daily Life Observation’ was most frequently used in ‘Task 3: Pulley KLM’ and ‘Task 7: Circular Motion’ at 8% and was not used in ‘Task 2: Inclined Plane 1,’ ‘Task 5: Pulley XY,’ and ‘Task 8: Atwood Machine.’ Its usage was also notably low, at 2%, in ‘Task 1: Weighing.’ ‘School’ appeared most frequently in ‘Task 5: Pulley XY’ at 63% and was least frequent in ‘Task 1: Weighing’ at 29%. ‘Implicit’ was most frequent in ‘Task 3: Pulley KLM’ at 51% and least frequent in ‘Task 6: Inclined Plane 2’ at 11%.

All these results demonstrate that the differences and trends in students’ use of justification sources depend on context and relatability. It appears that tasks which students can easily relate to from their daily lives or observations not only encourage a broader range of justification source types but also improve the quality of engagement. This view is supported by the findings for ‘Task 7: Circular Motion,’ but the findings for ‘Task 1: Weighing’ highlight significant challenges in applying theoretical knowledge, daily experiences, or observations to this task. These challenges indicate that students faced unique difficulties in understanding or engaging with the underlying principles of the ‘Weighing’ concept.

Before moving on to Sections 4.4 and 4.5, which will present findings related to the fourth and fifth research questions and their sub questions, it is important to note that some students have used multiple sources in their justifications. However, research questions 2 and 3 aimed to focus on how frequently each type of justification source is used, so each justification source type was coded separately.

Therefore, Tables 4.1 and 4.4, prepared for Research Questions 2 and 3, show the variation in types of justification sources ‘across the six phases for all tasks’ and ‘across the eight tasks for all phases,’ respectively. However, in addressing the study’s fourth and fifth questions, the focus shifts to the change in types of justification sources after group discussion parts and we are also interested in the role of multiple justification sources in this change. Therefore, the following result tables will include multiple justification source types.

4.4 Findings for Research Question 4

Research Question 4: How do participants’ justification source types change after Group Discussion 1 (before the demonstration)?

To illustrate these changes, eight tables have been created, one for each task (see Appendix F). These tables demonstrate the variations in justification source types across Phases 1, 3, 4, and 6 for each of the eight tasks.

Then, Table 4.5 has been compiled to present the percentage values of justification source types for both ‘Phase 1: Initial Justifications’ and ‘Phase 3: Revised Justifications after Group Discussion 1 - Before the Demonstration’ for each task. This table, which shows the percentages of justification source types for Phases 1 and 3 across each of the eight tasks and all tasks, is presented below.

Table 4.5 Percentages of Justification Source Types for Phases 1 And 3 Across Each of the Eight Tasks and All Tasks

	Task 1: Weighing		Task 2: Inclined Plane 1		Task 3: Pulley KLM		Task 4: Dynamometer		Task 5: Pulley XY		Task 6: Inclined Plane 2		Task 7: Circular Motion		Task 8: Atwood Machine		All Tasks	
	Phase		Phase		Phase		Phase		Phase		Phase		Phase		Phase		Phase	
	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3
Justification Source Types	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Daily Life Experiences	29	62	13	4	0	0	9	9	4	8	27	41	24	28	0	0	13	18
Real-Exper-R	0	0	4	4	0	0	0	0	0	0	14	36	12	16	0	0	4	7
Real-Exper-I	0	0	8	0	0	0	9	9	4	8	14	5	8	8	0	0	5	4
Illusi-Exper-I	29	62	0	0	0	0	0	0	0	0	0	0	4	4	0	0	4	8
Daily Life Observations	5	0	0	0	5	14	4	0	0	0	14	9	0	0	0	0	3	3
Real-Obser-R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Real-Obser-I	0	0	0	0	5	14	4	0	0	0	9	5	0	0	0	0	2	2
Illusi-Obser-I	5	0	0	0	0	0	0	0	0	0	5	5	0	0	0	0	1	1
Media-Obser-R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Media-Obser-I	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
School	57	38	54	58	64	64	39	43	79	75	27	27	36	32	50	54	51	49
Teacher-R	0	0	0	0	0	0	0	0	0	0	5	5	0	0	0	0	1	1
Teacher-I	5	5	4	0	9	0	0	0	4	4	5	5	8	12	4	4	5	4
Book-R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Book-I	0	0	4	4	5	5	0	0	0	0	0	0	0	0	0	0	1	1
School-Life-R	0	0	0	0	0	0	9	9	4	4	5	5	4	4	0	0	3	3
School-Life-I	52	33	42	42	50	59	22	22	46	46	9	9	24	16	25	21	34	31

Table 4.5 (continued)

	Task 1: Weighing		Task 2: Inclined Plane 1		Task 3: Pulley KLM		Task 4: Dynamometer		Task 5: Pulley XY		Task 6: Inclined Plane 2		Task 7: Circular Motion		Task 8: Atwood Machine		All Tasks	
	Phase		Phase		Phase		Phase		Phase		Phase		Phase		Phase		Phase	
	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3
Justification Source Types	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Experiment-Demo-R	0	0	0	0	0	0	4	4	8	8	0	0	0	0	0	0	2	2
Experiment-Demo-I	0	0	4	13	0	0	4	9	17	13	5	5	0	0	21	29	6	9
Implicit	0	0	0	4	14	9	26	26	13	13	5	5	12	12	17	21	11	11
Implicit -R	0	0	0	4	0	0	0	0	4	4	5	5	4	4	0	0	2	2
Implicit-I	0	0	0	0	14	9	26	26	8	8	0	0	8	8	17	21	9	9
Experience-Observation	0	0	0	0	0	0	0	0	0	0	0	0	8	8	0	0	1	1
Real-Exper-R Media-Obser-R	0	0	0	0	0	0	0	0	0	0	0	0	4	8	0	0	1	1
Real-Exper-I Media-Obser-I	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	1	0
Experience-School	5	0	29	33	5	5	13	13	0	0	0	0	16	16	0	0	9	9
School-Life-R Real-Exper-R	0	0	0	0	0	0	0	0	0	0	0	0	4	4	0	0	1	1
School-Life-I Real-Exper-I	5	0	25	29	5	5	9	9	0	0	0	0	8	8	0	0	6	6
Teacher-R Real-Exper-R	0	0	0	0	0	0	4	4	0	0	0	0	0	0	0	0	1	1
Teacher-I Real-Exper-R	0	0	0	0	0	0	0	0	0	0	0	0	4	4	0	0	1	1

Table 4.5 (continued)

Justification Source Types	Task 1: Weighing		Task 2: Inclined Plane 1		Task 3: Pulley KLM		Task 4: Dynamometer		Task 5: Pulley XY		Task 6: Inclined Plane 2		Task 7: Circular Motion		Task 8: Atwood Machine		All Tasks	
	Phase		Phase		Phase		Phase		Phase		Phase		Phase		Phase		Phase	
	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Real-Exper-I School-Life-I Teacher-I	0	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Observation-School	5	0	0	0	9	5	4	4	0	0	5	0	0	0	0	0	3	1
Teacher-R Media-Obser-R	0	0	0	0	0	0	4	4	0	0	0	0	0	0	0	0	1	1
Teacher-I Media-Obser-I	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
School-Life-I Media-Obser-I	0	0	0	0	5	5	0	0	0	0	5	0	0	0	0	0	1	1
School-Life-I Teacher-I Illusi-Obser-I	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	1	0
School-School	0	0	4	0	5	5	4	4	4	4	23	18	4	4	33	25	10	8
Teacher-R Book-R	0	0	0	0	0	0	4	4	4	4	0	0	0	0	0	0	1	1
Teacher-I Book-I	0	0	0	0	5	5	0	0	0	0	5	5	4	4	4	0	2	2
Book-I School-Life-I	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

Table 4.5 (continued)

	Task 1: Weighing		Task 2: Inclined Plane 1		Task 3: Pulley KLM		Task 4: Dynamometer		Task 5: Pulley XY		Task 6: Inclined Plane 2		Task 7: Circular Motion		Task 8: Atwood Machine		All Tasks	
	Phase		Phase		Phase		Phase		Phase		Phase		Phase		Phase		Phase	
	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3
Justification Source Types	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
School-Life-R Experiment-Demo-R	0	0	0	0	0	0	0	0	0	0	5	5	0	0	0	0	1	1
School-Life-I Experiment-Demo-I	0	0	0	0	0	0	0	0	0	0	14	9	0	0	29	25	5	4
None (No Justifications)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

When examining the percentage values of justification source types for Phases 1 and 3, as presented in Table 4.5, it is observed that ‘Justifications Based on Daily Life Experiences’ account for 12.97% in ‘Phase 1: Initial Justifications’ increasing to 18.38% in ‘Phase 3: Revised Justifications.’ ‘Justifications Based on Daily Life Observations’ account for 3.24% in ‘Phase 1: Initial Justifications’ decreasing to 2.70% in ‘Phase 3: Revised Justifications.’ ‘Justifications Based on School’ account for 50.81% in ‘Phase 1: Initial Justifications’ decreasing to 49.19% in ‘Phase 3: Revised Justifications.’ ‘Implicit Justifications’ account for 10.81% in ‘Phase 1: Initial Justifications’ increasing to 11.35% in ‘Phase 3: Revised Justifications.’ ‘Experience-Observation Multiple Based Justifications’ account for 1.08% both in ‘Phase 1: Initial Justifications’ and ‘Phase 3: Revised Justifications.’ ‘Experience-School Multiple Based Justifications’ account for 8.65% both in ‘Phase 1: Initial Justifications’ and ‘Phase 3: Revised Justifications.’ ‘Observation-School Multiple Based Justifications’ accounts for 2.70% in ‘Phase 1: Initial Justifications’ decreasing to 1.08% in ‘Phase 3: Revised Justifications.’ ‘School-School Multiple Based Justifications’ account for 9.73% in ‘Phase 1: Initial Justifications’ decreasing to 7.57% in ‘Phase 3: Revised Justifications.’

However, this variability may differ when we examine Table 4.5 task-by-task. For example, ‘Justifications Based on Daily Life Experiences’ show an increase in ‘Phase 3: Revised Justifications’ compared to ‘Phase 1: Initial Justifications,’ but this is only true for four tasks (‘Task 1: Weighing’, ‘Task 5: Pulley XY’, ‘Task 6: Inclined Plane 2’, ‘Task 7: Circular Motion’). In contrast, for ‘Task 2: Inclined Plane 1’, there is a decrease in Phase 3 compared to Phase 1. Additionally, ‘Justifications Based on Daily Life Experiences’ remain unchanged in ‘Task 4: Dynamometer’ and are not used at all in ‘Task 3: Pulley KLM’ and ‘Task 8: Atwood Machine.’

Similarly, only in 2 tasks (‘Task 2: Inclined Plane 1’ and ‘Task 8: Atwood Machine’), ‘Implicit Justifications’ show an increase in ‘Phase 3: Revised Justifications’ compared to ‘Phase 1: Initial Justifications.’ In ‘Task 3: Pulley KLM’, there is a decrease in ‘Phase 3: Revised Justifications’ compared to ‘Phase 1: Initial Justifications’. ‘Implicit Justifications’ show no change in ‘Task 4: Dynamometer’, ‘Task 5: Pulley XY’, ‘Task 6: Inclined Plane 2’, and ‘Task 7: Circular Motion’, and are never used in ‘Task 1: Weighing.’

Therefore, the general examination of Table 4.5, which considers all tasks based on justification source types, reveals that some types of justification sources have experienced an increase or decrease in their percentage values in ‘Phase 3: Revised Justifications’ compared to their values in ‘Phase 1: Initial Justifications.’

To analyze this trend further, data from Table 4.5 has been used to create Table 4.6. This table illustrates the percentage change in justification source types for all eight tasks, comparing their percentage values in both ‘Phase 1: Initial Justifications’ and ‘Phase 3: Revised Justifications.’

Table 4.6 Percentages of Justification Source Types for Phase 1 and Phase 3, And the Changes between These Phases across All Tasks

	All Tasks		
	Percentages of Justification Sources Types for		Percentage Change in Justification Source Types Between Phase 1 and Phase 3
Justification Source Types	Phase 1: Initial Justifications	Phase 3: Revised Justifications After Group Discussion 1- Before the Demonstration	
Daily Life Experience	12.97	18.38	5.41
Daily Life Observation	3.24	2.70	-0.54
School	50.81	49.19	-1.62
Implicit	10.81	11.35	0.54
Experience-Observation	1.08	1.08	0.00
Experience-School	8.65	8.65	0.00
Observation-School	2.70	1.08	-1.62
School-School	9.73	7.57	-2.16

Table 4.6 is examined, considering all tasks based on justification source types. It is noted that as a result of 'Phase 2: Group Discussion 1,' which is conducted before the demonstration parts of the tasks, the percentage of 'Justifications Based on Daily Life Experiences' increased from 12.97% in 'Phase 1: Initial Justifications' to 18.38% in 'Phase 3: Revised Justifications.' Among all types of justification sources, the 'Daily Life Experience' category showed the most significant increase, rising by 5.41% during 'Phase 2: Group Discussion 1.' This indicates its effectiveness in persuading others to change their justifications. In other words, the 'Daily Life Experience' source seems more effective in convincing others during 'Phase 2: Group Discussion 1.'

However, the 'School-School Multiple Based Justifications' percentage decreased from 9.73% in 'Phase 1: Initial Justifications' to 7.57% in 'Phase 3: Revised Justifications.' Consequently, among all types of justification sources, the 'School-School' category showed the largest decline, with a decrease of 2.16% during 'Phase 2: Group Discussion 1.' This suggests that these justification sources tend to be less persuasive to others. In other words, the 'School-School' source seems more prone to change during 'Phase 2: Group Discussion 1.'

The following subsections present the results for the two sub-questions related to the fourth research question. These sub-questions investigate the changes in justification source types after 'Phase 2: Group Discussion 1' across eight tasks and in terms of whether the justifications are relevant or irrelevant.

4.4.1 Findings for Research Question 4.1

Research Question 4.1 asks, 'How do participants' justification source types change after Group Discussion 1 (before the demonstration) across eight tasks?' Table 4.7 has been compiled to address this question using data from Table 4.5.

Table 4.7 Percentage Change in Justification Source Types from Phase 1 to Phase 3 across Eight Tasks and All Tasks

	The Percentage of Change of Justification Source Types between Phase 1 and Phase 3 of								
Justification Source Types	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6	Task 7	Task 8	All Tasks
Daily Life Experience	33.33	- 8.33	NE	0	4.16	13.64	4.00	NE	5.41
Daily Life Observation	- 4.76	NE	9.09	-4.35	NE	- 4.55	NE	NE	-0.54
School	-19.04	4.17	0	4.35	-4.17	0	-4.00	4.17	-1.62
Implicit	NE	4.17	- 4.55	0	0	0	0	4.16	0.54
Experience-Observation	NE	NE	NE	NE	NE	NE	0	NE	0
Experience-School	- 4.76	4.17	0	0	NE	NE	0	NE	0
Observation-School	- 4.76	NE	-4.54	0	NE	- 4.55	NE	NE	-1.62
School-School	NE	-4.17	0	0	0	- 4.55	0	-8.33	-2.16

*NE: Justification source types did not emerge.

This table illustrates the percentage change in justification source types from 'Phase 1: Initial Justifications' to 'Phase 3: Revised Justifications after Group Discussion 1 - Before the Demonstration' across the eight tasks and all tasks.

When Table 4.7 is examined in terms of observed increases, it is noted that across the overall eight tasks, and specifically in 'Task 1: Weighing,' 'Task 5: Pulley XY,' 'Task 6: Inclined Plane 2,' and 'Task 7: Circular Motion,' there are increases of 33.33%, 4.17%, 13.64%, and 4% respectively in using the 'Justifications Based on Daily Life Experiences.' These increases suggest that the 'Daily Life Experience' source appears more effective in convincing others during 'Phase 2: Group Discussion 1.' On the other hand, for 'Task 2: Inclined Plane 1,' there is a 4.17% increase in using the 'School,' 'Implicit,' and 'Experience-School' sources. This indicates that these sources seem more effective in convincing others during 'Phase 2: Group Discussion 1.' For 'Task 3: Pulley KLM,' there is a 9.09% increase in using the 'Daily Life Observation' source category. This suggests that the 'Daily Life Observation' source appears more effective in convincing others during 'Phase 2: Group Discussion 1.' For 'Task 4: Dynamometer,' there is a 4.35% increase in using the 'School' source category. This suggests that the 'School' source appears more effective in convincing others during 'Phase 2: Group Discussion 1.' For 'Task 8: Atwood Machine,' there is a 4.17% increase in using the 'School' source category. This suggests that the 'School' source appears more effective in convincing others during 'Phase 2: Group Discussion 1.'

When Table 4.7 is examined in terms of observed decreases, it is noted that across the overall eight tasks, and specifically in 'Task 6: Inclined Plane 2' and 'Task 8: Atwood Machine,' there are decreases of 4.55% and 8.33% respectively in using the 'School-School Multiple Based Justifications.' These decreases suggest that the 'School-School Multiple' source appears more prone to change during 'Phase 2: Group Discussion 1.' On the other hand, in 'Task 1: Weighing,' 'Task 5: Pulley XY,' and 'Task 7: Circular Motion,' there are respective decreases of 19.04%, 4.17%, and 4% in using the 'Justifications Based on School.' These decreases suggest that the

‘School’ source appears more prone to change during ‘Phase 2: Group Discussion 1.’ For ‘Task 2: Inclined Plane 1,’ there is an 8.33% decrease in using the ‘Justifications Based on Daily Life Experiences.’ This indicates that the ‘Daily Life Experience’ source appears more prone to change during ‘Phase 2: Group Discussion 1.’ For ‘Task 3: Pulley KLM,’ there is a decrease of 4.55% in using the both ‘Implicit Justifications’ and ‘Observation-School Multiple Based Justifications.’ These decreases suggest that the ‘Implicit’ and ‘Observation-School Multiple’ sources appear more prone to change during ‘Phase 2: Group Discussion 1.’ For ‘Task 4: Dynamometer,’ there is a 4.35% decrease in using the ‘Justifications Based on Daily Life Observations.’ This indicates that the ‘Daily Life Observation’ source appears more prone to change during ‘Phase 2: Group Discussion 1.’ For ‘Task 6: Inclined Plane 2,’ there are 4.55% decreases in using the ‘School-School Multiple Based Justifications,’ ‘Justifications Based on Daily Life Observations,’ and ‘Observation-School Multiple Based Justifications.’ These decreases suggest that the ‘School-School Multiple,’ ‘Daily Life Observation,’ and ‘Observation-School Multiple’ sources appear more prone to change during ‘Phase 2: Group Discussion 1.’

As a result, in light of the above data, the effectiveness of a justification source type in convincing others or its susceptibility to change during ‘Phase 2: Group Discussion 1’ varies according to the task.

4.4.2 Findings for Research Question 4.2

Research Question 4.2 asks, ‘How do participants’ justification source types change after Group Discussion 1 (before the demonstration) in terms of being relevant or irrelevant?’ Tables 4.8 and 4.9 have been created to answer this research question based on data from Table 4.5. These tables show the percentages of relevant and irrelevant justification source types for ‘Phase 1: Initial Justifications’ to ‘Phase 3: Revised Justifications after Group Discussion 1 - Before the Demonstration’ across each of the eight tasks and all tasks.

Table 4.8 Percentages of Relevant Justification Source Types for Phases 1 and 3 Across each of the Eight Tasks and All Tasks

	Task 1: Weighing		Task 2: Inclined Plane 1		Task 3: Pulley KLM		Task 4: Dynamometer		Task 5: Pulley XY		Task 6: Inclined Plane 2		Task 7: Circular Motion		Task 8: Atwood Machine		All Tasks	
	Phase		Phase		Phase		Phase		Phase		Phase		Phase		Phase		Phase	
	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3
Relevant Justification Source Types	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Daily Life Experiences-R	0	0	100	50	0	0	0	0	0	0	43	67	43	44	0	0	27	38
Real-Exper-R	0	0	100	50	0	0	0	0	0	0	43	67	43	44	0	0	27	38
School-R	0	0	0	0	0	0	50	50	60	60	29	17	14	11	0	0	35	26
Teacher-R	0	0	0	0	0	0	0	0	0	0	14	8	0	0	0	0	4	3
School-Life-R	0	0	0	0	0	0	33	33	20	20	14	8	14	11	0	0	19	15
Experiment-Demo-R	0	0	0	0	0	0	17	17	40	40	0	0	0	0	0	0	12	9
Implicit-R	0	0	0	50	0	0	0	0	20	20	14	8	14	11	0	0	12	12
Implicit-R	0	0	0	50	0	0	0	0	20	20	14	8	14	11	0	0	12	12
Experience-Observation-R	0	0	0	0	0	0	0	0	0	0	0	0	14	22	0	0	4	6
Real-Exper-R Media-Obser-R	0	0	0	0	0	0	0	0	0	0	0	0	14	22	0	0	4	6
Experience-School-R	0	0	0	0	0	0	17	17	0	0	0	0	14	11	0	0	8	6
School-Life-R Real-Exper-R	0	0	0	0	0	0	0	0	0	0	0	0	14	11	0	0	4	3
Teacher-R Real-Exper-R	0	0	0	0	0	0	17	17	0	0	0	0	0	0	0	0	4	3
Observation-School-R	0	0	0	0	0	0	17	17	0	0	0	0	0	0	0	0	4	3
Teacher-R Media-Obser-R	0	0	0	0	0	0	17	17	0	0	0	0	0	0	0	0	4	3
School-School-R	0	0	0	0	0	0	17	17	20	20	14	8	0	0	0	0	12	9
Teacher-R Book-R	0	0	0	0	0	0	17	17	20	20	0	0	0	0	0	0	8	6
School-Life-R Experiment-Demo-R	0	0	0	0	0	0	0	0	0	0	14	8	0	0	0	0	4	3
None ((No Justifications)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	100	100	0	0	100	100	100	100	100	100	100	100	0	0	100	100

Table 4.9 Percentages of Irrelevant Justification Source Types for Phases 1 and 3 across Each of the Eight Tasks and All Tasks

	Task 1: Weighing		Task 2: Inclined Plane 1		Task 3: Pulley KLM		Task 4: Dynamometer		Task 5: Pulley XY		Task 6: Inclined Plane 2		Task 7: Circular Motion		Task 8: Atwood Machine		All Tasks	
	Phase		Phase		Phase		Phase		Phase		Phase		Phase		Phase		Phase	
	1	3	1	3	1	3	1	3	1	1	3	1	3	1	3	1	3	1
Irrelevant Justification Source Types	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Daily Life Experiences-I	29	62	9	0	0	0	12	12	5	11	20	10	18	20	0	0	11	14
Real-Exper-I	0	0	9	0	0	0	12	12	5	11	20	10	12	13	0	0	6	5
Illusi-Exper-I	29	62	0	0	0	0	0	0	0	0	0	0	6	7	0	0	4	9
Daily Life Observations-I	5	0	0	0	5	14	6	0	0	0	20	20	0	0	0	0	4	3
Real-Obser-I	0	0	0	0	5	14	6	0	0	0	13	10	0	0	0	0	3	3
Illusi-Obser-I	5	0	0	0	0	0	0	0	0	0	7	10	0	0	0	0	1	1
School-I	57	38	57	64	64	64	35	41	84	79	27	40	47	47	50	54	54	55
Teacher-I	5	5	4	0	9	0	0	0	5	5	7	10	12	20	4	4	6	5
Book-I	0	0	4	5	5	5	0	0	0	0	0	0	0	0	0	0	1	1
School-Life-I	52	33	43	45	50	59	29	29	58	58	13	20	35	27	25	21	39	38
Experiment-Demo-I	0	0	4	14	0	0	6	12	21	16	7	10	0	0	21	29	8	11
Implicit-I	0	0	0	0	14	9	35	35	11	11	0	0	12	13	17	21	11	11
Implicit-I	0	0	0	0	14	9	35	35	11	11	0	0	12	13	17	21	11	11
Experience-Observation-I	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	1	0
Real-Exper-I Media-Obser-I	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	1	0
Experience-School-I	5	0	30	36	5	5	12	12	0	0	0	0	12	13	0	0	8	9
School-Life-I Real-Exper-I	5	0	26	32	5	5	12	12	0	0	0	0	12	13	0	0	8	8

Table 4.9 (continued)

	Task 1: Weighing		Task 2: Inclined Plane 1		Task 3: Pulley KLM		Task 4: Dynamometer		Task 5: Pulley XY		Task 6: Inclined Plane 2		Task 7: Circular Motion		Task 8: Atwood Machine		All Tasks	
	Phase		Phase		Phase		Phase		Phase		Phase		Phase		Phase		Phase	
	1	3	1	3	1	3	1	3	1	1	3	1	3	1	3	1	3	1
Irrelevant Justification Source Types	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Real-Exper-I School-Life-I Teacher-I	0	0	4	5	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Observation-School-I	5	0	0	0	9	5	0	0	0	0	7	0	0	0	0	0	3	1
Teacher-I Media-Obser-I	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
School-Life-I Media-Obser-I	0	0	0	0	5	5	0	0	0	0	7	0	0	0	0	0	1	1
School-Life-I Teacher-I Illusi-Obser-I	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	1	0
School-School-I	0	0	4	0	5	5	0	0	0	0	27	30	6	7	33	25	9	7
Teacher-I Book-I	0	0	0	0	5	5	0	0	0	0	7	10	6	7	4	0	3	2
Book-I School-Life-I	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
School-Life-I Experiment-Demo-I	0	0	0	0	0	0	0	0	0	0	20	20	0	0	29	25	6	5
None ((No Justifications)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table 4.10 has been created to further analyze the change in relevant justification source types based on data from Table 4.8.

Table 4.10 Percentages of Relevant Justification Source Types for Phase 1 and Phase 3, And the Changes between These Phases across All Tasks

	All Tasks		
	Percentages of Relevant Justification Sources Types for		Percentage Change in Relevant Justification Source Types Between Phase 1 and Phase 3
Relevant Justification Source Types	Phase 1: Initial Justifications	Phase 3: Revised Justifications After Group Discussion 1- Before the Demonstration	
Daily Life Experience	26.92	38.24	11.31
Daily Life Observation	0.00	0.00	0.00
School	34.62	26.47	-8.14
Implicit	11.54	5.88	-5.66
Experience-Observation	3.85	5.88	2.04
Experience-School	7.69	5.88	-1.81
Observation-School	3.85	2.94	-0.90
School-School	11.54	8.82	-2.71

Table 4.10 illustrates the percentage change in relevant justification source types across all eight tasks. It compares their values in both ‘Phase 1: Initial Justifications’ and ‘Phase 3: Revised Justifications’ Table 4.10 is examined, considering all tasks based on relevant justification source types. It is observed that as a result of ‘Phase 2: Group Discussion 1’ which is conducted before the demonstration parts of the tasks, the percentage of ‘Relevant Justifications Based on Daily Life Experiences’ increased from 26.92% in ‘Phase 1: Initial Justifications’ to 38.24% in ‘Phase 3: Revised Justifications’. Among all relevant types of justification sources, the ‘Relevant Daily Life Experience’ category showed the most significant increase, rising by 11.31% during ‘Phase 2: Group Discussion 1.’ This indicates its effectiveness in persuading others to change their justifications. In other words, the ‘Relevant Daily Life Experience’ source seems more effective in convincing others during ‘Phase 2: Group Discussion 1.’ However, the ‘Relevant Justifications Based

on School' percentage decreased from 34.62% in 'Phase 1: Initial Justifications' to 26.47% in 'Phase 3: Revised Justifications.' Consequently, among all relevant types of justification sources, the 'Relevant School' category showed the largest decline, with a decrease of 8.14% during 'Phase 2: Group Discussion 1.' This suggests that these justification sources tend to be less persuasive to others. In other words, the 'Relevant School' source seems more prone to change during 'Phase 2: Group Discussion 1.'

Additionally, Table 4.11 has been created to further analyze the change in irrelevant justification source types based on data from Table 4.9. This table illustrates the percentage change in irrelevant justification source types across all eight tasks. It compares their values in both 'Phase 1: Initial Justifications' and 'Phase 3: Revised Justifications.'

Table 4.11 Percentages of Irrelevant Justification Source Types for Phase 1 and Phase 3, And the Changes between These Phases across All Tasks

	All Tasks		
	Percentages of Irrelevant Justification Sources Types for		Percentage Change in Irrelevant Justification Source Types Between Phase 1 and Phase 3
Irrelevant Justification Source Types	Phase 1: Initial Justifications	Phase 3: Revised Justifications After Group Discussion 1- Before the Demonstration	
Daily Life Experience	10.76	14.00	3.24
Daily Life Observation	3.80	3.33	-0.46
School	53.80	54.67	0.87
Implicit	10.76	11.33	0.57
Experience-Observation	0.63	0.00	-0.63
Experience-School	8.23	8.67	0.44
Observation-School	2.53	0.67	-1.86
School-School	9.49	7.33	-2.16

Table 4.11 is examined, considering all tasks based on irrelevant justification source types. It is observed that as a result of ‘Phase 2: Group Discussion 1’ which is conducted before the demonstration parts of the tasks, the percentage of ‘Irrelevant Justifications Based on Daily Life Experiences’ increased from 10.76% in ‘Phase 1: Initial Justifications’ to 14% in ‘Phase 3: Revised Justifications.’ Among all irrelevant types of justification sources, the ‘Irrelevant Daily Life Experience’ category showed the most significant increase, rising by 3.24% during ‘Phase 2: Group Discussion 1.’ This indicates its effectiveness in persuading others to change their justifications. In other words, the ‘Irrelevant Daily Life Experience’ source seems more effective in convincing others during ‘Phase 2: Group Discussion 1.’ However, the ‘Irrelevant School-School Multiple Based Justifications’ percentage decreased from 9.49% in ‘Phase 1: Initial Justifications’ to 7.33% in ‘Phase 3: Revised Justifications.’ Consequently, among all irrelevant types of justification sources, the ‘Irrelevant School-School’ category showed the largest decline, with a decrease of 2.16% during ‘Phase 2: Group Discussion 1.’ This suggests that this justification source tends to be less persuasive to others. In other words, the ‘Irrelevant School-School’ source seems more prone to change during ‘Phase 2: Group Discussion 1.’

Consequently, when examining all the data from Tables 4.5, 4.8, 4.9, 4.10, and 4.11 collectively and considering both relevant and irrelevant justification source types, it appears that both ‘Relevant Daily Life Experience’ and ‘Irrelevant Daily Life Experience’ sources are more effective in persuading the opposing side and changing their justifications during ‘Phase 2: Group Discussion 1.’ This trend is consistent across all eight tasks. On the other hand, when considering the relevant justification source types, it appears that, unlike the general trend observed in the eight tasks, the ‘Relevant School’ source is more prone to change. This is particularly noticeable at the point where students changed their own justifications after being convinced by the other side during ‘Phase 2: Group Discussion 1.’ Additionally, when considering the irrelevant justification source types, it appears that, in line with the general trend observed across the eight tasks, the ‘Irrelevant School-School Multiple’ source is more prone to change. This is particularly noticeable at the point where students changed their own justifications after being convinced by the other side during ‘Phase 2: Group Discussion 1.’

As a result, in light of the above data, the effectiveness of a justification source type in convincing others or its susceptibility to change during ‘Phase 2: Group Discussion 1’ does not vary based on whether it is relevant or irrelevant.

4.5 Findings for Research Question 5

The fifth research question of this study investigates how participants’ justification source types change after Group Discussion 2, which occurs after the demonstration. To illustrate these changes, Table 4.12 presents the percentage values of justification source types. These percentages are shown for two phases: ‘Phase 4: Revised Justifications after the Demonstration’ and ‘Phase 6: Final Justifications after Group Discussion 2 - After the Demonstration.’ This data is derived from eight tables in Appendix F and covers each of the eight tasks and all tasks. The table is presented below.

When examining the percentage values of justification source types for Phases 4 and 6, as presented in Table 4.12, it is observed that ‘Justifications Based on Daily Life Experiences’ account for 11.35% in ‘Phase 4: Revised Justifications’ increasing to 15.14% in ‘Phase 6: Final Justifications’ ‘Justifications Based on Daily Life Observations’ are not used in either ‘Phase 4: Revised Justifications’ or in ‘Phase 6: Final Justifications.’ ‘Justifications Based on School’ account for 15.14% in ‘Phase 4: Revised Justifications’ decreasing to 13.51% in Phase 6: Final Justifications.’ ‘Implicit Justifications’ account for 51.89% in ‘Phase 4: Revised Justifications’ increasing to 55.14% in ‘Phase 6: Final Justifications.’ ‘Experience-Observation Multiple Based Justifications’ account for 1.62% both in ‘Phase 4: Revised Justifications’ and ‘Phase 6: Final Justifications’

Table 4.12 Percentages of Justification Source Types for Phases 4 and 6 across Each of the Eight Tasks and All Tasks

	Task 1: Weighing		Task 2: Inclined Plane 1		Task 3: Pulley KLM		Task 4: Dynamometer		Task 5: Pulley XY		Task 6: Inclined Plane 2		Task 7: Circular Motion		Task 8: Atwood Machine		All Tasks	
	Phase		Phase		Phase		Phase		Phase		Phase		Phase		Phase		Phase	
	4	6	4	6	4	6	4	6	4	6	4	6	4	6	4	6	4	6
Justification Source Types	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Daily Life Experiences	0	19	13	17	0	0	0	0	0	0	55	55	24	32	0	0	11	15
Real-Exper-R	0	0	13	17	0	0	0	0	0	0	55	55	24	32	0	0	11	13
Real-Exper-I	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Illusi-Exper-I	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Daily Life Observations	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Real-Obser-R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Real-Obser-I	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Illusi-Obser-I	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Media-Obser-R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Media-Obser-I	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
School	0	0	0	0	0	0	26	26	38	29	27	18	12	16	17	17	15	14
Teacher-R	0	0	0	0	0	0	0	0	0	0	5	5	0	0	0	0	1	1
Teacher-I	0	0	0	0	0	0	0	0	0	0	0	0	8	12	0	0	1	2
Book-R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Book-I	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
School-Life-R	0	0	0	0	0	0	17	17	13	8	9	9	4	4	0	0	5	5
School-Life-I	0	0	0	0	0	0	4	4	0	0	0	0	0	0	0	0	1	1
Experiment-Demo-R	0	0	0	0	0	0	4	4	25	21	0	0	0	0	0	0	4	3
Experiment-Demo-I	0	0	0	0	0	0	0	0	0	0	14	5	0	0	17	17	4	3
Implicit	57	71	88	83	82	95	43	52	50	50	9	14	28	12	58	67	52	55
Implicit -R	0	0	42	71	18	36	26	39	46	50	9	14	20	8	0	0	21	28
Implicit-I	57	71	46	13	64	59	17	13	4	0	0	0	8	4	58	67	31	28

Table 4.12 (continued)

Justification Source Types	Task 1: Weighing		Task 2: Inclined Plane 1		Task 3: Pulley KLM		Task 4: Dynamometer		Task 5: Pulley XY		Task 6: Inclined Plane 2		Task 7: Circular Motion		Task 8: Atwood Machine		All Tasks	
	Phase		Phase		Phase		Phase		Phase		Phase		Phase		Phase		Phase	
	4	6	4	6	4	6	4	6	4	6	4	6	4	6	4	6	4	6
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Experience-Observation	0	0	0	0	0	0	0	0	0	0	0	0	12	12	0	0	2	2
Real-Exper-R Media-Obser-R	0	0	0	0	0	0	0	0	0	0	0	0	12	12	0	0	2	2
Experience-School	0	0	0	0	0	0	13	13	0	0	0	0	16	16	0	0	4	4
School-Life-R Real-Exper-R	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	1	0
School-Life-I Real-Exper-I	0	0	0	0	0	0	4	4	0	0	0	0	0	0	0	0	1	1
Teacher-R Real-Exper-R	0	0	0	0	0	0	9	9	0	0	0	0	0	0	0	0	1	1
Teacher-I Real-Exper-R	0	0	0	0	0	0	0	0	0	0	0	0	12	16	0	0	2	2
Observation-School	0	0	0	0	0	0	9	4	0	0	0	0	0	0	0	0	1	1
Teacher-R Media-Obser-R	0	0	0	0	0	0	9	4	0	0	0	0	0	0	0	0	1	1
School-School	0	0	0	0	0	0	4	4	13	17	9	9	0	0	13	17	5	6
Teacher-R Book-R	0	0	0	0	0	0	4	4	13	17	0	0	0	0	0	0	2	3
School-Life-R Experiment-Demo-R	0	0	0	0	0	0	0	0	0	0	9	9	0	0	0	0	1	1
School-Life-I Experiment-Demo-I	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	17	2	2

Table 4.12 (continued)

Justification Source Types	Task 1: Weighing		Task 2: Inclined Plane 1		Task 3: Pulley KLM		Task 4: Dynamometer		Task 5: Pulley XY		Task 6: Inclined Plane 2		Task 7: Circular Motion		Task 8: Atwood Machine		All Tasks	
	Phase		Phase		Phase		Phase		Phase		Phase		Phase		Phase		Phase	
	4	6	4	6	4	6	4	6	4	6	4	6	4	6	4	6	4	6
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
School-Implicit	0	0	0	0	0	0	0	0	0	4	0	5	0	0	0	0	0	1
School-Life-R Implicit-R	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	1
Experiment-Demo-I Implicit-R	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	1
Implicit-Implicit	0	0	0	0	0	5	0	0	0	0	0	0	4	12	0	0	1	2
Implicit-R Implicit-I	0	0	0	0	0	5	0	0	0	0	0	0	4	12	0	0	1	2
Observation-School-Implicit	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	1	0
Teacher-R Media-Obser-R Implicit-R	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	1	0
None (No Justifications)	43	10	0	0	18	0	0	0	0	0	0	0	4	0	13	0	9	1
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

‘Experience-School Multiple Based Justifications’ account for 3.78% both in ‘Phase 4: Revised Justifications’ and ‘Phase 6: Final Justifications.’ ‘Observation-School Multiple Based Justifications’ accounts for 1.08% in ‘Phase 4: Revised Justifications’ decreasing to 0.54% in ‘Phase 6: Final Justifications.’‘School-School Multiple Based Justifications’ account for 4.86% in ‘Phase 4: Revised Justifications’ increasing to 5.95% in ‘Phase 6: Final Justifications.’ ‘School-Implicit Multiple Based Justifications’ are not used in ‘Phase 4: Revised Justifications,’ increasing to 1.08% in ‘Phase 6: Final Justifications.’‘Implicit-Implicit Multiple Based Justifications’ account for 0.54% in ‘Phase 4: Revised Justifications’ increasing to 2.16% in ‘Phase 6: Final Justifications.’ ‘Observation-School-Implicit Multiple Based Justifications’ account for 0.54% in ‘Phase 4: Revised Justifications’ and are not used in ‘Phase 6: Final Justifications.’

However, this variability may differ when we examine Table 4.12 task-by-task. For example, ‘Justifications Based on Daily Life Experiences’ show an increase in ‘Phase 6: Final Justifications’ compared to ‘Phase 4: Revised Justifications,’ but this is only true for three tasks (‘Task 1: Weighing’, ‘Task 2: Inclined Plane 1’, ‘Task 7: Circular Motion’). In contrast, for ‘Task 6: Inclined Plane 2,’ there is no change in Phase 6 compared to Phase 4. Additionally, ‘Justifications Based on Daily Life Experiences’ in ‘Task 3: Pulley KLM’, ‘Task 4: Dynamometer’, ‘Task 5: Pulley XY’, and ‘Task 8: Atwood Machine’ are not used at all. Similarly, only in 2 tasks (Task 5: Pulley XY’ and ‘Task 6: Inclined Plane 2’), ‘Justifications Based on School’ show a decrease in ‘Phase 6: Final Justifications’ compared to ‘Phase 4: Revised Justifications,’ similar to the results seen across all tasks. However, in ‘Task 7: Circular Motion’, there is an increase in ‘Phase 6: Final Justifications’ compared to ‘Phase 4: Revised Justifications.’ ‘Justifications Based on School’ show no change in ‘Task 4: Dynamometer’ and ‘Task 8: Atwood Machine.’ They were never used in ‘Task 1: Weighing.’ ‘Task 2: Inclined Plane 1’ and ‘Task 3: Pulley KLM’

Therefore, the general examination of Table 4.12, which considers all tasks based on justification source types, reveals that some types of justification sources have experienced an increase or decrease in their percentage values in ‘Phase 6: Final Justifications’ compared to their values in ‘Phase 4: Revised Justifications.’ To analyze this trend further, data from Table 4.12 has been used to create Table 4.13. This table illustrates the percentage change in justification source types for all eight tasks, comparing their percentage values in both ‘Phase 4: Revised Justifications’ and ‘Phase 6: Final Justifications.’

Table 4.13 Percentages of Justification Source Types for Phase 4 and Phase 6, and the Changes between These Phases across All Tasks

	All Tasks		
	Percentages of Justification Sources Types for		Percentage Change in Justification Source Types Between Phase 4 and Phase 6
Justification Source Types	Phase 4: Revised Justifications After the Demonstration	Phase 6: Final Justifications After Group Discussion 2 - After the Demonstration	
Daily Life Experience	11.35	15.14	3.78
Daily Life Observation	0.00	0.00	0.00
School	15.14	13.51	-1.62
Implicit	51.89	55.14	3.24
Experience-Observation	1.62	1.62	0.00
Experience-School	3.78	3.78	0.00
Observation-School	1.08	0.54	-0.54
School-School	4.86	5.95	1.08
School-Implicit	0.00	1.08	1.08
Implicit-Implicit	0.54	2.16	1.62
Observation-School-Implicit	0.54	0.00	-0.54

Table 4.13 is examined, considering all tasks based on justification source types. It is noted that as a result of ‘Phase 5: Group Discussion 2,’ which is conducted after the demonstration parts of the tasks, the percentage of ‘Justifications Based on Daily Life Experiences’ increased from 11.35% in ‘Phase 4: Revised Justifications’ to 15.14% in ‘Phase 6: Final Justifications.’ Among all types of justification sources, the ‘Daily Life Experience’ category showed the most significant increase, rising by 3.78% during ‘Phase 5: Group Discussion 2.’ This indicates its effectiveness in

persuading others to change their justifications. In other words, the 'Daily Life Experience' source seems more effective in convincing others during 'Phase 5: Group Discussion 2.' However, the 'Justifications Based on School' percentage decreased from 15.14% in 'Phase 4: Revised Justifications' to 13.51% in 'Phase 6: Final Justifications.' Consequently, among all types of justification sources, the 'School' category showed the largest decline, with a decrease of 1.62% during 'Phase 5: Group Discussion 2.' This suggests that these justification sources tend to be less persuasive to others. In other words, the 'School' source seems more prone to change during 'Phase 5: Group Discussion 2.' The following subsections present the results for the two sub-questions related to the fifth research question. These sub-questions investigate the changes in justification source types after 'Phase 5: Group Discussion 2' across eight tasks and in terms of whether the justifications are relevant or irrelevant.

4.5.1 Findings for the Research Question 5.1

Research Question 5.1 asks, 'How do participants' justification source types change after Group Discussion 2 (after the demonstration) across eight tasks?' Table 4.14 has been compiled to address this question using data from Table 4.12.

This table illustrates the percentage change in justification source types 'Phase 4: Revised Justifications after the Demonstration' to 'Phase 6: Final Justifications after Group Discussion 2 - After the Demonstration' across the eight tasks and all tasks.

When Table 4.14 is examined in terms of observed increases, it is noted that across the overall eight tasks, and specifically in 'Task 1: Weighing,' 'Task 2: Inclined Plane 1,' and 'Task 7: Circular Motion,' there are increases of 19.05%, 4.17%, and 8% respectively in using the 'Justifications Based on Daily Life Experiences.' These increases suggest that the 'Daily Life Experience' source appears more effective in convincing others during 'Phase 5: Group Discussion 2.'

Table 4.14 Percentage Change in Justification Source Types from Phase 4 to Phase 6 across Eight Tasks and All Tasks

Justification Source Types	The Percentage of Change of Justification Source Types between Phase 4 and Phase 6 of								
	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6	Task 7	Task 8	All Tasks
Daily Life Experience	19.05	4.17	NE	NE	NE	0	8	NE	3.78
Daily Life Observation	NE	NE	NE	NE	NE	NE	NE	NE	0.00
School	NE	NE	NE	0	-8.33	-9.09	4	0	-1.62
Implicit	14.29	-4.17	13.64	8.70	0	4.55	-16	8.33	3.24
Experience-Observation	NE	NE	NE	NE	NE	NE	0	NE	0.00
Experience-School	NE	NE	NE	0	NE	NE	0	NE	0.00
Observation-School	NE	NE	NE	-4.35	NE	NE	NE	NE	-0.54
School-School	NE	NE	NE	0	4.17	0	NE	4.17	1.08
School-Implicit	NE	NE	NE	NE	4.17	4.55	NE	NE	1.08
Implicit-Implicit	NE	NE	4.55	NE	NE	NE	8	NE	1.62
Observation-School-Implicit	NE	NE	NE	-4.35	NE	NE	NE	NE	-0.54

*NE: Justification source types did not emerge.

On the other hand, for ‘Task 3: Pulley KLM’, ‘Task 4: Dynamometer,’ and ‘Task 8: Atwood Machine’ there are increases of 13.64%, 8.70%, and 8.33%, respectively, in using the ‘Implicit’ source.

This indicates that this source seems more effective in convincing others during ‘Phase 5: Group Discussion 2.’ For ‘Task 5: Pulley XY,’ there is a 4.17% increase in using both the ‘School-School Multiple’ and ‘School-Implicit Multiple’ source categories.

This suggests that these sources appear more effective in convincing others during ‘Phase 5: Group Discussion 2.’ For ‘Task 6: Inclined Plane 2,’ there is a 4.55% increase in using both the ‘Implicit’ and ‘School-Implicit Multiple’ source categories.

This suggests that these sources appear more effective in convincing others during ‘Phase 5: Group Discussion 2.’ For Task 7: Circular Motion,’ there is also an 8% increase in using the ‘Implicit-Implicit Multiple’ source category, similar to the ‘Daily Life Experience’ source.

This suggests that this source also appears more effective in convincing others during ‘Phase 5: Group Discussion 2.’

When Table 4.14 is examined in terms of observed decreases, it is noted that across the overall eight tasks, and specifically in ‘Task 5: Pulley XY’ and ‘Task 6: Inclined Plane 2’ there are decreases of 8.33% and 9.09% respectively in using the ‘Justifications Based on School.’

These decreases suggest that the ‘School’ source appears more prone to change during ‘Phase 5: Group Discussion 2.’ On the other hand, in ‘Task 2: Inclined Plane 1’ and ‘Task 7: Circular Motion,’ there are respective decreases of 4.17% and 16% in using the ‘Implicit Based Justifications.’

These decreases suggest that the ‘Implicit’ source appears more prone to change during ‘Phase 5: Group Discussion 2.’ For ‘Task 4: Dynamometer,’ there is a 4.35%

decrease in using the ‘Observation-School Multiple’ and ‘Observation-School-Implicit Multiple’ source categories.

These decreases suggest that these sources appear more prone to change during ‘Phase 5: Group Discussion 2.’

As a result, in light of the above data, the effectiveness of a justification source type in convincing others or its susceptibility to change during ‘Phase 5: Group Discussion 2’ varies according to the task.

4.5.2 Findings for the Research Question 5.2

Research Question 5.2 asks, ‘How do participants’ justification source types change after Group Discussion 2 (after the demonstration) in terms of being relevant or irrelevant?’ Tables 4.15 and 4.16 have been created to answer this research question based on data from Table 4.12.

Tables 4.15 and 4.16 show the percentages of relevant and irrelevant justification source types for ‘Phase 4: Revised Justifications after the Demonstration’ to ‘Phase 6: Final Justifications after Group Discussion 2 - After the Demonstration’ across each of the eight tasks and all tasks.

Table 4.17 has been created to further analyze the change in relevant justification source types based on data from Table 4.15.

This table illustrates the percentage change in relevant justification source types across all eight tasks. It compares their values in both ‘Phase 4: Revised Justifications’ and ‘Phase 6: Final Justifications.’

Table 4.15 Percentages of Relevant Justification Source Types for Phases 4 and 6 across Each of the Eight Tasks and All Tasks

Relevant Justification Source Types	Task 1: Weighing		Task 2: Inclined Plane 1		Task 3: Pulley KLM		Task 4: Dynamometer		Task 5: Pulley XY		Task 6: Inclined Plane 2		Task 7: Circular Motion		Task 8: Atwood Machine		All Tasks	
	Phase		Phase		Phase		Phase		Phase		Phase		Phase		Phase		Phase	
	4	6	4	6	4	6	4	6	4	4	6	4	6	4	6	4	6	4
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Daily Life Experience-R	0	0	23	19	0	0	0	0	0	0	63	60	35	57	0	0	19	22
Real-Exper-R	0	0	23	19	0	0	0	0	0	0	63	60	35	57	0	0	19	22
School-R	0	0	0	0	0	0	29	28	39	29	16	15	6	7	0	0	17	15
Teacher-R	0	0	0	0	0	0	0	0	0	0	5	5	0	0	0	0	1	1
School-Life-R	0	0	0	0	0	0	24	22	13	8	11	10	6	7	0	0	9	8
Experiment-Demo-R	0	0	0	0	0	0	6	6	26	21	0	0	0	0	0	0	6	6
Implicit-R	0	0	77	81	50	100	35	50	48	50	11	15	29	14	0	0	35	48
Implicit-R	0	0	77	81	50	100	35	50	48	50	11	15	29	14	0	0	35	48
Experience-Observation-R	0	0	0	0	0	0	0	0	0	0	0	0	18	21	0	0	3	3
Real-Exper-R Media-Obser-R	0	0	0	0	0	0	0	0	0	0	0	0	18	21	0	0	3	3
Experience-School-R	0	0	0	0	0	0	12	11	0	0	0	0	6	0	0	0	3	2
School-Life-R Real-Exper-R	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	1	0
Teacher-R Real-Exper-R	0	0	0	0	0	0	12	11	0	0	0	0	0	0	0	0	2	2

Table 4.15 (continued)

Relevant Justification Source Types	Task 1: Weighing		Task 2: Inclined Plane 1		Task 3: Pulley KLM		Task 4: Dynamometer		Task 5: Pulley XY		Task 6: Inclined Plane 2		Task 7: Circular Motion		Task 8: Atwood Machine		All Tasks	
	Phase		Phase		Phase		Phase		Phase		Phase		Phase		Phase		Phase	
	4	6	4	6	4	6	4	6	4	4	6	4	6	4	6	4	6	4
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Observation-School-R	0	0	0	0	0	0	12	6	0	0	0	0	0	0	0	0	2	1
Teacher-R Media-Obser-R	0	0	0	0	0	0	12	6	0	0	0	0	0	0	0	0	2	1
School-School-R	0	0	0	0	0	0	6	6	13	17	11	10	0	0	0	0	6	7
Teacher-R Book-R	0	0	0	0	0	0	6	6	13	17	0	0	0	0	0	0	4	5
School-Life-R Experiment-Demo-R	0	0	0	0	0	0	0	0	0	0	11	10	0	0	0	0	2	2
School-Implicit-R	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	1
School-Life-R Implicit-R	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	1
Observation-School-Implicit-R	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	1	0
Teacher-R Media-Obser-R Implicit-R	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	1	0
None (No Justifications)	100	100	0	0	50	0	0	0	0	0	0	0	6	0	100	0	16	2
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0	100	100

Table 4.16 Percentages of Irrelevant Justification Source Types for Phases 4 and 6 across Each of the Eight Tasks and All Tasks

	Task 1: Weighing		Task 2: Inclined Plane 1		Task 3: Pulley KLM		Task 4: Dynamometer		Task 5: Pulley XY		Task 6: Inclined Plane 2		Task 7: Circular Motion		Task 8: Atwood Machine		All Tasks	
	Phase		Phase		Phase		Phase		Phase		Phase		Phase		Phase		Phase	
	4	6	4	6	4	6	4	6	4	6	4	6	4	6	4	6	4	6
Irrelevant Justification Source Types	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Daily Life Experience-I	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
Illusi-Exper-I	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
School-I	0	0	0	0	0	0	17	20	0	0	100	100	40	75	17	17	11	13
Teacher-I	0	0	0	0	0	0	0	0	0	0	0	0	40	75	0	0	2	4
School-Life-I	0	0	0	0	0	0	17	20	0	0	0	0	0	0	0	0	1	1
Experiment-Demo-I	0	0	0	0	0	0	0	0	0	0	100	100	0	0	17	17	8	7
Implicit-I	57	71	100	100	78	100	67	60	100	0	0	0	40	25	58	67	65	72
Implicit-I	57	71	100	100	78	100	67	60	100	0	0	0	40	25	58	67	65	72
Experience-School-I	0	0	0	0	0	0	17	20	0	0	0	0	0	0	0	0	1	1
School-Life-I Real-Exper-I	0	0	0	0	0	0	17	20	0	0	0	0	0	0	0	0	1	1
School-School-I	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	17	3	6
School-Life-I Experiment-Demo-I	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	17	3	6
None (No Justifications)	43	10	0	0	22	0	0	0	0	0	0	0	20	0	13	0	19	3
Total	100	100	100	100	100	100	100	100	100	0	100	100	100	100	100	100	100	100

Table 4.17 Percentages of Relevant Justification Source Types for Phase 4 and Phase 6, and the Changes between These Phases across All Tasks

	All Tasks		
	Percentages of Relevant Justification Sources Types for		Percentage Change in Relevant Justification Source Types Between Phase 4 and Phase 6
Relevant Justification Source Types	Phase 4: Revised Justifications After the Demonstration	Phase 6: Final Justifications After Group Discussion 2 - After the Demonstration	
Daily Life Experience	19.27	22.43	3.16
Daily Life Observation	0.00	0.00	0.00
School	16.51	14.95	-1.56
Implicit	34.86	47.66	12.80
Experience-Observation	2.75	2.80	0.05
Experience-School	2.75	1.87	-0.88
Observation-School	1.83	0.93	-0.90
School-School	5.50	6.54	1.04
School-Implicit	0.00	0.93	0.93
Implicit-Implicit	0.00	0.00	0.00
Observation-School-Implicit	0.92	0.00	-0.92

Table 4.17 is examined, considering all tasks based on relevant justification source types. It is observed that as a result of 'Phase 5: Group Discussion 2 - After the Demonstration,' which is conducted before the demonstration parts of the tasks, the percentage of 'Relevant Implicit Justifications' increased from 34.86% in 'Phase 4: Revised Justifications' to 47.66% in 'Phase 6: Final Justifications.' Among all relevant types of justification sources, the 'Relevant Implicit' category showed the most significant increase, rising by 12.80% during 'Phase 5: Group Discussion 2.' This indicates its effectiveness in persuading others to change their justifications. In other words, the 'Relevant Implicit' source seems more effective in convincing others during 'Phase 5: Group Discussion 2.' However, the 'Relevant Justifications Based on School' percentage decreased from 16.51% in 'Phase 4: Revised Justifications' to 14.95% in 'Phase 6: Final Justifications.' Consequently, among all

relevant types of justification sources, the ‘Relevant School’ category showed the largest decline, with a decrease of 1.56% during ‘Phase 5: Group Discussion 2.’ This suggests that these justification sources tend to be less persuasive to others. In other words, the ‘Relevant School’ source seems more prone to change during ‘Phase 5: Group Discussion 2.’

Additionally, Table 4.18 has been created to further analyze the change in irrelevant justification source types based on data from Table 4.16. This table illustrates the percentage change in irrelevant justification source types across all eight tasks. It compares their values in both ‘Phase 4: Revised Justifications’ and ‘Phase 6: Final Justifications.’

Table 4.18 is examined, considering all tasks based on irrelevant justification source types. It is observed that as a result of ‘Phase 5: Group Discussion 2,’ which is conducted before the demonstration parts of the tasks, the percentage of ‘Irrelevant Implicit Justifications’ increased from 65.17% in ‘Phase 4: Revised Justifications’ to 71.83% in ‘Phase 6: Final Justifications.’ Among all irrelevant types of justification sources, the ‘Irrelevant Implicit’ category showed the most significant increase, rising by 6.66% during ‘Phase 5: Group Discussion 2.’ This indicates its effectiveness in persuading others to change their justifications. In other words, the ‘Irrelevant Implicit’ source seems more effective in convincing others during ‘Phase 5: Group Discussion 2.’ However, when Table 4.16 is examined, it is observed that the ‘Irrelevant Experiment-Demo (School) Based Justifications’ percentage decreased from 7.87% in ‘‘Phase 4: Revised Justifications’ to 7.04% in ‘Phase 6: Final Justifications.’ Consequently, among all irrelevant types of justification sources, the ‘Irrelevant Experiment-Demo (School)’ category showed the largest decline, with a decrease of 0.83% during ‘Phase 5: Group Discussion 2.’ This suggests that this justification source tends to be less persuasive to others. In other words, the ‘Irrelevant Experiment-Demo (School)’ source seems more prone to change during ‘Phase 5: Group Discussion 2.’

Table 4.18 Percentages of irrelevant justification source types for phase 4 and phase 6, and the changes between these phases across all tasks

	All Tasks		
	Percentages of Irrelevant Justification Sources Types for		Percentage Change in Irrelevant Justification Source Types Between Phase 4 and Phase 6
Irrelevant Justification Source Types	Phase 4: Revised Justifications After the Demonstration	Phase 6: Final Justifications After Group Discussion 2 - After the Demonstration	
Daily Life Experience	0.00	5.63	5.63
Daily Life Observation	0.00	0.00	0.00
School	11.24	12.68	1.44
Implicit	65.17	71.83	6.66
Experience-Observation	0.00	0.00	0.00
Experience-School	1.12	1.41	0.28
Observation-School	0.00	0.00	0.00
School-School	3.37	5.63	2.26
School-Implicit	0.00	0.00	0.00
Implicit-Implicit	0.00	0.00	0.00
Observation-School-Implicit	0.00	0.00	0.00

Consequently, when examining all the data from Tables 4.12, 4.15, 4.16, 4.17, and 4.18 collectively and considering both relevant and irrelevant justification source types, it appears that both 'Relevant Implicit' and 'Irrelevant Implicit' sources are more effective in persuading the opposing side and changing their justifications during 'Phase 2: Group Discussion 1.' This trend is consistent across all eight tasks. On the other hand, when considering the relevant justification source types, it appears that, in line with the general trend observed across the eight tasks, the 'Relevant School' source is more prone to change. This is particularly noticeable at the point where students changed their own justifications after being convinced by the other side during 'Phase 5: Group Discussion 2.' Additionally, when considering the irrelevant justification source types, it appears that, unlike the general trend observed in the eight tasks, the 'Irrelevant Experiment-Demo (School)' source is more prone to change. This is particularly noticeable at the point where students changed their own justifications after being convinced by the other side during ‘Phase 5: Group Discussion 2.’

As a result, in light of the above data, the effectiveness of a justification source type in convincing others or its susceptibility to change during ‘Phase 5: Group Discussion 2’ does not vary based on whether it is relevant or irrelevant.

4.6 Summary of the Findings

This study used the POE instructional strategy and debatable inquiry tasks with counterintuitive physics questions within an argumentation process. The objectives were twofold: first, to identify the sources of justifications used in the argumentation and second, to investigate how these sources interact and potentially influence each other during the process. In line with these objectives, five research questions were addressed.

This section presents the study’s findings, organized according to each research question. We identified the sources of justifications that emerged in the six-phase argumentation process and attempted to track the changes in these sources, focusing mainly on how they influenced each other.

Table 4.19 has been prepared to display the percentage change in types of justification sources from Phase 1 to Phase 3 (before the demonstration) and from Phase 4 to Phase 6 (after the demonstration).

It considers the changes among all justification source types, only relevant justification source types, and only irrelevant justification source types.

Table 4.19 Summary of the Findings on the Percentage Change in Justification Source Types before and After the Demonstration

	Before Demonstration			After Demonstration		
	Percentage Change in Justification Source Types Between Phase 1 and Phase 3			Percentage Change in Justification Source Types Between Phase 4 and Phase 6		
	Among All Justification Source Types	Among Only Relevant Justification Source Types	Among Only Irrelevant Justification Source Types	Among All Justification Source Types	Among Only Relevant Justification Source Types	Among Only Irrelevant Justification Source Types
Most Increasing	Daily Life Experience	Daily Life Experience	Daily Life Experience	Daily Life Experience	Implicit	Implicit
	%5,41	%11,31	%3,24	%3,78	%12,80	%6,66
Most Decreasing	School-School Multiple	School	School-School Multiple	School	School	School (Experiment -Demo)
	%-2,16	%-8,14	%-2,16	%-1,62	%-1,56	%-0,82

When Table 4.19 is analyzed for the percentage change in justification source types with the highest increases between phases, it is observed that the 'Daily Life Experience' source seems most effective in convincing others. This trend is evident both between Phase 1 and Phase 3, as well as between Phase 4 and Phase 6, among 'All Justification Source Types.' Additionally, within both 'Relevant Justification Source Types' and 'Irrelevant Justification Source Types,' 'Daily Life Experience' seems most effective in convincing others between Phase 1 and Phase 3.

When analyzing Table 4.19 for the percentage change in justification source types with the most significant decrease in percentages between phases—both between Phase 1 and Phase 3 as well as between Phase 4 and Phase 6—across 'All, Relevant, and Irrelevant Justification Source Types,' it appears that 'School' source are more prone to change.

In conclusion, this study finds that students' 'Justifications Based on Daily Life Experiences,' which are derived from their personal experiences in daily life in response to the questions they encounter, tend to be more effective in influencing the justifications of other students during the argumentation processes. On the other hand, ‘Justifications Based on School,’ produced by students based on school-related sources (such as teachers, textbooks, class experiments/demonstrations, and school life), are observed to be more easily influenced and changed by the justifications of other students throughout the argumentation process.

CHAPTER 5

DISCUSSION AND CONCLUSION

In this concluding chapter, we discuss our research findings and draw conclusions from our investigation into the argumentation process. A series of research questions have guided our exploration, focused on understanding the types of justification sources used in argumentation and how these sources change. This discussion reveals the nature and variation of these justification sources across different phases and tasks and examines their transformation through group discussions. We reflect here on the answers to these questions, specifically exploring:

1. The nature and diversity of justification sources that emerged during the argumentation process.
2. The variation in these justification sources throughout the six phases of argumentation.
3. The variation in these justification sources across the eight tasks.
4. The transformation in types of justification sources after the group discussion (before the demonstration), considering their changes across tasks and in terms of relevance.
5. The transformation in types of justification sources after the group discussion (after the demonstration), considering their changes across tasks and in terms of relevance.

This chapter aims to present the results of this study and offer a clearer understanding of the patterns and shifts in justification sources within the argumentation process, highlighting their implications for future research and practice.

5.1 Discussion and Implications of Research Question 1

In addressing the study's first research question concerning the types of justification sources that emerged during the argumentation process, our analysis revealed ten distinct sources categorized into four main groups. The first group, 'Daily Life Experience,' encompasses sources like 'Real Experiences,' based on actual daily life events, and 'Illusive Experiences,' drawn from imagined scenarios. The second group, 'Daily Life Observation,' includes 'Real Observations' from personal daily life observations, 'Illusive Observations' based on imagination, and 'Observations from Media' gained from media sources. The third category involves 'School' sources, which cover a range of sources from 'Teacher,' 'Textbooks,' and 'Experiments or Demonstrations in class,' to broader learning and experiences of 'School Life.' Lastly, the 'Implicit' category comprises sources that are not mentioned explicitly. This study primarily examines the variety of sources participants use for justifications in problem-solving and argumentation, including during group discussions and demonstrations. It does not assess whether these justifications are scientifically correct or lead to a solution. Instead, the study acknowledges that justifications, based on these ten different source types described above, may not always lead to a correct or appropriate solution and can be either relevant or irrelevant. The primary aim is to analyze the sources of these justifications, not their scientific accuracy, though the relevance or irrelevance of these justifications is noted for future detailed analysis. Additionally, during group discussions, some participants could not provide counterarguments; they only expressed disagreement or simply repeated results from demonstrations without offering justifications.

Comparing the identification of these ten distinct justification source types, which are categorized into four main groups in this study, with findings from other studies reveals an alignment with several key findings in prior research on the types of sources used for justifications in argumentation. The presence of several of these ten categories of justification source types aligns with categories found in the literature, such as personal experiences, opinions, or prior experiences (Albe, 2008; Bilican, 2018; Bråten et al., 2016; Knight, 2015; McNeill & Pimentel, 2010; Salmerón et al., 2016; Sandoval & Çam, 2011; Schwarz et al., 2003); background knowledge and use of theoretical concepts (Ludwig et al., 2021; Schwarz et al., 2003); the appeal to authority (Knight, 2015; Ludwig et al., 2021; Sandoval & Çam, 2011; Schwarz et al., 2003); empirical evidence, science ideas, and data-based evidence (Bilican, 2018; Knight, 2015; Ludwig et al., 2021; McNeill & Pimentel, 2010; Sandoval & Çam, 2011); as well as other types and external sources (McNeill & Pimentel, 2010; Salmerón et al., 2016). The unique contribution of this study is to specify these general categories into specific categories. Moreover, among these specific categories, several categories are new contributions to the existing literature, including 'Illusive Experiences' and 'Illusive Observations.'

The findings also highlight the varied strategies participants employed in constructing their justifications. Notably, some participants preferred to base their justifications on a single source. This approach suggests a focused or perhaps limited perspective in addressing the problem. On the other hand, other participants adopted a more integrative approach by using multiple sources for their justifications. This approach indicates a more comprehensive understanding of the issues being discussed; reflecting their ability to view the problem from many angles and synthesize diverse viewpoints or information. Also, using multiple sources for justifications in argumentation is aligned with the literature (Bilican, 2018; Bråten et al., 2013; Knight, 2015; McNeill & Pimentel, 2010).

In summary, these alignments between the types of justification sources identified in this study and the use of multiple sources, as supported by existing literature, emphasize our categorization's validity, consistency, and relevance. Both existing and new categories emphasize the complexity and diversity of justification sources that individuals use during the argumentation process and highlight the consensus regarding the multifaceted nature of argumentation (Duschl, 2007, 2008; Lee et al., 2014; Nussbaum, 2011; Sandoval & Millwood, 2005). Additionally, by highlighting these compatibilities and introducing new categories, this research contributes to a broader understanding of a wide range of justification sources individuals use and rely on during argumentative reasoning and enhances our understanding of justification strategies within argumentative contexts. It also offers a broader perspective on how individuals use real and imagined experiences and observations to support their justifications. This expansion of categories enriches the discourse on argumentation, providing insights into how individuals construct and justify their positions. Consequently, as with other similar studies, it should not be forgotten that the categorization of justification source types in this study is conducted distinctly, thus serving different purposes. The existence of both previously emerging and newly emerging categories demonstrates how the study's findings are influenced by mechanics units within the field of physics. This highlights the field-specific nature of argumentation and the importance of field-dependent criteria in argument analysis studies, as emphasized by other researchers (Erduran, 2007; Mendonça & Justi, 2014; Sampson & Blanchard, 2012; Sampson & Clark, 2008; Sandoval & Millwood, 2005; Toulmin, 2003; van Eemeren et al., 1996). This underlines the necessity of considering each study's unique context and objectives when analyzing argumentation and justification sources.

The discovery of types of justification sources utilized during the argumentation process provides a foundation for and supports further studies in related research areas. Furthermore, this discovery facilitates the examination of how different sources of justification influence the quality and effectiveness of argumentation, offering valuable insights for educators and researchers interested in promoting critical thinking and reasoning skills. This contribution to related research underscores the importance of recognizing and analyzing the diversity of justification sources in argumentation, highlighting potential areas for future investigation and application in educational settings.

Identifying ten distinct sources, including the novel categories of ‘Illusive Experiences’ and ‘Illusive Observations,’ underscores the diversity of sources individuals employ during scientific argumentation. This diversity highlights the need for educational strategies that acknowledge and develop the ability to critically evaluate and integrate a wide range of sources, including those based on personal experiences, observations, and media, as well as more formal educational content.

Additionally, by categorizing the sources of justification, we aim to gain insights into the cognitive processes supporting students' argumentation in physics, revealing how they use evidence, reasoning, and scientific principles to construct and defend their arguments. This examination not only contributes to our understanding of the role of justification in scientific argumentation but also provides valuable perspectives on improving instructional strategies to more effectively assist students in developing argumentation skills in physics education.

For educators, understanding the variety of sources students use for their justifications is crucial for recognizing what they bring into the classroom. Teachers should be aware not only of the instances when students rely on different types of sources for their justifications but also of situations where students may not provide justifications. Additionally, educators need to know that students might use ‘Illusive Experiences’ and ‘Illusive Observations’ as part of their argumentation. Being prepared for what they encounter in the classroom allows teachers to address justifications based on illusive sources effectively. This awareness prepares educators to better guide students in approaching these ‘Illusive Source Types’ in classroom discussions. By preparing for these situations, teachers can help students manage the complexities of constructing arguments, promoting an environment where critical thinking and reasoned debate are encouraged. Understanding these dynamics is crucial to developing strategies that improve students’ ability to formulate comprehensive and well-supported justifications, thus enriching the educational experience.

In addition to this, for educators, these findings suggest the importance of designing learning activities that encourage students to explore and express their justifications using various sources. By doing so, educators can help students develop a more deep understanding of topics, encouraging critical thinking and problem-solving skills. Furthermore, the study's findings on some participants' preference for relying on a single source rather than multiple sources for their justifications highlight the importance of teaching students the value of integrating multiple perspectives to build qualified, comprehensive justifications.

Regarding curriculum development, including activities that simulate real-life problem-solving and argumentation scenarios could be beneficial. Such activities could encourage students to use their own experiences, observations, and the broader information environment, including digital and media sources, thus reflecting the complex nature of justification in everyday argumentation. Moreover, the identification of 'None (No justifications)' instances where participants failed to provide justifications or counterarguments highlights a critical area for intervention, suggesting that students may benefit from explicit instruction in argumentation strategies, including how to engage with opposing viewpoints and express well-founded justifications constructively.

5.2 Discussion and Implications of Research Question 2

In addressing the study's second research question concerning the variation in these ten distinct justification sources throughout the six phases of argumentation, our examination revealed that in terms of the total number of justification source types, the greatest number was observed in 'Group Discussion 1.' This phase marks the first group discussion occurring before the demonstration. On the other hand, the smallest number of justification source types was recorded in 'Phase 4: Revised Justifications,' a phase where students revised and updated their justifications following the demonstration.

Considering the formation of as many heterogeneous discussion groups as possible according to different claims in this study, one of the reasons for the maximum number of justification source types emerging in Phase 2 is that students share their initial justifications, established in ‘Phase 1: Initial Justifications,’ for the first time with other group members. Additionally, the number of counter-justifications aimed at refuting the opposing side’s justifications, in addition to these initial justifications, is higher in the ‘Group Discussion 1’ conducted before the demonstration. This increase is because ‘Group Discussion 1’ is conducted when the correct answer to the question is not yet definitively known, thus contributing to the uncertainty, in contrast to ‘Group Discussion 2’ held after the demonstration. Another reason is that ‘Group Discussion 1’ lacks external factors such as demonstration, the correct answer, or teacher direction to support the participants’ claims and justifications. Therefore, during this phase, justifications for different claims, including all counter-justifications, were intensely debated. This phase witnessed the highest level of conflict among participants and constituted the longest portion of the argumentation process, averaging 25-30 minutes, in contrast to ‘Group Discussion 2’ held after the demonstration. Additionally, this observed peak in the variety of justification sources during ‘Group Discussion 1’ suggests a critical moment in the argumentation process where students are likely exploring a wide range of sources to support their initial justifications. This exploration phase is crucial for developing critical thinking and reasoning skills, as students are not yet influenced by the correct answer to the given counter-intuitive physics question presented during the demonstration. They might rely on their prior knowledge, experience, observations, intuitions, and perhaps speculative reasoning to justify their positions.

One reason for the minimal number of justification source types emerging in ‘Phase 4: Revised Justifications After the Demonstration’ is that participants likely encountered difficulties in generating justifications during this phase, primarily due to the surprise they experienced in demonstration parts. This is also supported by the findings in Chapter 4, which reveal that only 27% of the participants could generate correct claims before Phase 4. Additionally, decreasing the variety of justification sources by ‘Phase 4: Revised Justifications’ could show a more focused approach. After seeing the demonstration, students might use direct observations as their primary justification sources, possibly leaving out other types of justification sources thought to be less relevant or invalid after getting new information. This phase shows thought processes, where the direct observations from the demonstration act as a filter, deciding which justifications are valuable and which should be changed or left out. Moreover, when comparing the instances of ‘no justifications’ across different phases, it is noteworthy that Phase 4 ranks highest, with 8.13%. This may stem from students' general reactions when encountering anomalous data, similar to the cognitive conflict experienced during the demonstration parts of counterintuitive questions in this study. Such reactions include ignoring, rejecting, excluding, and holding these types of data as highlighted in the literature (Chinn & Brewer, 1998; Driver et al., 2000; Lombardi, Nussbaum, & Sinatra, 2016; Sampson & Clark, 2008; Zeidler, 1997).

In summary, this variation in the use of justification sources across the six phases of argumentation emphasizes the dynamic nature of the argumentation process within educational settings, particularly highlighting how justification sources fluctuate across different phases of argumentation. This variation also underscores the complexity of the learning and argumentation process in educational contexts. The initial broad use of justification sources in ‘Phase 2: Group Discussion 1’ reflects the openness of the argumentative discourse and how students are encouraged to engage with diverse perspectives and reasoning strategies. As the argumentation progresses, especially after empirical evidence is demonstrated, in ‘Phase 4: Revised Justifications,’ there is a significant shift towards more focused justifications.

For educators, these results underscore the importance of designing learning activities such as POE that encourage students to explore and use various justification sources in their arguments. This could aid in enhancing students’ abilities to evaluate information and integrate insights from diverse sources critically.

In addition to this, the wide variety of justification sources observed in the 'Group Discussion 1' phase suggests that students are likely to explore a broad range of sources to support their initial justifications. Educators can view this exploratory phase as an opportunity to develop students' critical thinking and adaptability skills.

Furthermore, the highest occurrence of 'no justifications' in Phase 4 reflects students' reactions to encountering unexpected, anomalous data. Educators can guide students through challenging and counter-intuitive problems, teaching them how to effectively respond to and process such data.

These insights suggest that developing strategies to help students manage the use of justification sources in their argumentation processes can lead to more informed and effective guidance. This, in turn, can enhance students' critical evaluation skills, integrate diverse perspectives, and construct more qualified justifications in scientific discussions.

5.3 Discussion and Implications of Research Question 3

In addressing the study's third research question concerning the variation in justification sources across the eight tasks, our analysis revealed the most diverse justification sources used in 'Task 7: Circular Motion.' Moreover, participants frequently used the 'Daily Life Experience' and 'Daily Life Observation' sources to justify their claims, more so than in any other task. Additionally, 'Task 7: Circular Motion' had a high number of participants who started with a correct claim and supported these claims with relevant justifications, ranking it second highest in both of these aspects among the eight tasks examined. In contrast to 'Task 7: Circular Motion', 'Task 1: Weighing' exhibited a markedly different pattern in using justification sources, showing the least diversity among the tasks. This was particularly evident, as it was one of only two tasks where participants initially failed to present a correct claim. Furthermore, 'Task 1: Weighing' was one of three tasks where participants did not produce relevant justifications for a correct claim.

There are several key factors to consider regarding participants' performance in 'Task 7: Circular Motion.' The high diversity of justification source types and the frequent use of 'Daily Life Experience' and 'Daily Life Observation' in Task 7 suggest that participants are more likely to engage deeply with tasks when they can relate them to their personal and observational experiences from daily life. This engagement is reflected not only in the variety of justifications provided but also in the accuracy of their initial claims and the relevance of their following justifications. It implies that the context of circular motion may be inherently more relatable or that the task was presented in a way that made it easier for participants to connect with their daily lives. Participants might have found this task comparatively easier than others when it came to presenting the correct claim and producing relevant justifications. This relative ease might explain why participants used a broader spectrum of justification source types in this task. Additionally, the nature of the question for this task, which included five options, contributed to decreased consensus among the participants. The presence of multiple answer choices likely led to a variety of perspectives in group discussions and, subsequently, a wider range of justification source types being used. These factors collectively suggest that the unique characteristics of 'Task 7: Circular Motion,' including its relative ease, the prevalence of certain justification source types, and the presence of multiple answer options, influenced the participants' choice of justification source types and their overall performance in 'Task 7: Circular Motion.'

On the other hand, 'Task 1: Weighing' presented significant challenges, as evidenced by the low diversity in justification sources and the absence of correct initial claims and relevant justifications. This could suggest that participants found it difficult to relate the concept of weighing to their personal experiences or observations or that the task was not as intuitively relatable as circular motion. Consequently, it is understood that this task was relatively more difficult for participants to present the correct claim and produce relevant justifications compared to other tasks. This increased difficulty likely resulted in participants using a lower range of justification source types when constructing their arguments for this task. The challenge in producing relevant justifications also suggests a gap in the participants' understanding of the concept or their ability to apply abstract scientific principles to tangible tasks. Moreover, the task design, which lacked multiple options for the question and where answers tended to either 'increase' or 'remain unchanged,' led to a high consensus among participants. In such a situation, with slight variation in responses, the level of discussion was relatively low, leading to a limited number of justifications being generated.

In summary, the insights from the analysis highlight the importance of context and relatability in educational tasks. Tasks that participants can easily relate to their daily lives or observations encourage not only a wider range of justification source types but also enhance the quality of engagement, as seen in 'Task 7: Circular Motion.' Conversely, findings related to 'Task 1: Weighing' highlight a significant challenge in applying theoretical knowledge, daily experiences, or observations to this task, suggesting it was a particularly difficult topic for participants to grasp or relate to. This difficulty indicates a unique set of challenges in understanding or engaging with the underlying principles of the 'Weighing' concept. The task's conceptual challenges reveal the complexities of translating abstract scientific ideas into practical understanding and application, underscoring the need for innovative teaching strategies to bridge these gaps.

The findings from 'Task 7: Circular Motion' highlight the importance of designing educational tasks directly related to students' everyday experiences and observations, implying that tasks closely tied to real-world experiences or easily visualized through daily observations may facilitate better learning outcomes.

Educators might consider framing scientific concepts in contexts that students find familiar or engaging, thus increasing the likelihood of students using a wide range of justification sources and making accurate and relevant claims. This analysis confirms the critical role of task design in educational settings, indicating that the relatability of tasks can significantly enhance engagement and comprehension. Therefore, educators and curriculum developers are encouraged to consider how tasks connect with students' experiences and observations, ultimately aiming for a balanced approach that challenges students and remains accessible and meaningful to them.

The varied responses to tasks with and without multiple answer choices indicate that task design can significantly influence the quality and range of student argumentation. Incorporating tasks that present multiple perspectives or solutions may encourage students to explore and justify their reasoning more thoroughly, promoting critical thinking and dialogue.

Furthermore, these implications support a pedagogical approach that not only values the diversity of justification sources but also recognizes the role of task design, context, and relatability in enhancing students' argumentation skills and conceptual understanding. By addressing these aspects, educators can better support students in developing the skills needed for effective argumentation and critical thinking in science education.

5.4 Discussion and Implications of Research Question 4

In addressing the study's fourth research question, which concerns the change in types of justification sources after the group discussion (before the demonstration), our analysis revealed interesting shifts in how participants justify their viewpoints. Notably, the most significant increase occurred in 'daily life experience' sources among all types of justification sources following the first group discussion phase, before any demonstration activities; this increase suggests that ‘Daily Life Experience’ sources seem particularly effective in persuading others to reconsider and change their initial justifications. Conversely, reliance on ‘School-School Multiple’ sources experienced the largest decline in the same period. This decrease suggests that such sources might be less compelling in influencing others' perspectives during first group discussions before demonstration parts. In other words, the ‘School’ sources seem more prone to change.

It is noteworthy that ‘Daily Life Experience’ sources were particularly effective in persuading the opposing side and causing participants to change their justifications, especially when compared to the more formal ‘School’ sources during ‘Phase 2: Group Discussion 1 - Before the Demonstration.’ ‘Daily Life Experience’ sources appear to appeal more with participants, perhaps due to their relatability or the tangible evidence they provide. Moreover, it was observed that some participants lacked a solid understanding of the formal-based knowledge gained from ‘School’ sources used in their justifications. They struggled to integrate this formal knowledge into their own understanding, which left them weak when confronted with information derived from ‘Daily Life Experience’ sources during ‘Phase 2: Group Discussion 1 - Before the Demonstration.’ This move from academic or formally learned sources towards more personal justifications might reflect a preference for practical, real-world evidence over theoretical knowledge or academic learning in group discussions.

In summary, these shifts in using justification sources underscore the dynamic nature of how people construct and reconstruct their arguments when exposed to group discussions and the dynamic interplay between personal experience and formal knowledge in shaping justifications and opinions. They highlight that personal experiences can be more influential in shaping opinions, particularly in collaborative or group settings where individuals are open to changing their views based on the persuasive arguments of their peers. This conclusion calls for a more holistic approach to education that values and integrates a wide range of justification sources, thus enriching the learning process and enhancing the development of critical thinkers.

The effectiveness of 'Daily Life Experience' sources in influencing opinion change highlights the need for educational strategies that highlight personal experience as a valuable learning component. Educators might develop discussions encouraging students to use their own lives, making abstract concepts more concrete and relatable. This approach could facilitate a deeper understanding and retention of information using the persuasive power and relatability of daily life experiences.

The observed decline in the persuasive power of 'School' sources suggests a reassessment of how formal education content is presented. This suggests a need for educational materials that are more relatable and applicable to real-world scenarios. There may be a greater opportunity to blend formal knowledge with personal experiences, making the learning experience more relevant and engaging for students.

Understanding the different influences of justification sources can help educators design interventions that enhance students' persuasion and argumentation skills. Teaching students how to effectively use and integrate 'Daily Life Experience' sources into their arguments could make for more compelling and persuasive communicators.

This shift towards personal justification in group discussions indicates a broader preference for practical, real-world evidence. Educators should consider this when designing learning activities, ensuring they align with students' natural inclinations and interests, thus creating a more engaging learning environment.

These findings highlight a significant move towards combining personal experiences with formal educational materials, pointing out the need for pedagogical strategies that make learning more engaging, relevant, and skilled at encouraging critical thinking and argumentation abilities. By valuing and mixing various sources of knowledge, especially those from students' everyday experiences, educators can improve students' ability to analyze, discuss, and effectively justify their viewpoints.

5.4.1 Discussion and Implications of Research Question 4.1

In addressing the first sub-question of the fourth research question, which examines the changes in types of justification sources after group discussions (before the demonstration) across tasks, our analysis revealed variation on the effectiveness of justification sources in convincing others. This variability was noted across eight tasks, with notable increases and decreases attributed to two distinct sources of justifications: 'Daily Life Experience' and 'School-School Multiple.' 'Daily Life Experience' sources led to an increased usage rate across all eight tasks, specifically in 'Task 1: Weighing,' 'Task 5: Pulley XY,' 'Task 6: Inclined Plane 2,' and 'Task 7: Circular Motion.' These increases suggest that justifications based on 'Daily Life Experience' may be more effective in convincing others during 'Phase 2: Group Discussion 1 - Before the Demonstration.' Conversely, 'School-School Multiple' sources led to a decreased usage rate across all eight tasks, specifically in 'Task 6: Inclined Plane 2' and 'Task 8: Atwood Machine.' This trend indicates that justifications based on 'School-School Multiple' sources may be more susceptible to change during Phase 2, implying a lower effectiveness in convincing others compared to 'Daily Life Experiences.' Therefore, the effectiveness of a justification source type to convince others or its susceptibility to change during Phase 2 differs depending on the specific task.

The analysis distinctly highlights the variability in the effectiveness of 'Daily Life Experience' as a justification source in convincing others across different tasks. It is notably effective in tasks such as 'Task 1: Weighing,' 'Task 6: Inclined Plane 2,' and 'Task 7: Circular Motion,' where the nature of these tasks aligns closely with everyday experiences. This alignment allows participants to easily draw upon their personal experiences for justifications, making ‘Daily Life Experience’ a powerful source to convince others in scenarios where the task's context is familiar or relatable to participants' daily lives. It also highlights the value of personal and observable experiences in forming convincing arguments when the task at hand mirrors these real-life scenarios. Conversely, the variance in the effectiveness of ‘Daily Life Experience’ across different tasks, particularly its surprising inefficacy in ‘Task 2: Inclined Plane 1’ and its unexpected efficacy in ‘Task 5: Pulley XY,’ points to a critical understanding of how participants engage with tasks and use their experiential knowledge. Since, despite its apparent relation to real-life scenarios in ‘Task 2: Inclined Plane 1,’ ‘Daily Life Experience’ does not emerge as the most effective justification source for convincing others. Instead, ‘Experience-School Multiple’ sources take the lead in this instance. This result suggests that the effectiveness of justification sources can be task-specific and may not always align with expectations based on the task's nature. Interestingly, ‘Daily Life Experience’ is an effective justification source for convincing others in ‘Task 5: Pulley XY,’ a task not immediately associated with daily life scenarios. This exception highlights the complexity of how different tasks interact with justification sources, indicating that the straightforward applicability of ‘Daily Life Experience’ in forming justifications may be influenced by factors beyond the surface-level characteristics of the tasks, such as participants’ perceptions of relevance or their creative engagement with the task. Furthermore, ‘Daily Life Experience’ is not universally an effective justification source, as evidenced by tasks like ‘Task 3: Pulley KLM,’ ‘Task 4: Dynamometer,’ and ‘Task 8: Atwood Machine.’ These tasks do not inherently align with the direct application of everyday experiences, demonstrating that there is not a natural fit between these tasks’ requirements and the types of justifications that participants can readily generate from their daily lives.

The analysis also shows the observed trend in the decreased usage of ‘School-School Multiple’ sources across various tasks, particularly in ‘Task 6: Inclined Plane 2’ and ‘Task 8: Atwood Machine,’ highlighting significant insights into the dynamics of group discussions before demonstrations. This pattern suggests that justifications based on academic or multiple school-related sources might not hold as much persuasive power, or they may be more prone to reconsideration or change when shared in group discussions. The contrast with 'Daily Life Experience' sources, which have seen increased usage and effectiveness, highlights a crucial aspect of persuasive communication within argumentative contexts: the sources significantly influence the persuasive efficacy of justifications. Also, the fact that 'School-School Multiple' sources work better in tasks where 'Daily Life Experience' does not fit so well shows that participants smartly use more formal, educational content in situations where daily life does not directly help. This ability to adapt approaches shows how crucial it is to consider the situation, the type, and the nature of the task when choosing the best way to convince others.

Overall, the study's findings demonstrate that the alignment between the characteristics and nature of specific tasks and the nature of available justification sources critically influences the effectiveness of those sources in persuading others. For example, 'Task 1: Weighing' saw a significant increase in the use of 'Daily Life Experience' following Phase 2. This increase underscores the greater effectiveness of 'Daily Life Experience' over other types of justification sources on a task-by-task basis, largely due to the nature of 'Task 1: Weighing,' where participants can readily apply their everyday life experiences in forming justifications. However, when considering all eight tasks implemented in the study, it is evident that four tasks ('Task 1: Weighing,' 'Task 2: Inclined Plane 1,' 'Task 6: Inclined Plane 2,' and 'Task 7: Circular Motion') naturally favor justifications based on daily life experiences, as these tasks are easily relatable to or observable in daily life. The remaining four tasks ('Task 3: Pulley KLM,' 'Task 4: Dynamometer,' 'Task 5: Pulley XY,' and 'Task 8: Atwood Machine') are less favorable to such justifications. Thus, this distinction highlights that when faced with a task that can be easily experienced or observed in daily life, the justifications predominantly include 'Daily Life Experience' and 'Daily Life Observation' sources. Specifically, in tasks like 'Task 1: Weighing,' ‘Task 2: Inclined Plane 1,’ ‘Task 6: Inclined Plane 2,’ and ‘Task 7: Circular Motion,’ which inherently possess this characteristic, daily life sources are used to a greater extent compared to other types of justification. Interestingly, the task most influenced by ‘Daily Life Experience’ is not ‘Task 1: Weighing’ but ‘Task 7: Circular Motion.’ However, when assessing the impact of ‘Daily Life Experience’ sources in convincing others, ‘Task 1: Weighing’ emerges as the most effective.

In conclusion, this study of how different types of justification sources change during group discussions before demonstrations shows a complicated relationship between the kind of tasks and how well different sources can convince others. To summarize, evaluating the data not only from tasks that inherently enable participants to form justifications using everyday life experiences but also from all tasks collectively, it is observed that ‘Daily Life Experience’ sources maintain a significant level of their effectiveness in convincing others during Phase 2 despite the varied effectiveness across tasks. This shows the close relationship between the task’s nature and the applicability of daily life experiences in forming persuasive justifications, and it is particularly important when considering the educational goal of promoting critical thinking and the ability to argue effectively. This relationship also highlights the critical importance of aligning educational tasks with learners’ real-world experiences to enhance the persuasiveness of justifications and, by extension, the learning process. These findings suggest that students might find ‘Daily Life Experience’ more relatable or easier to explain convincingly during group discussions, perhaps because these experiences are perceived as more real or directly observable. On the other hand, ‘School-School Multiple’ sources, despite their thorough academic nature, might not connect as effectively with peers in discussions aimed at persuasion, possibly due to their perceived abstractness or the complexity of integrating multiple academic perspectives. This conclusion also emphasizes the need to adjust justification sources to the particular task context to maximize the persuasive effect during educational group discussions.

Recognizing that the persuasiveness of justification sources can be task-specific highlights the need for educators to adapt learning activities based on the unique aspects of each task. This might involve pre-discussion activities that help students connect their personal experiences with the task at hand or post-discussion reflections on how different sources of justification affected the outcome.

The findings also indicate a need for teaching students adaptive argumentation strategies that allow them to select the most effective justification sources based on the task context. This includes guiding students on when to use personal experiences versus when to rely on formal knowledge, enhancing their ability to construct persuasive arguments across a variety of scenarios.

The study reveals the nature of persuasion within educational settings, suggesting that the persuasiveness of justifications is influenced not only by the source but also by the task's alignment with the students' lived experiences. This highlights the need for strategies that value the authenticity and relevance of argument sources. These strategies underscore the dynamic interplay between task design, justification sources, and the effectiveness of persuasion, offering a comprehensive approach to enhancing argumentation in education.

5.4.2 Discussion and Implications of Research Question 4.2

In addressing the second sub-question, which examines the changes in types of justification sources after group discussions (before the demonstration) in terms of their scientific relevance, a notable pattern emerging from the findings is the significant role played by both ‘Relevant Daily Life Experience’ and ‘Irrelevant Daily Life Experience’ as sources of justification. These justifications’ source types proved more effective in persuading the opposing side and influencing participants to reconsider and change their original justifications. This effectiveness was consistently observed across all eight tasks, indicating a broad applicability of daily life experiences in fostering persuasive argumentation. This suggests that experiences from daily life, whether directly relevant to the task or not, possess a unique persuasive power in discussions, potentially due to their relatability and the personal connection individuals have with their own experiences. However, the analysis also points to a differentiation in the susceptibility of relevant versus irrelevant justification sources to change. Specifically, the 'Relevant School' source was found to be more prone to change than other relevant sources. This indicates certain openness among participants to re-evaluate and adjust their justifications derived from formal educational contexts when faced with persuasive arguments from their peers. This flexibility was particularly evident in the group discussion phase before the demonstration, suggesting a critical engagement with formally based knowledge acquired from school during discussions. On the other hand, within the category of irrelevant justification sources, the 'Irrelevant School-School Multiple' source was more likely to change. This aligns with the overall pattern and shows the complex nature of how school-based justifications, even when they are irrelevant, are critically discussed among participants in a group setting. It also highlights that participants might have been at a disadvantage against justifications derived from daily life experiences because they could not entirely own or transform the formally based knowledge acquired from school into their own knowledge, regardless of whether it was relevant or irrelevant.

In summary, the effectiveness of a justification source in convincing others, or its susceptibility to change, does not necessarily vary based on its relevance or irrelevance. Instead, the critical factors appear to be the personal and relatable nature of the justification sources, especially those derived from daily life experiences, whether relevant or irrelevant to the task at hand. Moreover, the observed openness to reconsidering justifications related to school sources, both relevant and irrelevant, highlights the importance of critical reflection and the re-evaluation of learned knowledge in the face of peer discussions. These findings emphasize the dynamic interplay between personal experience and formal knowledge in shaping persuasive arguments and the evolution of justification sources in collaborative learning environments.

The influence of both relevant and irrelevant daily life experiences on persuasive argumentation underscores the importance of integrating personal experiences into the teaching of scientific concepts. Educators should encourage students to use their daily lives as a bridge to understand and engage with scientific ideas, thus making science more accessible and relatable.

The findings that school-based justifications are open to change highlight the need for educational strategies that promote critical thinking and reflection on formal knowledge. Educators can facilitate activities that challenge students to critically assess and integrate their school-learned knowledge with personal experiences in argumentation, encouraging a deeper understanding and ownership of scientific concepts.

5.5 Discussion and Implications of Research Question 5

In addressing the fifth research question, which concerns the change in types of justification sources after the group discussion (after the demonstration), our analysis revealed a preference for the perceived credibility and persuasiveness of different sources of justification among participants. The analysis of changes in justification sources shows a notable trend toward the increased effectiveness of ‘Daily Life Experience’ sources among all types of justification sources. This increase suggests that ‘Daily Life Experience’ sources seem particularly effective in persuading others to reconsider and change their justifications. In contrast, reliance on ‘School’ sources experienced the largest decline in the same period. This decrease suggests that such sources might be less compelling in influencing others’ perspectives during second group discussions after demonstration parts. In other words, the ‘School’ sources seem more prone to change.

The observed increase in ‘Daily Life Experience’ sources underscores the influential role that personal and tangible experiences play in shaping opinions and convincing others. The increased reliance on these justification sources suggests that participants might find personal experiences and anecdotes more relatable and convincing after engaging in Group Discussion 2 following the demonstration. This could be due to the personalized nature of such justification sources, which likely connect more deeply emotionally, thus enhancing their persuasive power. Interestingly, this trend was not only observed after the demonstrations parts (during ‘Phase 5: Group Discussion 2 - After the Demonstration’) but was also evident in earlier group discussions (during Phase 2: Group Discussion 1 - Before the Demonstration’), indicating a consistent preference for ‘Daily Life Experience’ sources over more formal, school-based sources throughout the argumentation process. The fact that ‘Daily Life Experience’ sources continue to exist as persuasive sources, despite the initial shock and cognitive conflict participants experienced after seeing the correct answers in the demonstration parts, along with the difficulties they faced in producing justifications, is particularly noteworthy. Participants tended to shift predominantly towards using ‘Implicit’ sources in their new justifications after the demonstration, suggesting a struggle to express explicit reasoning based on the newly presented information. However, ‘Daily Life Experience’ sources remained the most effective means of persuasion.

The observed decrease in the use of ‘School’ sources during ‘Group Discussion 2’ indicates a decline in the influence of formal education and structured knowledge, highlighting the powerful impact of immediate and practical experiences shared among peers. This trend suggests that formal education and theoretical knowledge are less effective within group discussions compared to the practical, tangible experiences individuals bring from their daily lives. This shift challenges using formal educational content to convince others in informal, discussion-based settings, where personal stories and experiences are more influential. Furthermore, the end of the process reveals an interesting paradox regarding the participants' relationship with formal education. While maintaining the formal information obtained from their school life, they appear to struggle to internalize or transform this knowledge. This inability to own or adapt their formal education powerfully against other justification sources, especially daily life experiences, points to a deeper issue within the learning process. Participants showed a marked difficulty in integrating formal-based knowledge into their understanding, which made them vulnerable in discussions where personal experiences were valued more highly.

In summary, the findings from this analysis provide valuable insights into the preferences regarding justification sources in group discussions, especially following demonstration activities. The notable preference for daily life experience-based justifications over school-based justifications reflects a broader trend in the persuasive process. This pattern, especially observed in 'Daily Life Experience,' highlights that participants prefer relying on their own experiences and stories from daily life as a means to convince others, even when confronted with factual or demonstrable evidence that challenges their preconceptions. This reliance on personal experiences over formal educational content suggests a fundamental aspect of human psychology: People find stories and personal experiences more compelling and easier to relate to than abstract principles or theoretical knowledge. On the other hand, the vulnerability participants experienced in using 'School' sources is particularly evident during 'Phase 5: Group Discussion 2 - After the Demonstration,' where participants who relied heavily on formal justifications found themselves at a disadvantage. The struggle to integrate and apply formal knowledge meaningfully suggests a gap between acquiring formal education and its practical application in real-world scenarios. It underscores the need for educational strategies that teach formal knowledge and emphasize developing skills necessary to adapt and apply this knowledge in diverse contexts. These conclusions emphasize the importance of considering the source and nature of justifications when facilitating group discussions or educational interventions to change viewpoints or enhance critical thinking skills.

Despite introducing new, potentially conflicting information during the demonstrations, the increased reliance on ‘Daily Life Experience’ sources for changing opinions and the decreased use of ‘School’ sources underscore a pedagogical shift towards prioritizing practical experiences in the learning process. By valuing practical knowledge as equally important as academic learning, educators can foster a more balanced and enriched educational experience and better prepare students for real-life argumentation and decision-making. This calls for innovative teaching methods that blend formal knowledge with personal experiences, enhancing their relevance and applicability in discussions. This ensures that students can confidently blend their learned school knowledge with personal anecdotes. These innovative teaching methods are necessary because the findings also indicate a gap between formal education and its application in persuasive contexts, suggesting the need to bridge this gap.

Furthermore, given the effectiveness of personal experiences in persuasion, there is a clear need to develop students’ persuasive communication skills that incorporates personal stories. This includes teaching students how to tell their experiences effectively and blend these stories with formal education to make their arguments more convincing.

5.5.1 Discussion and Implications of Research Question 5.1

In addressing the first sub-question of the fifth research question, which examines the changes in types of justification sources after group discussions (after the demonstration) across tasks, our analysis revealed some variations in the effectiveness of justifications convincing others and susceptibility to change. ‘Daily Life Experience’ sources had an increased usage rate across all eight tasks, particularly in ‘Task 1: Weighing,’ ‘Task 2: Inclined Plane 1,’ and ‘Task 7: Circular Motion.’ These increases suggest that ‘Daily Life Experience’ sources might be more persuasive during ‘Group Discussion 2.’ Conversely, ‘School’ sources had a decreased usage rate across all eight tasks, particularly in ‘Task 5: Pulley XY’ and ‘Task 6: Inclined Plane 2.’ These decreases suggest that ‘School’ sources may be more susceptible to change during ‘Group Discussion 2,’ highlighting that they are less effective in convincing others than ‘Daily Life Experiences.’ Therefore, the capability of a specific type of justification source to influence others or its potential for change during ‘Phase 5: Group Discussion 2 - After the Demonstration’ varies based on the task at hand.

The analysis shows that ‘Daily Life Experience’ varies in convincing effectiveness across tasks, standing out in ‘Task 1: Weighing,’ ‘Task 2: Inclined Plane 1,’ and ‘Task 7: Circular Motion.’ These tasks connect with everyday experiences, making it easier for participants to use personal experiences in justifications. This suggests that ‘Daily Life Experience’ is a particularly effective source in contexts familiar to the participants’ daily lives, underscoring the importance of personal and observable experiences in producing persuasive arguments in real-life-like scenarios. Moreover, Daily Life Experience’ does not always serve as an effective justification source, as seen in tasks such as ‘Task 3: Pulley KLM,’ ‘Task 4: Dynamometer,’ ‘Task 5: Pulley XY,’ and ‘Task 8: Atwood Machine.’ These tasks lack a direct connection to everyday experiences, showing a mismatch between the tasks’ demands and the justification sources participants can easily derive from their daily lives. Surprisingly, even in tasks like ‘Task 6: Inclined Plane 2,’ which seems closely related to real-life situations, ‘Daily Life Experience’ is not the most effective source for convincing others. The analysis also shows a trend of decreased reliance on ‘School’ sources in all tasks, especially in ‘Task 5: Pulley XY’ and ‘Task 6: Inclined Plane 2.’ This indicates that school-based justifications may lack persuasive strength or be more susceptible to change during group discussions. These results suggest that the impact of justification sources is task-specific and might not always meet the expectations suggested by the task’s nature.

In conclusion, our study reveals an interaction between task types and the effectiveness of various justification sources in group discussions post-demonstrations. ‘Daily Life Experience’ sources generally maintain their persuasive power during ‘Phase 5: Group Discussion 2 - After the Demonstration,’ despite varying levels of effectiveness. Highlighting the crucial relationship between task context and justification sources is essential for enhancing persuasion in educational group discussions and fostering critical thinking and argumentation skills.

The observation that the persuasiveness of justification sources remains task-specific even after demonstrations reconfirms the importance for educators to customize learning activities to match the specific characteristics of each task. This consistency in task-specific effectiveness, both before and after demonstrations, underscores the necessity of adjusting instructional strategies to address the varied contexts and challenges of different tasks. By adjusting teaching methods to meet the specific needs of each learning situation, educators can better improve students’ critical thinking, argumentation skills, and use of different justification sources effectively in various contexts.

The findings support teaching strategies that encourage students to evaluate various sources for their justifications. By understanding the strengths and limitations of different types of sources, students can become more skilled at selecting the most appropriate sources for their arguments depending on the task context.

5.5.2 Discussion and Implications of Research Question 5.2

In addressing the second sub-question, which examines the changes in types of justification sources after group discussions (after the demonstration) in terms of their scientific relevance, our analysis revealed a notable pattern. Specifically, both ‘Relevant Implicit’ and ‘Irrelevant Implicit’ sources emerged as having significant effectiveness in convincing others and encouraging participants to reconsider and change their justifications during ‘Group Discussion 2.’ This effectiveness was consistently observed across all eight tasks. However, the analysis highlights a distinction in the responsiveness of relevant versus irrelevant justification sources to change. Notably, in line with the general trend observed across the eight tasks, the ‘Relevant School’ source exhibited greater susceptibility to change than other relevant sources. This suggests willingness among participants to reconsider and modify justifications based on formal educational sources when confronted with persuasive arguments from peers. Interestingly, this trend was not only observed after the demonstrations parts (during ‘Phase 5: Group Discussion 2 - After the Demonstration’) but was also evident in earlier group discussions (during Phase 2: Group Discussion 1 - Before the Demonstration’), indicating a consistent willingness for ‘‘Relevant School’ sources to be reconsidered and changed throughout the argumentation process. Conversely, among irrelevant justification sources and contrary to the overall pattern seen across the eight tasks, the ‘Irrelevant Experiment-Demo (School)’ category exhibited a higher potential for change. This suggests that participants may struggle to fully assimilate or adapt formally acquired school knowledge into their own understanding, regardless of its relevance. In summary, a justification source’s effectiveness or susceptibility to change does not necessarily depend on its relevance or irrelevance. Moreover, the willingness to reconsider both relevant and irrelevant school-based justifications highlights the importance of re-evaluating knowledge learned in school during peer discussions.

The distinct behavior of the ‘Irrelevant Experiment-Demo (School)’ category highlights the complexity of justification source evaluation in collaborative learning environments. It calls for further research into how educational content is internalized and utilized in reasoning processes. These findings suggest the need for educators to encourage students to critically reassess and question the knowledge they acquire in school. This involves creating a learning environment where questioning and debating formally taught concepts based on new evidence or perspectives is accepted and encouraged.

Given the significant impact of demonstrations on the persuasiveness of both relevant and irrelevant justification sources, integrating demonstrations with discussions can be a powerful strategy. These discussions should help students explain why some sources appealed to them and how they changed their views on different topics.

Consequently, this study points to the need for science education to align more closely with students' lived experiences. The consistent effectiveness of 'Daily Life Experience' sources throughout different phases of the study, despite the complexity of the tasks and the introduction of new, potentially conflicting information during demonstration parts, emphasizes the need for science educators and facilitators to consider the power of personal and experiential learning. It suggests that integrating personal experiences with formal educational approaches could enhance the persuasiveness of justifications and support deeper learning outcomes. This insight is particularly relevant for designing educational interventions, group discussions, and persuasive communication strategies that aim to foster critical thinking in science. By doing so, science becomes an academic subject and a meaningful part of students' daily lives, enhancing their ability to relate to and understand scientific concepts.

This study also contributes to our understanding of persuasion dynamics in group settings and underscores the evolving nature of credibility and persuasiveness in justification sources. As we continue to explore the complexities of learning and persuasion, integrating insights from such research can significantly enhance educational practices and the effectiveness of group discussions in various contexts.

5.6 General Conclusion from Research Question 4 and 5

In summary, this study concludes that 'Justifications based on Daily Life Experience,' which stem from participants' personal experiences in daily life in response to given questions, are notably more effective in changing the justifications of other participants during the argumentation processes. In contrast, 'Justifications

Based on School,' which are derived from school contexts (such as teachers, textbooks, class experiments/demonstrations, and school life), show a greater tendency to be influenced and changed by the justifications of other participants throughout the argumentation process. This distinction highlights the significant impact of personal experience in persuasive argumentation and the higher susceptibility of educational-based justifications to be influenced within discourse.

This study's conclusion that justifications based on 'Daily Life Experience' are significantly more effective in changing other participants' justifications aligns with findings from the literature, highlighting the significant role of personal experience in shaping opinions and arguments. For instance, Bråten et al. (2016) observed a noticeable trend where participants relied more on their personal experiences and beliefs than other sources, especially in making decisions on controversial health-related topics. This tendency to prioritize personal experience and opinions over other types of sources highlights the fundamental importance individuals attach to their lived experiences when forming judgments. Similarly, McNeill and Pimentel (2010) found that when teachers allowed various source types in classroom discussions, students more frequently used their daily experiences and external sources such as media reports and anecdotes from others. This suggests that an educational environment that values a variety of justification sources can encourage students to integrate their personal experiences into their argumentation. Sandoval and Çam (2011) further support these findings by demonstrating that children generally rank sources of justifications in a loose order, with a preference for data and plausible mechanisms (personal experience) over authority. This preference for personal experience, especially when it provides a plausible mechanism supporting a claim, indicates a fundamental criterion for credibility in justifications among younger participants. Moreover, Salmerón et al. (2016) identified a trend where primary students favored personal experience. Lastly, Kolstø's (2006) observation that no participants considered the scientific knowledge from school textbooks essential for their arguments and that students did not use this type of sources further highlights the limited influence of formal educational sources compared to personal experience and anecdotal sources.

On the other hand, there are several findings that appear to diverge from the general trend observed in our study. For example, Bråten et al. (2013) discovered that students placed significantly more trust in what they perceived as authoritative sources, like textbooks, teachers, and scientists, over personal opinions. However, they also stated that when it comes to the relatively lower value assigned to personal justifications, it is noted that students may still see personal opinions and experiences as relevant and valuable when evaluating various ideas and perspectives in literature. Similarly, Knight (2015) found that students exhibited a strong preference for justifications rooted in empirical data over those based on authority statements or personal experiences. She acknowledges the overall preference for empirical data among students but also notes that some students selected justifications based on authority opinions and their own prior experiences. This variation underscores students' awareness of multiple sources. She encountered challenges in determining a clear hierarchy between authority statements and personal experiences due to diverse student responses. She concludes that while empirical evidence is predominantly favored among middle school students, they also value and, at times, use other sources like authority statements or personal experiences. These alternative sources of justification, though less favored, are not deemed inherently unsuitable for scientific arguments.

In summary, these studies collectively emphasize the significant impact of personal experience in persuasive argumentation and its higher effectiveness in influencing discourse, mirroring the primary findings of this research. The preference for personal experience over educational sources, as noted across different age groups and educational contexts, aligns with the conclusion that justifications based on 'Daily Life Experience' are more effective and influential in argumentation processes.

The effectiveness of justifications based on 'Daily Life Experience,' which are grounded in individuals' personal experiences, in persuading others and changing their justifications during the argumentation process, continues to be a topic of discussion in the literature. Piaget's constructivist theory provides a theoretical foundation for understanding the process by which students engage in argumentation and construct knowledge individually by linking current evidence with personal experiences within their own minds (Piaget, 1954, as cited in Li, Li, & Wang, 2021). However, "little is known about the intricate process and potential negotiation patterns between students during scientific argumentation" (Governor, Lombardi, & Duffield, 2021, p. 1389). As previously mentioned, argumentation involves formulating, backing, questioning, and enhancing ideas. This distinctive feature of scientific argumentation, as opposed to other types of argumentation, lies in the standards individuals use to assess the validity or acceptability of arguments (Grooms, Sampson, & Enderle, 2018).

Several reasons can be listed for why justifications based on 'Daily Life Experience' have become so prominent in convincing other participants during the argumentation process.

One of these reasons could be the significant interplay between students' personal experiences and scientific discourse in the classroom, as well as the consideration and use of personal experience as an appropriate, productive, trustworthy, sensible, high-quality, and valuable source of justification in the science classroom.

As stated by Aguiar (2016), science classroom dialogues are recognized as a unique form of discourse that integrates students' everyday knowledge with the academic realm of scientific knowledge. This integration suggests that effective classroom discourse should not only engage students in the disciplinary practices of science but also respect and incorporate their everyday experiences and ways of thinking, as McNeill and Pimentel (2010) argued. They emphasize the importance of engaging students in argumentation implementations that promote the social construction of knowledge, where claims are supported by relevant evidence and reasoning, utilizing students' personal experiences. Furthermore, McNeill and Berland (2017) highlight the significant impact of students' personal experiences on improving classroom teaching methods, noting that incorporating personal and social aspects related to the curriculum greatly enhances student participation and empowerment. Similarly, Cheuk (2016) underscores the social nature of argumentation in science, pointing out that students' historical backgrounds and personal experiences are integral to their participation and motivation in scientific argumentation, suggesting that students' real-life experiences serve as a powerful motivator in their engagement with science.

In scientific discussions, research indicates a prevalent use of daily life personal experiences and informal criteria among students during the process of scientific argumentation instead of evidence-based arguments. Several studies highlight a tendency and observe a similar pattern among students to support or challenge ideas in their scientific debates through personal experiences, beliefs, and attacks, as well as by referencing stories derived from prior experiences rather than arguing from evidence (Knight, 2015; McNeill & Pimentel, 2010; Sampson, Enderle, & Grooms, 2013; Tang, Levin, Chumbley, & Elby, 2022). Further, Marttunen and Laurinen (2007) found that students often use their broader knowledge of the world, acquired outside the educational setting, in both collaborative and individual tasks. Skoumios (2013) points out the discrepancy between the criteria students use to evaluate scientific ideas and those established by the scientific community. This reliance on informal reasoning, according to Sampson and Clark (2011), favors consistency with personal experiences over empirical evidence in assessing scientific concepts. Salmerón et al. (2016) and McNeill and Berland (2017) further support this by noting the role of personal experiences as a frequent source of information in students' inquiries and suggesting that everyday observations can be repurposed as scientific evidence to facilitate understanding of the natural world.

Personal experience and stories are recognized as appropriate (Tang et al., 2022) and trustworthy sources for students to support their claims and enhance their understanding of scientific phenomena (Cheuk, 2016; Chin & Osborne, 2010; Knight, 2015; McNeill & Pimentel, 2010) in science classrooms. Personal experience also provides 'make sense' and 'highest quality' reasons, valued for their alignment with generally accepted beliefs or personal experiences (Salmerón et al., 2016; Schwarz et al., 2003). Furthermore, these experiences are considered valuable sources, as both students and adult users appreciate the firsthand experiences and engagement they contribute to the community (Salmerón et al., 2016). Additionally, Knight (2015) highlights the concept of 'productive resources,' emphasizing that context-specific knowledge leads students to apply their cognitive resources in scenarios they perceive as relevant. Specifically, when a type of knowledge has been activated and proven useful in a past experience, it is then seen as 'productive' and is likely to be used in similar situations in the future. This is evident in how students often argue in everyday life, using personal experiences as justifications. This familiarity with using personal experience in arguments is then extended to their approach in scientific discussions, reflecting their recognition of its 'productiveness' in previous instances.

Another reason why justifications based on 'Daily Life Experience' are effective in convincing others during argumentation could be that first-hand experience is inherently believable and reliable. Sarangapani (2003) stated, "The feeling of certainty that accompanies what one has seen 'with one's own eyes' often makes the usual epistemic requirements of evidence and skepticism irrelevant. It is in this sense that personal experience places one in a 'privileged epistemic position (p 201)." Sarangapani (2003) highlights how personal experience serves as a powerful source, pointing out that children, even though they might be initially reluctant, understand and value the certainty, reliability, and authenticity of what they see. This first-hand involvement with events allows them to share and validate their experiences without the need for additional evidence or doubt, giving them a special advantage in understanding and explaining their personal experiences. Sarangapani (2003) points out how personal experience can make someone's arguments stronger, especially when talking to others. When individuals are asked to prove something is true, their enthusiastic response, “It's true, I have seen! (p. 201)” shows how much their own experiences mean to them and how important these experiences can be in a discussion. Their excitement comes not just from proving their point but also from getting the chance sharing their stories with others, making these stories accepted more widely. As Sarangapani (2003) shows through the participants’ responses, the ability to say, “This I can't say. We had fields, so I know about that (p. 201),” highlights the real impact and persuasive power of first-hand experience. This kind of statement shows how confidently people can talk about their own experiences and how these experiences can influence conversations, helping to connect personal views with what everyone can understand. Russ and Odden (2017) take this discussion into the field of physics, comparing the credibility given to daily life anecdotes against that of data from controlled experiments. They point out a possible difference in how students view the trustworthiness of these two types of evidence, suggesting that the authenticity and repetitive nature of everyday experiences might give them a sense of certainty, reality, and reliability that formal scientific evidence may lack. Chinn, Buckland, and Samarapungavan (2011) explore the psychology behind this discussion, talking about what they call tacit epistemic beliefs or commitments. These are beliefs or ways of acting that are not directly stated but can be understood from how people often use their own experiences to support what they know. This behavior highlights a basic human instinct to trust and value our own experiences as a primary source of knowledge.

In summary, this discussion may give some insight into why personal experience is effective in convincing others. The natural trustworthiness of personal experience and its ability to be seen as valid source without external proof allow people to share their views confidently. The enthusiasm and acceptance gained from discussing personal experiences in social settings not only make these experiences seem like reliable sources but also show how naturally people tend to believe in what they have seen and experienced themselves or others. This combination of insights from education, psychology, and science philosophy provides a comprehensive view of personal experience's important role in sharing and creating knowledge. The concept that "seeing is believing," highlighted by Murray (2011, p. 124), emphasizes the reliability and inherent trustworthiness of first-hand experiences. Alongside this, the credibility of sources providing testimony and the reasons behind trusting various sources of knowledge have been subjects of curiosity and exploration (Bricker & Bell, 2008; Chinn et al., 2011).

The third reason why justifications based on 'Daily Life Experience' are so effective in convincing others during arguments could be related to the level of familiarity or unfamiliarity with the topic, context, and issue at hand. Research indicates that people's preferences for using personal experiences over external sources in discussions vary significantly with the topic's familiarity (Salmerón et al., 2016). This is further supported by findings suggesting that people are more open to ideas supported by daily life observations and experiences when unfamiliar with the subject matter. This lack of knowledge makes them hesitant to strongly support or oppose specific viewpoints because they are unsure about the main issues of content (Grooms et al., 2018). Moreover, when individuals encounter unfamiliar content, they tend to draw from their prior experiences, even in scientific argumentation, suggesting a potential for learning and adopting new criteria for supporting claims (Grooms et al., 2018). This idea is also seen when students who have no prior scientific engagement with a topic like 'light' in science use their own everyday experiences when asked. This shows that personal stories can change how we see and understand things (Mason, Gava, & Boldrin, 2008). Furthermore, the impact of personal experience is notable in discussions about complex social and science topics. How much people are familiar with these topics greatly affects how they think and the variety of justifications they provide (Bilican, 2018).

In summary, when someone shares their personal experiences, it helps listeners gain more background knowledge and approach the subject from a new perspective. This process is particularly beneficial for students who unfamiliar with the subject or lack prior knowledge, as it helps them understand the topic and makes them more inclined to accept arguments supported by observational insights. Because, when individuals lack prior knowledge or are unfamiliar with a subject, they are more inclined to accept ideas supported by observational insights. Conversely, familiarity with a topic encourages a greater reliance on personal experiences and opinions. This demonstrates the power of personal experiences and observations in significantly impacting the learning process. Since listeners tend to be more open to the views of individuals with similar experiences, using personal experience and observations to convey a message enhances its impact and strengthens persuasion. Essentially, personal and observational insights serve as accessible and relatable bridges that connect speakers and listeners, making the unfamiliar familiar and, thus, more convincing. In other words, familiarity with the topic significantly influences the effectiveness of using 'Daily Life Experience' in justifications.

5.7 Suggestions for the Further Researches

Building on the insights gained from our investigation into the nature and changes in sources of justification during the argumentation process, it becomes clear that argumentation is a complex interplay of cognitive, social, and epistemic elements. While our study provides a detailed view of how these sources of justification change during argumentation, several areas remain that require further exploration. The following recommendations aim to identify these areas, offering directions for future studies to provide a more thorough understanding of the complexities involved in justification and argumentation.

By focusing on the specific aspects that make personal experiences effective sources of justification compared to formal educational content, future studies could investigate how types of justification sources emerge and change in argumentation across diverse educational contexts. This exploration could extend to different cases. Firstly, the study participants were first-year undergraduate students with below-average achievement levels, as indicated by their responses to counter-intuitive physics problems. Exploring how the nature and change of justification sources differ with more advanced participants would be interesting. Secondly, most of the counter-intuitive physics problems selected for this study were related to everyday situations, allowing students to connect the problems to their daily lives. It would also provide interesting results to explore how the nature of justification sources changes when the problems are far removed from everyday contexts, such as those in quantum physics. Thirdly, examining the impact of instructional strategies beyond the Predict-Observe-Explain (POE) method could reveal how alternative pedagogical approaches influence the use and effectiveness of justification sources in argumentation. This could lead to engaging findings on the adaptability of students' argumentation skills across various teaching methodologies. Fourthly, considering question types other than counter-intuitive questions might offer insights into how different forms of inquiry affect the development and application of justification sources. Investigating how students justify their arguments in response to a broader range of questions could uncover comprehensive understandings of argumentation dynamics in educational settings.

Exploring 'Illusive Experiences' and 'Illusive Observations' offers an interesting path for future research in argumentation. These should be studied more systematically and separately from argumentation literature to better understand their unique role in reasoning and justification processes. These phenomena, where non-experiential elements are mistaken for real experiences, demand a more detailed investigation due to their potential influence on how individuals construct arguments and justify their claims. Future research should adopt a general framework for this exploration such as thought experiments and imaginary reasoning, to examine the nuances of how ‘Illusive Experiences’ and ‘Illusive Observations’ influence how people argue and justify their points.

The growing utilization of the internet and social media among younger generations is a prevailing trend, compounded by the emergence of new platforms such as TikTok. Consequently, the experiences encountered through these digital mediums may have a more pronounced influence than tangible, real-world experiences. Moreover, the emergence of the COVID-19 pandemic catalyzed a notable shift towards online educational resources, replacing traditional hands-on experiments with computer simulations. In light of these evolving dynamics, replicating the present study holds promise for clarifying shifts in the sources of justification in our contemporary socio-technological era.

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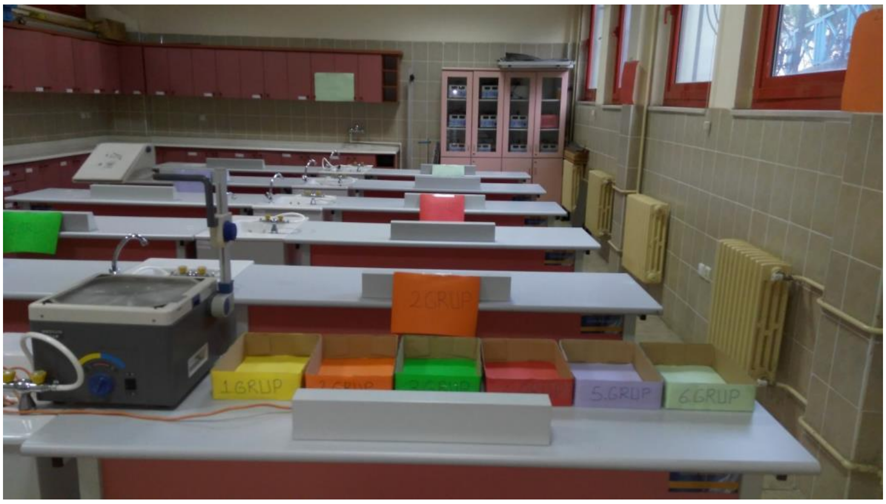
APPENDICES

A. The Pictures of Each of the Six Phases of the Argumentation Process

Lab Environment



Phase 1: Initial Justifications

Phase 2: Group Discussion 1 - Before the Demonstration

Phase 3: Revised Justifications After Group Discussion 1 - Before the Demonstration

Demonstration

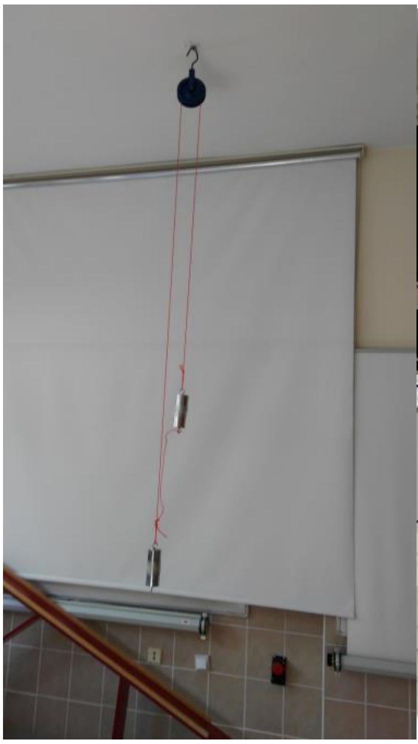
Slow- motion videos

Phase 4: Revised Justifications After the Demonstration

Phase 5: Group Discussion 2 - After the Demonstration

Phase 6: Final Justifications After Group Discussion 2 - After the Demonstration

B. Visuals from Implementations

C. Argumentation Worksheet

İLKÖĞRETİM BÖLÜMÜ
FEN BİLGİSİ ÖĞRETMENLİĞİ PROGRAMI GÜZ DÖNEMİ
FBO 103- GENEL FİZİK LABORATUARI-1 DERSİ

EĞİK DÜZLEM-1

ÖĞRENCİNİN ADI SOYADI:

BÖLÜM-1: İLK İDDİANIZ VE GEREKÇENİZ

SORU:

1.iddianız: Yukarıda verilen soruya yönelik **cevabınız nedir?**

2. gerekçeniz: Yukarıdaki **cevabınızı açıklayınız** (cevabınızı destekleyen **gerekçelerinizi, fikirlerinizi, nedenlerinizi** yazınız).
(Açıklamalarınızı karşınızdakini ikna edici şekilde gerekçelendiriniz. Şekil çizerek de destekleyebilirsiniz)

1

ÖĞRENCİNİN ADI SOYADI:

BÖLÜM-1: DEVAMI

3. Önceki soruları cevaplarken yazdıklarınızı **nereden hatırlıyorsunuz**? (**kaynağı** için ne söyleyebilirsiniz?)

2

BÖLÜM-2: GRUP TARTIŞMASI-1

ÖĞRENCİNİN ADI SOYADI:

1. Verilen soruyla ilgili **yazdıklarınızı arkadaşlarınızla paylaşıp** tartışınız.
2. **Tartışmadan sonra** grup arkadaşlarınızın **söylediklerini** ayrı ayrı değerlendirip aşağıdaki tabloyu uygun biçimde doldurunuz.
3. Tabloda arkadaşlarınızın **hangi görüşlerini mantıklı, hangilerini mantıksız bulduğunuzu açık biçimde yazmayı** unutmayınız.

Adı soyadı:	Beni **ikna etti;** söyledikleri **bana göre mantıklı çünkü:**	Söyledikleri **mantıklı olmasına rağmen** beni **ikna etmedi, çünkü:**	Beni **ikna etmedi;** söyledikleri **bana göre mantıksız çünkü:**	**Sen onu ikna etmek için ne söyledin?**

ÖĞRENCİNİN ADI SOYADI:

BÖLÜM-3: TARTIŞMA SONRASI İDDİANIZ VE GEREKÇENİZ

Arkadaşlarınızla tartıştıktan sonra:

1. (Yeni) iddianızı yazınız:

2. (Yeni) gerekçenizi yazınız (cevabınızı destekleyen **gerekçelerinizi, fikirlerinizi, nedenlerinizi** yazınız).

3. İddianız ve gerekçeniz **değiştiyse sizce neden değişti?**

4. İddianız ve gerekçeniz **değişmediyse sizce neden değişmedi**?

Bu kâğıdı lütfen grubunuzun kutusuna bırakınız.

4

ÖĞRENCİNİN ADI SOYADI:

BÖLÜM: GÖZLEM

Yapılan gösteriyi gözlemleyiniz. Bölüm-4'e geçiniz.

BÖLÜM-4: GÖZLEM SONRASI İDDİANIZ VE GEREKÇENİZ

Gözlemlerinizden sonra: **1. (Yeni) iddianızı** yazınız:
2. (Yeni) gerekçenizi yazınız (lütfen **cevabınızı veya gözlem sonucunu tekrarlamayınız;** cevabınızı destekleyen **gerekçelerinizi, fikirlerinizi, nedenlerinizi** yazınız).
Bu kâğıdı lütfen grubunuzun kutusuna bırakınız.

5

BÖLÜM-5: GRUP TARTIŞMASI-2

ÖĞRENCİNİN ADI SOYADI:

1. Gözlemlerinize göre, verilen soruyla ilgili tekrar gözden geçirdiğiniz **cevabınızı ve gerekçelerinizi arkadaşlarınızla paylaşıp** tartışınız.
2. Tartışmadan sonra grup arkadaşlarınızın **söylediklerini** ayrı ayrı değerlendirip aşağıdaki tabloyu uygun biçimde doldurunuz.
3. Tabloda arkadaşlarınızın **hangi görüşlerini mantıklı, hangilerini mantıksız bulduğunuzu açık biçimde yazmayı** unutmayınız.

Adı soyadı:	Beni **ikna etti;** söyledikleri **bana göre mantıklı çünkü:**	Söyledikleri **mantıklı olmasına rağmen** beni **ikna etmedi, çünkü:**	Beni **ikna etmedi;** söyledikleri **bana göre mantıksız çünkü:**	**Sen onu ikna etmek için ne söyledin?**

ÖĞRENCİNİN ADI SOYADI:

BÖLÜM-6: SON İDDİANIZ VE GEREKÇENİZ

Gözlemlerinizi arkadaşlarınızla tartıştıktan sonra:

1. **Son iddianızı** yazınız:

2. **Son gerekçenizi yazınız** (cevabınızı destekleyen **gerekçelerinizi, fikirlerinizi, nedenlerinizi** yazınız).

3. İddianız ve gerekçeniz **değiştiyse sizce neden değişti?**

4. İddianız ve gerekçeniz **değişmediyse sizce neden değişmedi**?

Bu kâğıdı lütfen grubunuzun kutusuna bırakınız.

7

D. The Variation of Justification Source Types across Each of the Six Phases and Across All Phases for All Tasks

The Variation of Justification Source Types across Each of the Six Phases and Across All Phases of Task 1: Weighing

	Task 1:Weighing																			
	Phase 1: Initial			Phase 2: Discussion 1			Phase 3: Revised			Phase 4: Revised			Phase 5: Discussion 2			Phase 6: Final			All Phases	
Justification Source Types	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%	n	%
Daily Life Experience		7	30,43		9	37,50		13	61,90		0	0,00		4	17,39		4	21,05	37	30,33
Real-Exper-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Real-Exper-I	I-1	1	4,35	I-2	1	4,17			0,00			0,00			0,00			0,00	2	1,64
Illusi-Exper-I	D-1 F-1 G-1 L-1 O-1 W-1	6	26,09	D-2 E-2 F-2 G-2 L-2 O-2 W-2 X-2	8	33,33	B-3 A-3 D-3 E-3 F-3 H-3 I-3 G-3 L-3 O-3 S-3 W-3 X-3	13	61,90			0,00	B-5 A-5 D-5 R-5	4	17,39	B-6 A-6 D-6 R-6	4	21,05	35	28,69
Daily Life Observation		2	8,70		1	4,17		0	0,00		0	0,00		0	0,00		0	0,00	3	2,46
Real-Obser-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Real-Obser-I			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Illusi-Obser-I	A-1	1	4,35	A-2	1	4,17			0,00			0,00			0,00			0,00	2	1,64
Media-Obser-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Media-Obser-I	E-1	1	4,35			0,00			0,00			0,00			0,00			0,00	1	0,82
School		14	60,87		13	54,17		8	38,10		0	0,00		0	0,00		0	0,00	35	28,69
Teacher-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Teacher-I	E-1 N-1	2	8,70	N-2	1	4,17	N-3	1	4,76			0,00			0,00			0,00	4	3,28
Book-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Book-I			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
School-Life-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
School-Life-I	B-1 R-1 T-1 V-1 K-1 H-1 I-1 Z-1 C-1 M-1 S-1 X-1	12	52,17	B-2 R-2 T-2 V-2 K-2 H-2 I-2 Z-2 C-2 M-2 S-2 X-2	12	50,00	R-3 T-3 V-3 K-3 Z-3 C-3 M-3	7	33,33			0,00			0,00			0,00	31	25,41
Experiment-Demo-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Experiment-Demo-I			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Implicit		0	0,00		1	4,17		0	0,00		12	100,00		19	82,61		15	78,95	47	38,52

Implicit -R			0,00	O-2new	1	4,17			0,00			0,00	E-5new F-5new C-5new M-5new O-5 new	5	21,74			0,00	6	4,92
Implicit-I			0,00			0,00			0,00	D-4 T-4 V-4 K-4 H-4 G-4 Z-4 C-4 M-4 N-4 O-4 X-4	12	100,00	T-5 V-5 F-5 K-5 H-5 I-5 G-5 Z-5 C-5 L-5new M-5 N-5 O-5 X-5	14	60,87	T-6 V-6 F-6 K-6 H-6 I-6 G-6 Z-6 C-6 L-6 M-6 N-6 O-6 W-6 X-6	15	78,95	41	33,61
Total		23	100		24	100		21	100		12	100		23	100		19	100	122	100
None (No Justifications)				R-2 E-2 E-2 X-2	4	14,29				B-4 A-4 R-4 E-4 F-4 I-4 L-4 S-4 W-4	9	42,86	E-5 E-5 T-5 T-5 C-5 C-5 L-5 L-5 L-5 S-5 S-5 S-5 W-5 W-5 X-5	15	39,47	E-6 S-6	2	9,52	30	19,74
Multiple SourceTypes																				
Experience-Observation																				
Real-Exper-R Media-Obser-R																				
Real-Exper-I Media-Obser-I																				
Experience-School																				
School-Life-R Real-Exper-R																				
School-Life-I Real-Exper-I	I-1	1		I-2	1															
Teacher-R Real-Exper-R																				
Teacher-I Real-Exper-R																				
Real-Exper-I School-Life-I Teacher-I																				
Observation-School																				
Teacher-R Media-Obser-R																				

Teacher-I Media-Obser-I	E-1	1																
School-Life-I Media-Obser-I																		
School-Life-I Teacher-I Illusi-Obser-I																		
School-School																		
Teacher-R Book-R																		
Teacher-I Book-I																		
Book-I School-Life-I																		
School-Life-R Experiment-Demo-R																		
School-Life-I Experiment-Demo-I																		
School-Implicit																		
School-Life-R Implicit-R																		
Experiment-Demo-I Implicit-R																		
Implicit-Implicit																		
Implicit-R Implicit-I																		
Observation-School- Implicit																		
Teacher-R Media-Obser-R Implicit-R																		

The variation of justification source types across each of the six phases and across all phases of Task 2: Inclined Plane 1

	Task 2: Inclined Plane 1																			
	Phase 1: Initial			Phase 2: Discussion 1			Phase 3: Revised			Phase 4: Revised			Phase 5: Discussion 2			Phase 6: Final			All Phases	
Justification Source Types	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%	n	%
Daily Life Experience		10	30,30		11	30,56		9	27,27		3	12,50		4	16,67		4	16,67	41	23,56
Real-Exper-R	L-1	1	3,03	L-2 C-2 new	2	5,56	L-3	1	3,03	A-4 G-4 L-4	3	12,50	A-5 G-5 L-5 R-5	4	16,67	A-6 G-6 L-6 R-6	4	16,67	15	8,62
Real-Exper-I	A-1 Y-1 Z-1 I-1 K-1 S-1 T-1 F-1 V-1	9	27,27	A-2 Y-2 Z-2 I-2 K-2 S-2 T-2 F-2 V-2	9	25,00	A-3 Z-3 I-3 K-3 S-3 T-3 F-3 V-3	8	24,24			0,00			0,00			0,00	26	14,94
Illusi-Exper-I			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Daily Life Observation		0	0,00		0	0,00		0	0,00		0	0,00		0	0,00		0	0,00	0	0,00
Real-Obser-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Real-Obser-I			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Illusi-Obser-I			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Media-Obser-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Media-Obser-I			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
School		23	69,70		22	61,11		23	69,70		0	0,00		0	0,00		0	0,00	68	39,08
Teacher-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Teacher-I	Z-1 D-1	2	6,06	Z-2 D-2	2	5,56	Z-3	1	3,03			0,00			0,00			0,00	5	2,87
Book-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Book-I	R-1 W-1	2	6,06	R-2 W-2	2	5,56	R-3	1	3,03			0,00			0,00			0,00	5	2,87
School-Life-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
School-Life-I	A-1 G-1 B-1 C-1 O-1 U-1 H-1 Q-1 Y-1 Z-1 N-1 W-1 I-1 K-1 S-1 T-1 M-1 P-1	18	54,55	A-2 G-2 B-2 C-2 O-2 U-2 H-2 Y-2 Z-2 N-2 W-2 I-2 K-2 S-2 T-2 M-2 P-2	17	47,22	A-3 G-3 B-3 C-3 O-3 U-3 H-3 Y-3 Z-3 N-3 I-3 K-3 S-3 T-3 F-3 M-3 P-3 V-3	18	54,55			0,00			0,00			0,00	53	30,46
Experiment-Demo-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Experiment-Demo-I	X-1	1	3,03	X-2	1	2,78	D-3 W-3 X-3	3	9,09			0,00			0,00			0,00	5	2,87
Implicit		0	0,00		3	8,33		1	3,03		21	87,50		20	83,33		20	83,33	65	37,36

Implicit -R			0,00	Q-2 new X-2 new	2	5,56	Q-3	1	3,03	O-4 H-4 Q-4 Y-4 W-4 X-4 S-4 T-4 M-4 P-4	10	41,67	C-5new O-5 H-5 Q-5 Y-5 W-5 X-5 S-5 T-5 M-5 P-5	11	45,83	B-6 C-6 O-6 U-6 H-6 Q-6 Y-6 Z-6 D-6 W-6 X-6 S-6 T-6 F-6 M-6 P-6 V-6	17	70,83	41	23,56
Implicit-I			0,00	G-2new	1	2,78			0,00	R-4 B-4 C-4 U-4 Z-4 D-4 N-4 I-4 K-4 F-4 V-4	11	45,83	B-5 U-5 Z-5 D-5 N-5 I-5 K-5 F-5 V-5	9	37,50	N-6 I-6 K-6	3	12,50	24	13,79
Total		33	100		36	100		33	100		24	100		24	100		24	100	174	100
None (No Justifications)			0,00	D-2 D-2	2	5,26			0,00			0,00	K-5 T-5		0,00			0,00	2	1,14
Multiple SourceTypes																				
Experience-Observation																				
Real-Exper-R Media-Obser-R																				
Real-Exper-I Media-Obser-I																				
Experience-School																				
School-Life-R Real-Exper-R																				
School-Life-I Real-Exper-I	A-1 Y-1 I-1 K-1 S-1 T-1	6		A-2 Y-2 I-2 K-2 S-2 T-2	6		A-3 I-3 K-3 S-3 T-3 F-3 V-3	7												
Teacher-R Real-Exper-R																				
Teacher-I Real-Exper-R																				
Real-Exper-I School-Life-I Teacher-I	Z-1	1		Z-2	1		Z-3	1												
Observation-School																				
Teacher-R Media-Obser-R																				
Teacher-I Media-Obser-I																				
School-Life-I Media-Obser-I																				

School-Life-I Teacher-I Illusi-Obser-I																		
School-School																		
Teacher-R Book-R																		
Teacher-I Book-I																		
Book-I School-Life-I	W-1	1		W-2	1													
School-Life-R Experiment-Demo-R																		
School-Life-I Experiment-Demo-I																		
School-Implicit																		
School-Life-R Implicit-R																		
Experiment-Demo-I Implicit-R																		
Implicit-Implicit																		
Implicit-R Implicit-I																		
Observation-School- Implicit																		
Teacher-R Media-Obser-R Implicit-R																		

The variation of justification source types across each of the six phases and across all phases of Task 3: Pulley KLM

	Task 3: Pulley KLM																			
	Phase 1: Initial			Phase 2: Discussion 1			Phase 3: Revised			Phase 4: Revised			Phase 5: Discussion 2			Phase 6: Final			All Phases	
Justification Source Types	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%	n	%
Daily Life Experience		1	3,70		1	3,33		1	4,00		0	0,00		0	0,00		0	0,00	3	2,05
Real-Exper-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Real-Exper-I	I-1	1	3,70	I-2	1	3,33	I-3	1	4,00			0,00			0,00			0,00	3	2,05
Illusi-Exper-I			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Daily Life Observation		3	11,11		5	16,67		4	16,00		0	0,00		0	0,00		0	0,00	12	8,22
Real-Obser-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Real-Obser-I	S-1	1	3,70	N-2 Z-2 S-2	3	10,00	N-3 Z-3 S-3	3	12,00			0,00			0,00			0,00	7	4,79
Illusi-Obser-I	Y-1	1	3,70	Y-2	1	3,33			0,00			0,00			0,00			0,00	2	1,37
Media-Obser-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Media-Obser-I	C-1	1	3,70	C-2	1	3,33	C-3	1	4,00			0,00			0,00			0,00	3	2,05
School		20	74,07		18	60,00		18	72,00		0	0,00		0	0,00		0	0,00	56	38,36
Teacher-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Teacher-I	E-1 Z-1 W-1 Y-1	4	14,81	E-2 W-2 Y-2	3	10,00	W-3	1	4,00			0,00			0,00			0,00	8	5,48
Book-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Book-I	R-1 W-1	2	7,41	R-2 W-2	2	6,67	R-3 W-3	2	8,00			0,00			0,00			0,00	6	4,11
School-Life-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
School-Life-I	B-1 X-1 C-1 G-1 I-1 K-1 M-1N-1 P-1 Q-1 O-1 T-1 U-1 Y-1	14	51,85	B-2 X-2 C-2 G-2 I-2 K-2 M-2 P-2 Q-2 O-2 T-2 U-2 Y-2	13	43,33	A-3 B-3 E-3 X-3 C-3 G-3 I-3 K-3 M-3 P-3 Q-3 O-3 T-3 U-3 Y-3	15	60,00			0,00			0,00			0,00	42	28,77
Experiment-Demo-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Experiment-Demo-I			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Implicit		3	11,11		6	20,00		2	8,00		18	100,00		23	100,00		23	100,00	75	51,37
Implicit -R			0,00	A-2 new, T-2 new,	2	6,67			0,00	B-4 L-4 N-4 P-4	4	22,22	B-5 K-5 L-5 N-5 P-5 Q-5 O-5new	7	30,43	B-6 K-6 L-6 R-6 N-6 P-6 Q-6 O-6 U-6	9	39,13	22	15,07

Implicit-I	A-1 D-1 L-1	3	11,11	A-2 D-2 L-2 W-2 new	4	13,33	D-3 L-3	2	8,00	E-4 X-4 D-4 C-4 I-4 K-4 M-4 R-4 S-4 O-4 T-4 U-4 W-4 Y-4	14	77,78	A-5 E-5 X-5 D-5 C-5 G-5 I-5new M-5 R-5 Z-5 S-5 O-5 T-5 U-5 W-5 Y-5	16	69,57	A-6 B-6 E-6 X-6 D-6 C-6 G-6 I-6new M-6 Z-6 S-6 T-6 W-6 Y-6	14	60,87	53	36,30
Total		27	100		30	100		25	100		18	100		23	100		23	100	146	100
None (No Justifications)			0,00	D-2 D-2 C-2 C-2 C-2 G-2 G-2 N-2 P-2 P-2 S-2 T-2 U-2 U-2 U-2 Y-2 Y-2	17	36,17			0,00	A-4 G-4 Q-4 Z-4	4	18,18	O-5 O-5 T-5 T-5 T-5 T-5 U-5 U-5 U-5 U-5 W-5 W-5 Y-5	13	36,11			0,00	34	18,89
Multiple SourceTypes																				
Experience-Observation																				
Real-Exper-R Media-Obser-R																				
Real-Exper-I Media-Obser-I																				
Experience-School																				
School-Life-R Real-Exper-R																				
School-Life-I Real-Exper-I	I-1	1		I-2	1		I-3	1												
Teacher-R Real-Exper-R																				
Teacher-I Real-Exper-R																				
Real-Exper-I School-Life-I Teacher-I																				
Observation-School																				
Teacher-R Media-Obser-R																				
Teacher-I Media-Obser-I																				
School-Life-I Media-Obser-I	C-1	1		C-2	1		C-3	1												

School-Life-I Teacher-I Illusi-Obser-I	Y-1	1		Y-2	1													
School-School																		
Teacher-R Book-R																		
Teacher-I Book-I	W-1	1		W-2	1		W-3	1										
Book-I School-Life-I																		
School-Life-R Experiment-Demo-R																		
School-Life-I Experiment-Demo-I																		
School-Implicit																		
School-Life-R Implicit-R																		
Experiment-Demo-I Implicit-R																		
Implicit-Implicit																		
Implicit-R Implicit-I																B-6	1	
Observation-School- Implicit																		

The variation of justification source types across each of the six phases and across all phases of Task 4: Dynamometer

	Task 4: Dynamometer																			
	Phase 1: Initial			Phase 2: Discussion 1			Phase 3: Revised			Phase 4: Revised			Phase 5: Discussion 2			Phase 6: Final			All Phases	
Justification Source Types	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%	n	%
Daily Life Experience		5	17,86		5	11,11		5	17,86		3	9,68		3	10,71		3	10,71	24	12,77
Real-Exper-R	Z-1	1	3,57	Z-2	1	2,22	Z-3	1	3,57	Z-4 N-4	2	6,45	Z-5 N-5	2	7,14	Z-6 N-6	2	7,14	9	4,79
Real-Exper-I	U-1 L-1 X-1 R-1	4	14,29	U-2 L-2 X-2 R-2	4	8,89	U-3 L-3 X-3 R-3	4	14,29	U-4	1	3,23	U-5	1	3,57	U-6	1	3,57	15	7,98
Illusi-Exper-I			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Daily Life Observation		2	7,14		1	2,22		1	3,57		3	9,68		1	3,57		1	3,57	9	4,79
Real-Obser-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Real-Obser-I	D-1	1	3,57			0,00			0,00			0,00			0,00			0,00	1	0,53
Illusi-Obser-I			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Media-Obser-R	Y-1	1	3,57	Y-2	1	2,22	Y-3	1	3,57	Y-4 X-4 R-4	3	9,68	Y-5	1	3,57	Y-6	1	3,57	8	4,26
Media-Obser-I			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
School		15	53,57		17	37,78		16	57,14		14	45,16		12	42,86		12	42,86	86	45,74
Teacher-R	W-1 Y-1 Z-1	3	10,71	W-2 D-2 Y-2 Z-2	4	8,89	W-3 Y-3 Z-3	3	10,71	W-4 Y-4 X-4 R-4 Z-4 N-4	6	19,35	W-5 Y-5 Z-5 N-5	4	14,29	W-6 Y-6 Z-6 N-6	4	14,29	24	12,77
Teacher-I			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Book-R	W-1	1	3,57	W-2 D-2	2	4,44	W-3	1	3,57	W-4	1	3,23	W-5	1	3,57	W-6	1	3,57	7	3,72
Book-I			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
School-Life-R	P-1 K-1	2	7,14	P-2 K-2	2	4,44	P-3 A-3	2	7,14	E-4 H-4 P-4 A-4	4	12,90	E-5 H-5 P-5 A-5	4	14,29	E-6 H-6 P-6 A-6	4	14,29	18	9,57
School-Life-I	U-1 B-1 E-1 H-1 R-1 C-1 I-1	7	25,00	U-2 B-2 E-2 H-2 R-2 C-2 I-2	7	15,56	U-3 B-3 E-3 H-3 R-3 C-3 I-3	7	25,00	U-4 C-4	2	6,45	U-5 C-5	2	7,14	U-6 C-6	2	7,14	27	14,36
Experiment-Demo-R	O-1	1	3,57	O-2	1	2,22	O-3	1	3,57	O-4	1	3,23	O-5	1	3,57	O-6	1	3,57	6	3,19
Experiment-Demo-I	T-1	1	3,57	T-2	1	2,22	T-3 D-3	2	7,14			0,00			0,00			0,00	4	2,13
Implicit		6	21,43		22	48,89		6	21,43		11	35,48		12	42,86		12	42,86	69	36,70
Implicit -R				T-2new D-2new D-2new L-2new E-2new E-2new H-2new H-2new Y-2new X-2new O-2new Z-2new	12	26,67				Q-4 B-4 L-4 X-4 S-4 K-4 I-4	7	22,58	Q-5 B-5 L-5 X-5 S-5 R-5 K-5 F-5 I-5	9	32,14	Q-6 B-6 L-6 X-6 S-6 R-6 K-6 F-6 I-6	9	32,14	37	19,68

Implicit-I	M-1 Q-1 A-1 S-1 F-1 N-1	6	21,43	M-2 Q-2 A-2 S-2 F-2 N-2 T-2new U-2new B-2new K-2new	10	22,22	M-3 Q-3 S-3 F-3 N-3 K-3new	6	21,43	T-4 M-4 D-4 F-4	4	12,90	T-5 M-5 D-5new	3	10,71	T-6 M-6 D-6	3	10,71	32	17,02
Total		28	100		45	100		28	100		31	100		28	100		28	100	188	100
None (No Justifications)			0,00	M-2 M-2 M-2 Q-2 Q-2 Q-2 L-2 L-2	8	15,09			0,00			0,00	X-5 S-5	2	6,67			0,00	10	5,05
Multiple SourceTypes																				
Experience-Observation																				
Real-Exper-R Media-Obser-R																				
Real-Exper-I Media-Obser-I																				
Experience-School																				
School-Life-R Real-Exper-R																				
School-Life-I Real-Exper-I	U-1 R-1	2		U-2 R-2	2		U-3 R-3	2		U-4	1		U-5	1		U-6	1			
Teacher-R Real-Exper-R	Z-1	1		Z-2	1		Z-3	1		Z-4 N-4	2		Z-5 N-5	2		Z-6 N-6	2			
Teacher-I Real-Exper-R																				
Real-Exper-I School-Life-I Teacher-I																				
Observation-School																				
Teacher-R Media-Obser-R	Y-1	1		Y-2	1		Y-3	1		Y-4 R-4	2		Y-5	1		Y-6	1			
Teacher-I Media-Obser-I																				
School-Life-I Media-Obser-I																				
School-Life-I Teacher-I Illusi-Obser-I																				
School-School																				
Teacher-R Book-R	W-1	1		W-2 D-2	2		W-3	1		W-4	1		W-5	1		W-6	1			
Teacher-I Book-I																				

Book-I School-Life-I																		
School-Life-R Experiment-Demo-R																		
School-Life-I Experiment-Demo-I																		
School-Implicit																		
School-Life-R Implicit-R																		
Experiment-Demo-I Implicit-R																		
Implicit-Implicit																		
Implicit-R Implicit-I																		
Observation-School- Implicit																		
Teacher-R Media-Obser-R Implicit-R										X-4	1							

The variation of justification source types across each of the six phases and across all phases of Task 5: Pulley XY

	Task 5: Pulley XY																			
	Phase 1: Initial			Phase 2: Discussion 1			Phase 3: Revised			Phase 4: Revised			Phase 5: Discussion 2			Phase 6: Final			All Phases	
Justification Source Types	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%	n	%
Daily Life Experience		1	4,00		1	2,38		2	8,00		0	0,00		0	0,00		0	0,00	4	2,27
Real-Exper-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Real-Exper-I	O-1	1	4,00	O-2	1	2,38	O-3 D-3	2	8,00			0,00			0,00			0,00	4	2,27
Illusi-Exper-I			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Daily Life Observation		0	0,00		0	0,00		0	0,00		0	0,00		0	0,00		0	0,00	0	0,00
Real-Obser-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Real-Obser-I			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Illusi-Obser-I			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Media-Obser-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Media-Obser-I			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
School		21	84,00		21	50,00		20	80,00		15	55,56		17	60,71		16	55,17	110	62,50
Teacher-R	W-1	1	4,00	W-2	1	2,38	W-3	1	4,00	W-4 T-4 A-4	3	11,11	W-5 T-5 Z-5 A-5	4	14,29	W-6 T-6 Z-6 A-6	4	13,79	14	7,95
Teacher-I	Z-1	1	4,00	Z-2	1	2,38	Z-3	1	4,00			0,00			0,00			0,00	3	1,70
Book-R	W-1	1	4,00	W-2	1	2,38	W-3	1	4,00	W-4 T-4 A-4	3	11,11	W-5 T-5 Z-5 A-5	4	14,29	W-6 T-6 Z-6 A-6	4	13,79	14	7,95
Book-I			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
School-Life-R	K-1	1	4,00	K-2	1	2,38	K-3	1	4,00	K-4 Y-4 C-4	3	11,11	K-5 Y-5 C-5	3	10,71	K-6 Y-6 C-6	3	10,34	12	6,82
School-Life-I	I-1 R-1 T-1 A-1 E-1 G-1 N-1 Y-1 C-1 P-1 H-1	11	44,00	I-2 R-2 T-2 A-2 E-2 G-2 N-2 Y-2 C-2 P-2 H-2	11	26,19	I-3 R-3 T-3 A-3 E-3 G-3 N-3 Y-3 C-3 P-3 H-3	11	44,00			0,00			0,00			0,00	33	18,75
Experiment-Demo-R	S-1 Q-1	2	8,00	S-2 Q-2	2	4,76	S-3 Q-3	2	8,00	S-4 I-4 O-4 D-4 Q-4 F-4	6	22,22	S-5 I-5 O-5 D-5 Q-5 F-5	6	21,43	S-6 O-6 D-6 Q-6 F-6	5	17,24	23	13,07
Experiment-Demo-I	D-1 U-1 B-1 X-1	4	16,00	D-2 U-2 B-2 X-2	4	9,52	U-3 B-3 X-3	3	12,00			0,00			0,00			0,00	11	6,25
Implicit		3	12,00		20	47,62		3	12,00		12	44,44		11	39,29		13	44,83	62	35,23

Implicit -R	L-1	1	4,00	L-2 S-2new W-2new T-2new E-2new E-2new K-2new K-2new C-2new C-2 new P-2new B-2new X-2new	13	30,95	L-3	1	4,00	L-4 E-4 U-4 G-4 V-4 R-4 N-4 P-4 B-4 X-4 H-4	11	40,74	L-5 E-5 U-5 G-5 V-5 R-5 N-5 P-5 B-5 X-5 H-5	11	39,29	L-6 E-6 U-6 G-6 V-6 R-6 I-6 N-6 Y-6 P-6 B-6 X-6 H-6	13	44,83	50	28,41
Implicit-I	V-1 F-1	2	8,00	V-2 F-2 O-2new T-2new X-2new X-2new H-2new	7	16,67	V-3 F-3	2	8,00	Z-4	1	3,70			0,00			0,00	12	6,82
Total		25	100		42	100		25	100		27	100		28	100		29	100	176	100
None (No Justifications)			0,00	C-2	1	2,33			0,00			0,00			0,00			0,00	1	0,56
Multiple SourceTypes																				
Experience-Observation																				
Real-Exper-R Media-Obser-R																				
Real-Exper-I Media-Obser-I																				
Experience-School																				
School-Life-R Real-Exper-R																				
School-Life-I Real-Exper-I																				
Teacher-R Real-Exper-R																				
Teacher-I Real-Exper-R																				
Real-Exper-I School-Life-I Teacher-I																				
Observation-School																				
Teacher-R Media-Obser-R																				
Teacher-I Media-Obser-I																				
School-Life-I																				

Media-Obser-I																		
School-Life-I Teacher-I Illusi-Obser-I																		
School-School																		
Teacher-R Book-R	W-1	1		W-2	1		W-3	1		W-4 T-4 A-4	3		W-5 T-5 Z-5 A-5	4		W-6 T-6 Z-6 A-6	4	
Teacher-I Book-I																		
Book-I School-Life-I																		
School-Life-R Experiment-Demo-R																		
School-Life-I Experiment-Demo-I																		
School-Implicit																		
School-Life-R Implicit-R																Y-6	1	
Experiment-Demo-I Implicit-R																		
Implicit-Implicit																		
Implicit-R Implicit-I																		
Observation-School-Implicit																		
Teacher-R Media-Obser-R Implicit-R																		

The variation of justification source types across each of the six phases and across all phases of Task 6: Inclined Plane 2

	Task 6: Inclined Plane 2																			
	Phase 1: Initial			Phase 2: Discussion 1			Phase 3: Revised			Phase 4: Revised			Phase 5: Discussion 2			Phase 6: Final			All Phases	
Justification Source Types	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%	n	%
Daily Life Experience		6	21,43		6	17,65		9	34,62		12	50,00		12	50,00		12	48,00	57	35,40
Real-Exper-R	E-1 G-1 L-1	3	10,71	E-2 G-2 I-2 L-2	4	11,76	E-3 Y-3 T-3 P-3 G-3 C-3 I-3 L-3	8	30,77	E-4 Y-4 X-4 T-4 P-4 G-4 C-4 N-4 B-4 I-4 L-4 F-4	12	50,00	E-5 Y-5 X-5 T-5 P-5 G-5 C-5 N-5 B-5 I-5 L-5 F-5	12	50,00	E-6 Y-6 X-6 T-6 P-6 G-6 C-6 N-6 B-6 I-6 L-6 F-6	12	48,00	51	31,68
Real-Exper-I	X-1 T-1 I-1	3	10,71	X-2 T-2	2	5,88	X-3	1	3,85			0,00			0,00			0,00	6	3,73
Illusi-Exper-I			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Daily Life Observation		4	14,29		4	11,76		2	7,69		0	0,00		0	0,00		0	0,00	10	6,21
Real-Obser-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Real-Obser-I	Y-1 R-1	2	7,14	Y-2 R-2	2	5,88	R-3	1	3,85			0,00			0,00			0,00	5	3,11
Illusi-Obser-I	F-1	1	3,57	F-2	1	2,94	F-3	1	3,85			0,00			0,00			0,00	3	1,86
Media-Obser-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Media-Obser-I	C-1	1	3,57	C-2	1	2,94			0,00			0,00			0,00			0,00	2	1,24
School		17	60,71		17	50,00		14	53,85		10	41,67		9	37,50		9	36,00	76	47,20
Teacher-R	Z-1	1	3,57	Z-2	1	2,94	Z-3	1	3,85	Z-4	1	4,17	Z-5	1	4,17	Z-6	1	4,00	6	3,73
Teacher-I	W-1 N-1	2	7,14	W-2 N-2	2	5,88	W-3 N-3	2	7,69			0,00			0,00			0,00	6	3,73
Book-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Book-I	W-1	1	3,57	W-2	1	2,94	W-3	1	3,85			0,00			0,00			0,00	3	1,86
School-Life-R	Q-1 K-1	2	7,14	Q-2 K-2	2	5,88	Q-3 K-3	2	7,69	Q-4 H-4 K-4 U-4	4	16,67	Q-5 H-5 K-5 U-5	4	16,67	Q-6 H-6 K-6 U-6	4	16,00	18	11,18
School-Life-I	A-1 C-1 P-1 B-1 H-1 U-1	6	21,43	A-2 C-2 P-2 B-2 H-2 U-2	6	17,65	A-3 B-3 H-3 U-3	4	15,38			0,00			0,00			0,00	16	9,94
Experiment-Demo-R	K-1	1	3,57	K-2	1	2,94	K-3	1	3,85	K-4 U-4	2	8,33	K-5 U-5	2	8,33	K-6 U-6	2	8,00	9	5,59
Experiment-Demo-I	S-1 P-1 B-1 U-1	4	14,29	S-2 P-2 B-2 U-2	4	11,76	S-3 B-3 U-3	3	11,54	S-4 A-4 R-4	3	12,50	S-5 R-5	2	8,33	S-6 R-6	2	8,00	18	11,18
Implicit		1	3,57		7	20,59		1	3,85		2	8,33		3	12,50		4	16,00	18	11,18
Implicit -R	V-1	1	3,57	V-2 E-2new E-2new Z-2new L-2new U-2new	6	17,65	V-3	1	3,85	V-4 W-4	2	8,33	V-5 A-5new W-5	3	12,50	V-6 A-6 R-6 W-6	4	16,00	17	10,56
Implicit-I			0,00	A-2new	1	2,94			0,00			0,00			0,00			0,00	1	0,62
Total		28	100		34	100		26	100		24	100		24	100		25	100	161	100
None (No Justifications)			0,00	Q-2 H-2 U-2	3	8,11			0,00			0,00			0,00			0,00	3	1,83
Multiple SourceTypes																				

Experience-Observation																		
Real-Exper-R Media-Obser-R																		
Real-Exper-I Media-Obser-I																		
Experience-School																		
School-Life-R Real-Exper-R																		
School-Life-I Real-Exper-I																		
Teacher-R Real-Exper-R																		
Teacher-I Real-Exper-R																		
Real-Exper-I School-Life-I Teacher-I																		
Observation-School																		
Teacher-R Media-Obser-R																		
Teacher-I Media-Obser-I																		
School-Life-I Media-Obser-I	C-1	1		C-2	1													
School-Life-I Teacher-I Illusi-Obser-I																		
School-School																		
Teacher-R Book-R																		
Teacher-I Book-I	W-1	1		W-2	1		W-3	1										
Book-I School-Life-I																		
School-Life-R Experiment-Demo-R	K-1	1		K-2	1		K-3	1		K-4 U-4	2		K-5 U-5	2		K-6 U-6	2	
School-Life-I Experiment-Demo-I	P-1 B-1 U-1	3		P-2 B-2 U-2	3		B-3 U-3	2										
School-Implicit																		
School-Life-R Implicit-R																		
Experiment-Demo-I Implicit-R																R-6	1	
Implicit-Implicit																		

Implicit-R Implicit-I																		
Observation-School-Implicit																		
Teacher-R Media-Obser-R Implicit-R																		

The variation of justification source types across each of the six phases and across all phases of Task 7: Circular Motion

	Task 7: Circular Motion																			
	Phase 1: Initial			Phase 2: Discussion 1			Phase 3: Revised			Phase 4: Revised			Phase 5: Discussion 2			Phase 6: Final			All Phases	
Justification Source Types	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%	n	%
Daily Life Experience		12	37,50		12	26,09		13	40,63		13	40,63		14	42,42		15	42,86	79	37,62
Real-Exper-R	G-1 U-1 Y-1 Q-1 P-1 V-1	6	18,75	G-2 U-2 Y-2 Q-2 P-2 V-2	6	13,04	G-3 D-3 U-3 Y-3 Q-3 O-3 P-3 V-3	8	25,00	G-4 D-4 L-4 A-4 U-4 W-4 K-4 Y-4 R-4 Q-4 O-4 P-4 V-4	13	40,63	G-5 D-5 L-5 A-5 N-5 U-5 W-5 K-5 Y-5 R-5 Q-5 O-5 P-5 V-5	14	42,42	G-6 D-6 L-6 A-6 N-6 U-6 W-6 K-6 Y-6 R-6 Q-6 I-6 O-6 P-6 V-6	15	42,86	62	29,52
Real-Exper-I	D-1 L-1 R-1 X-1 I-1	5	15,63	D-2 L-2 R-2 X-2 I-2	5	10,87	L-3 R-3 X-3 I-3	4	12,50			0,00			0,00			0,00	14	6,67
Illusi-Exper-I	A-1	1	3,13	A-2	1	2,17	A-3	1	3,13			0,00			0,00			0,00	3	1,43
Daily Life Observation		2	6,25		4	8,70		2	6,25		3	9,38		3	9,09		3	8,57	17	8,10
Real-Obser-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Real-Obser-I			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Illusi-Obser-I			0,00	S-2new	1	2,17			0,00			0,00			0,00			0,00	1	0,48
Media-Obser-R	G- 1	1	3,13	G-2 Z-2new	2	4,35	G-3 D-3	2	6,25	G-4 D-4 L-4	3	9,38	G-5 D-5 L-5	3	9,09	G-6 D-6 L-6	3	8,57	14	6,67
Media-Obser-I	D-1	1	3,13	D-2	1	2,17			0,00			0,00			0,00			0,00	2	0,95
School		15	46,88		15	32,61		14	43,75		7	21,88		8	24,24		8	22,86	67	31,90
Teacher-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Teacher-I	E-1 Z-1 W-1 Y-1	4	12,50	E-2 Z-2 W-2 Y-2	4	8,70	E-3 H-3 Z-3 W-3 Y-3	5	15,63	Z-4 B-4 K-4 Y-4 R-4	5	15,63	Z-5 B-5 S-5 K-5 Y-5 R-5 Q-5	7	21,21	Z-6 B-6 S-6 K-6 Y-6 R-6 Q-6	7	20,00	32	15,24
Book-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Book-I	W-1	1	3,13	W-2	1	2,17	W-3	1	3,13			0,00			0,00			0,00	3	1,43
School-Life-R	T-1 Q-1	2	6,25	T-2 Q-2	2	4,35	T-3 Q-3	2	6,25	T-4 Q-4	2	6,25	T-5	1	3,03	T-6	1	2,86	10	4,76
School-Life-I	C-1 H-1 B-1 S-1 K-1 R-1 I-1 O-1	8	25,00	C-2 H-2 B-2 S-2 K-2 R-2 I-2 O-2	8	17,39	C-3 B-3 S-3 K-3 R-3 I-3	6	18,75			0,00			0,00			0,00	22	10,48
Experiment-Demo-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Experiment-Demo-I			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Implicit		3	9,38		15	32,61		3	9,38		9	28,13		8	24,24		9	25,71	47	22,38

Implicit -R	F-1	1	3,13	F-2 F-2new L-2new G-2new G-2new T-2new T-2new P-2new P-2new	9	19,57	F-3	1	3,13	C-4 F-4 H-4 S-4 I-4 X-4	6	18,75	C-5 F-5 H-5 I-5 X-5	5	15,15	C-6 E-6 F-6 H-6 X-6	5	14,29	27	12,86
Implicit-I	M-1 N-1	2	6,25	M-2 N-2 E-2new S-2new I-2new X-2new	6	13,04	M-3 N-3	2	6,25	M-4 C-4 E-4	3	9,38	M-5 C-5 E-5	3	9,09	M-6 C-6 E-6 F-6	4	11,43	20	9,52
Total		32	100		46	100		32	100		32	100		33	100		35	100	210	100
None (No Justifications)			0,00	N-2	1	2,13			0,00	N-4	1	3,03			0,00			0,00	2	0,94
Multiple SourceTypes																				
Experience-Observation																				
Real-Exper-R Media-Obser-R	G-1	1		G-2	1		G-3 D-3	2		G-4 D-4 L-4	3		G-5 D-5 L-5	3		G-6 D-6 L-6	3			
Real-Exper-I Media-Obser-I	D-1	1		D-2	1															
Experience-School																				
School-Life-R Real-Exper-R	Q-1	1		Q-2	1		Q-3	1		Q-4	1									
School-Life-I Real-Exper-I	R-1 I-1	2		R-2 I-2	2		R-3 I-3	2												
Teacher-R Real-Exper-R																				
Teacher-I Real-Exper-R	Y-1	1		Y-2	1		Y-3	1		K-4 Y-4 R-4	3		K-5 Y-5 R-5 Q-5	4		K-6 Y-6 R-6 Q-6	4			
Real-Exper-I School-Life-I Teacher-I																				
Observation-School																				
Teacher-R Media-Obser-R																				
Teacher-I Media-Obser-I																				
School-Life-I Media-Obser-I																				
School-Life-I Teacher-I Illusi-Obser-I																				
School-School																				

Teacher-R Book-R																		
Teacher-I Book-I	W-1	1		W-2	1		W-3	1										
Book-I School-Life-I																		
School-Life-R Experiment-Demo-R																		
School-Life-I Experiment-Demo-I																		
School-Implicit																		
School-Life-R Implicit-R																		
Experiment-Demo-I Implicit-R																		
Implicit-Implicit																		
Implicit-R Implicit-I										C-4	1		C-5	1		C-6 E-6 F-6	3	
Observation-School- Implicit																		
Teacher-R Media-Obser-R Implicit-R																		

The variation of justification source types across each of the six phases and across all phases of Task 8: Atwood Machine

	Task 8: Atwood Machine																			
	Phase 1: Initial			Phase 2: Discussion 1			Phase 3: Revised			Phase 4: Revised			Phase 5: Discussion 2			Phase 6: Final			All Phases	
Justification Source Types	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%	n	%
Daily Life Experience		0	0,00		0	0,00		0	0,00		0	0,00		0	0,00		0	0,00	0	0,00
Real-Exper-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Real-Exper-I			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Illusi-Exper-I			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Daily Life Observation		0	0,00		0	0,00		0	0,00		0	0,00		0	0,00		0	0,00	0	0,00
Real-Obser-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Real-Obser-I			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Illusi-Obser-I			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Media-Obser-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Media-Obser-I			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
School		28	87,50		29	61,70		25	83,33		10	41,67		12	42,86		12	42,86	116	61,38
Teacher-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Teacher-I	W-1 Z-1	2	6,25	W-2 Z-2	2	4,26	Z-3	1	3,33			0,00			0,00			0,00	5	2,65
Book-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Book-I	W-1	1	3,13	W-2	1	2,13			0,00			0,00			0,00			0,00	2	1,06
School-Life-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
School-Life-I	T-1 P-1 Q-1 E-1 G-1 H-1 Y-1 I-1 M-1 K-1 C-1 V-1 R-1	13	40,63	T-2 P-2 Q-2 E-2 G-2 H-2 Y-2 I-2 M-2 K-2 C-2 V-2 R-2	13	27,66	E-3 G-3 D-3 H-3 Y-3 I-3 M-3 K-3 C-3 V-3 R-3	11	36,67	Y-4 I-4 B-4	3	12,50	H-5 Y-5 I-5 B-5	4	14,29	H-6 Y-6 I-6 B-6	4	14,29	48	25,40
Experiment-Demo-R			0,00			0,00			0,00			0,00			0,00			0,00	0	0,00
Experiment-Demo-I	U-1 P-1 Q-1 D-1 Y-1 I-1 B-1 K-1 C-1 X-1 R-1 L-1	12	37,50	T-2 U-2 P-2 Q-2 D-2 Y-2 I-2 B-2 K-2 C-2 X-2 R-2 L-2	13	27,66	T-3 U-3 P-3 Y-3 I-3 B-3 M-3 K-3 C-3 X-3 R-3 L-3 F-3	13	43,33	Y-4 I-4 B-4 L-4 F-4 Z-4 N-4	7	29,17	H-5 Y-5 I-5 B-5 L-5 F-5 Z-5 N-5	8	28,57	H-6 Y-6 I-6 B-6 L-6 F-6 Z-6 N-6	8	28,57	61	32,28
Implicit		4	12,50		18	38,30		5	16,67		14	58,33		16	57,14		16	57,14	73	38,62

Implicit -R			0,00	U-2new P-2new Q-2new Q-2new G-2new H-2new K-2new C-2new X-2new W-2new Z-2new	11	23,40			0,00			0,00			0,00			0,00	11	5,82
Implicit-I	A-1 S-1 F-1 N-1	4	12,50	A-2 S-2 F-2 N-2 Q-2new H-2new W-2new	7	14,89	A-3 S-3 N-3 Q-3 W-3	5	16,67	U-4 P-4 Q-4 A-4 E-4 G-4 D-4 K-4 C-4 V-4 X-4 R-4 W-4 S-4	14	58,33	T-5 U-5 P-5 Q-5 A-5 E-5 G-5 D-5 M-5 K-5 C-5 V-5 X-5 R-5 W-5 S-5	16	57,14	T-6 U-6 P-6 Q-6 A-6 E-6 G-6 D-6 M-6 K-6 C-6 V-6 X-6 R-6 W-6 S-6	16	57,14	62	32,80
Total		32	100		47	100		30	100		24	100		28	100		28	100	189	100
None (No Justifications)			0,00	E-2 D-2 C-2 S-2 S-2	5	9,62			0,00	T-4 H-4 M-4	3	11,11			0,00			0,00	8	4,06
Multiple SourceTypes																				
Experience-Observation																				
Real-Exper-R Media-Obser-R																				
Real-Exper-I Media-Obser-I																				
Experience-School																				
School-Life-R Real-Exper-R																				
School-Life-I Real-Exper-I																				
Teacher-R Real-Exper-R																				
Teacher-I Real-Exper-R																				
Real-Exper-I School-Life-I Teacher-I																				
Observation-School																				
Teacher-R Media-Obser-R																				
Teacher-I																				

Media-Obser-I																		
School-Life-I Media-Obser-I																		
School-Life-I Teacher-I Illusi-Obser-I																		
School-School																		
Teacher-R Book-R																		
Teacher-I Book-I	W-1	1		W-2	1													
Book-I School-Life-I																		
School-Life-R Experiment-Demo-R																		
School-Life-I Experiment-Demo-I	P-1 Q-1 Y-1 I-1 K-1 C-1 R-1	7		P-2 Q-2 Y-2 I-2 K-2 C-2 R-2	7		Y-3 I-3 K-3 C-3 M-3 R-3	6		Y-4 I-4 B-4	3		H-5 Y-5 I-5 B-5	4		H-6 Y-6 I-6 B-6	4	
School-Implicit																		
School-Life-R Implicit-R																		
Experiment-Demo-I Implicit-R																		
Implicit-Implicit																		
Implicit-R Implicit-I																		
Observation-School-Implicit																		
Teacher-R Media-Obser-R Implicit-R																		

E. The variation of justification source types across each of the six phases for each of the eight tasks, as well as for all tasks

The variation of justification source types across Phase 1 of each of the eight tasks, as well as for all tasks (Phase 1: Initial Justifications)

	Task 1: Weighing		Task 2: Inclined Plane 1		Task 3: Pulley KLM		Task 4: Dynamometer		Task 5: Pulley XY		Task 6: Inclined Plane 2		Task 7: Circular Motion		Task 8: Atwood Machine		All Tasks	
	Phase 1: Initial		Phase 1: Initial		Phase 1: Initial		Phase 1: Initial		Phase 1: Initial		Phase 1: Initial		Phase 1: Initial		Phase 1: Initial		Phase 1: Initial	
Source Types	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Daily Life Experience	7	30,43	10	30,30	1	3,70	5	17,86	1	4,00	6	21,43	12	37,50			42	18,42
Real-Exper-R			1	3,03			1	3,57			3	10,71	6	18,75			11	4,82
Real-Exper-I	1	4,35	9	27,27	1	3,70	4	14,29	1	4,00	3	10,71	5	15,63			24	10,53
Illusi-Exper-I	6	26,09											1	3,13			7	3,07
Daily Life Observation	2	8,70			3	11,11	2	7,14			4	14,29	2	6,25			13	5,70
Real-Obser-R																	0	0,00
Real-Obser-I					1	3,70	1	3,57			2	7,14					4	1,75
Illusi-Obser-I	1	4,35			1	3,70					1	3,57					3	1,32
Media-Obser-R							1	3,57					1	3,13			2	0,88
Media-Obser-I	1	4,35			1	3,70					1	3,57	1	3,13			4	1,75
School	14	60,87	23	69,70	20	74,07	15	53,57	21	84,00	17	60,71	15	46,88	28	87,50	153	67,11
Teacher-R							3	10,71	1	4,00	1	3,57					5	2,19
Teacher-I	2	8,70	2	6,06	4	14,81			1	4,00	2	7,14	4	12,50	2	6,25	17	7,46
Book-R							1	3,57	1	4,00							2	0,88
Book-I			2	6,06	2	7,41					1	3,57	1	3,13	1	3,13	7	3,07
School-Life-R							2	7,14	1	4,00	2	7,14	2	6,25			7	3,07
School-Life-I	12	52,17	18	54,55	14	51,85	7	25,00	11	44,00	6	21,43	8	25,00	13	40,63	89	39,04
Experiment-Demo-R							1	3,57	2	8,00	1	3,57					4	1,75
Experiment-Demo-I			1	3,03			1	3,57	4	16,00	4	14,29			12	37,50	22	9,65
Implicit					3	11,11	6	21,43	3	12,00	1	3,57	3	9,38	4	12,50	20	8,77
Implicit-R									1	4,00	1	3,57	1	3,13			3	1,32
Implicit-I					3	11,11	6	21,43	2	8,00			2	6,25	4	12,50	17	7,46
Total	23	100	33	100	27	100	28	100	25	100	28	100	32	100	32	100	228	100
None (No Justifications)																		

The variation of justification source types across Phase 2 of each of the eight tasks, as well as for all tasks (Phase 2: Group Discussion 1 - Before the Demonstration)

	Task 1: Weighing		Task 2: Inclined Plane 1		Task 3: Pulley KLM		Task 4: Dynamometer		Task 5: Pulley XY		Task 6: Inclined Plane 2		Task 7: Circular Motion		Task 8: Atwood Machine		All Tasks	
	Phase 2: Discussion 1		Phase 2: Discussion 1		Phase 2: Discussion 1		Phase 2: Discussion 1		Phase 2: Discussion 1		Phase 2: Discussion 1		Phase 2: Discussion 1		Phase 2: Discussion 1		Phase 2: Discussion 1	
Source Types	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Daily Life Experience	9	37,50	11	30,56	1	3,33	5	11,11	1	2,38	6	17,65	12	26,09			45	14,80
Real-Exper-R			2	5,56			1	2,22			4	11,76	6	13,04			13	4,28
Real-Exper-I	1	4,17	9	25,00	1	3,33	4	8,89	1	2,38	2	5,88	5	10,87			23	7,57
Illusi-Exper-I	8	33,33											1	2,17			9	2,96
Daily Life Observation	1	4,17			5	16,67	1	2,22			4	11,76	4	8,70			15	4,93
Real-Obser-R																	0	0,00
Real-Obser-I					3	10,00					2	5,88					5	1,64
Illusi-Obser-I	1	4,17			1	3,33					1	2,94	1	2,17			4	1,32
Media-Obser-R							1	2,22					2	4,35			3	0,99
Media-Obser-I					1	3,33					1	2,94	1	2,17			3	0,99
School	13	54,17	22	61,11	18	60,00	17	37,78	21	50,00	17	50,00	15	32,61	29	61,70	152	50,00
Teacher-R							4	8,89	1	2,38	1	2,94					6	1,97
Teacher-I	1	4,17	2	5,56	3	10,00			1	2,38	2	5,88	4	8,70	2	4,26	15	4,93
Book-R							2	4,44	1	2,38							3	0,99
Book-I			2	5,56	2	6,67					1	2,94	1	2,17	1	2,13	7	2,30
School-Life-R							2	4,44	1	2,38	2	5,88	2	4,35			7	2,30
School-Life-I	12	50,00	17	47,22	13	43,33	7	15,56	11	26,19	6	17,65	8	17,39	13	27,66	87	28,62
Experiment-Demo-R							1	2,22	2	4,76	1	2,94					4	1,32
Experiment-Demo-I			1	2,78			1	2,22	4	9,52	4	11,76			13	27,66	23	7,57
Implicit	1	4,17	3	8,33	6	20,00	22	48,89	20	47,62	7	20,59	15	32,61	18	38,30	92	30,26
Implicit-R	1	4,17	2	5,56	2	6,67	12	26,67	13	30,95	6	17,65	9	19,57	11	23,40	56	18,42
Implicit-I			1	2,78	4	13,33	10	22,22	7	16,67	1	2,94	6	13,04	7	14,89	36	11,84
Total	24	100	36	100	30	100	45	100	42	100	34	100	46	100	47	100	304	100
None (No Justifications)	4	14,29	2	5,26	17	36,17	8	15,09	1	2,33	3	8,11	1	2,13	5	9,62	41	11,88

The variation of justification source types across Phase 3 of each of the eight tasks, as well as for all tasks (Phase 3: Revised Justifications after Group Discussion 1 - Before the Demonstration)

	Task-1 Weighing		Task-2 Inclined Plane 1		Task-3 Pulley KLM		Task-4 Dynamometer		Task-5 Pulley XY		Task-6 Inclined Plane 2		Task-7 Circular Motion		Task-8 Atwood Machine		All Tasks	
	Phase 3: Revised		Phase 3: Revised		Phase 3: Revised		Phase 3: Revised		Phase 3: Revised		Phase 3: Revised		Phase 3: Revised		Phase 3: Revised		Phase 3: Revised	
Source Types	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Daily Life Experience	13	61,90	9	27,27	1	4,00	5	17,86	2	8,00	9	34,62	13	40,63			52	23,64
Real-Exper-R			1	3,03			1	3,57			8	30,77	8	25,00			18	8,18
Real-Exper-I			8	24,24	1	4,00	4	14,29	2	8,00	1	3,85	4	12,50			20	9,09
Illusi-Exper-I	13	61,90											1	3,13			14	6,36
Daily Life Observation					4	16,00	1	3,57			2	7,69	2	6,25			9	4,09
Real-Obser-R																	0	0,00
Real-Obser-I					3	12,00					1	3,85					4	1,82
Illusi-Obser-I											1	3,85					1	0,45
Media-Obser-R							1	3,57					2	6,25			3	1,36
Media-Obser-I					1	4,00											1	0,45
School	8	38,10	23	69,70	18	72,00	16	57,14	20	80,00	14	53,85	14	43,75	25	83,33	138	62,73
Teacher-R							3	10,71	1	4,00	1	3,85					5	2,27
Teacher-I	1	4,76	1	3,03	1	4,00			1	4,00	2	7,69	5	15,63	1	3,33	12	5,45
Book-R							1	3,57	1	4,00							2	0,91
Book-I			1	3,03	2	8,00					1	3,85	1	3,13			5	2,27
School-Life-R							2	7,14	1	4,00	2	7,69	2	6,25			7	3,18
School-Life-I	7	33,33	18	54,55	15	60,00	7	25,00	11	44,00	4	15,38	6	18,75	11	36,67	79	35,91
Experiment-Demo-R							1	3,57	2	8,00	1	3,85					4	1,82
Experiment-Demo-I			3	9,09			2	7,14	3	12,00	3	11,54			13	43,33	24	10,91
Implicit			1	3,03	2	8,00	6	21,43	3	12,00	1	3,85	3	9,38	5	16,67	21	9,55
Implicit-R			1	3,03					1	4,00	1	3,85	1	3,13			4	1,82
Implicit-I					2	8,00	6	21,43	2	8,00			2	6,25	5	16,67	17	7,73
Total	21	100	33	100	25	100	28	100	25	100	26	100	32	100	30	100	220	100
None (No Justifications)																		

The variation of justification source types across Phase 4 of each of the eight tasks, as well as for all tasks (Phase 4: Revised Justifications after the Demonstration)

	Task-1 Weighing		Task-2 Inclined Plane 1		Task-3 Pulley KLM		Task-4 Dynamometer		Task-5 Pulley XY		Task-6 Inclined Plane 2		Task-7 Circular Motion		Task-8 Atwood Machine		All Tasks	
	Phase 4: Revised		Phase 4: Revised		Phase 4: Revised		Phase 4: Revised		Phase 4: Revised		Phase 4: Revised		Phase 4: Revised		Phase 4: Revised		Phase 4: Revised	
Source Types	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Daily Life Experience			3	12,50			3	9,68			12	50,00	13	40,63			31	16,15
Real-Exper-R			3	12,50			2	6,45			12	50,00	13	40,63			30	15,63
Real-Exper-I							1	3,23									1	0,52
Illusi-Exper-I																	0	0,00
Daily Life Observation							3	9,68					3	9,38			6	3,13
Real-Obser-R																	0	0,00
Real-Obser-I																	0	0,00
Illusi-Obser-I																	0	0,00
Media-Obser-R							3	9,68					3	9,38			6	3,13
Media-Obser-I																	0	0,00
School							14	45,16	15	55,56	10	41,67	7	21,88	10	41,67	56	29,17
Teacher-R							6	19,35	3	11,11	1	4,17					10	5,21
Teacher-I													5	15,63			5	2,60
Book-R							1	3,23	3	11,11							4	2,08
Book-I																	0	0,00
School-Life-R							4	12,90	3	11,11	4	16,67	2	6,25			13	6,77
School-Life-I							2	6,45							3	12,50	5	2,60
Experiment-Demo-R							1	3,23	6	22,22	2	8,33					9	4,69
Experiment-Demo-I											3	12,50			7	29,17	10	5,21
Implicit	12	100,00	21	87,50	18	100,00	11	35,48	12	44,44	2	8,33	9	28,13	14	58,33	99	51,56
Implicit-R			10	41,67	4	22,22	7	22,58	11	40,74	2	8,33	6	18,75			40	20,83
Implicit-I	12	100,00	11	45,83	14	77,78	4	12,90	1	3,70			3	9,38	14	58,33	59	30,73
Total	12	100	24	100	18	100	31	100	27	100	24	100	32	100	24	100	192	100
None (No Justifications)	9	42,86		0,00	4	18,18		0,00					1	3,03	3	11,11	17	8,13

The variation of justification source types across Phase 5 of each of the eight tasks, as well as for all tasks (Phase 5: Group Discussion 2 - after the Demonstration)

	Task-1 Weighing		Task-2 Inclined Plane 1		Task-3 Pulley KLM		Task-4 Dynamometer		Task-5 Pulley XY		Task-6 Inclined Plane 2		Task-7 Circular Motion		Task-8 Atwood Machine		All Tasks	
	Phase 5: Discussion 2		Phase 5: Discussion 2		Phase 5: Discussion 2		Phase 5: Discussion 2		Phase 5: Discussion 2		Phase 5: Discussion 2		Phase 5: Discussion 2		Phase 5: Discussion 2		Phase 5: Discussion 2	
Source Types	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Daily Life Experience	4	17,39	4	16,67			3	10,71			12	50,00	14	42,42			37	17,54
Real-Exper-R			4	16,67			2	7,14			12	50,00	14	42,42			32	15,17
Real-Exper-I							1	3,57									1	0,47
Illusi-Exper-I	4	17,39															4	1,90
Daily Life Observation							1	3,57					3	9,09			4	1,90
Real-Obser-R																	0	0,00
Real-Obser-I																	0	0,00
Illusi-Obser-I																	0	0,00
Media-Obser-R							1	3,57					3	9,09			4	1,90
Media-Obser-I																	0	0,00
School							12	42,86	17	60,71	9	37,50	8	24,24	12	42,86	58	27,49
Teacher-R							4	14,29	4	14,29	1	4,17					9	4,27
Teacher-I													7	21,21			7	3,32
Book-R							1	3,57	4	14,29							5	2,37
Book-I																	0	0,00
School-Life-R							4	14,29	3	10,71	4	16,67	1	3,03			12	5,69
School-Life-I							2	7,14							4	14,29	6	2,84
Experiment-Demo-R							1	3,57	6	21,43	2	8,33					9	4,27
Experiment-Demo-I											2	8,33			8	28,57	10	4,74
Implicit	19	82,61	20	83,33	23	100,00	12	42,86	11	39,29	3	12,50	8	24,24	16	57,14	112	53,08
Implicit-R	5	21,74	11	45,83	7	30,43	9	32,14	11	39,29	3	12,50	5	15,15			51	24,17
Implicit-I	14	60,87	9	37,50	16	69,57	3	10,71					3	9,09	16	57,14	61	28,91
Total	23	100	24	100	23	100	28	100	28	100	24	100	33	100	28	100	211	100
None (No Justifications)	15	39,47			13	36,11	2	6,67									30	12,45

The variation of justification source types across Phase 6 of each of the eight tasks, as well as for all tasks (Phase 6: Final Justifications after Group Discussion 2 - After the Demonstration)

	Task-1 Weighing		Task-2 Inclined Plane 1		Task-3 Pulley KLM		Task-4 Dynamometer		Task-5 Pulley XY		Task-6 Inclined Plane 2		Task-7 Circular Motion		Task-8 Atwood Machine		All Tasks	
	Phase 6: Final		Phase 6: Final		Phase 6: Final		Phase 6: Final		Phase 6: Final		Phase 6: Final		Phase 6: Final		Phase 6: Final		Phase 6: Final	
Source Types	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Daily Life Experience	4	21,05	4	16,67			3	10,71			12	48,00	15	42,86			38	18,01
Real-Exper-R			4	16,67			2	7,14			12	48,00	15	42,86			33	15,64
Real-Exper-I							1	3,57									1	0,47
Illusi-Exper-I	4	21,05															4	1,90
Daily Life Observation							1	3,57					3	8,57			4	1,90
Real-Obser-R																	0	0,00
Real-Obser-I																	0	0,00
Illusi-Obser-I																	0	0,00
Media-Obser-R							1	3,57					3	8,57			4	1,90
Media-Obser-I																	0	0,00
School							12	42,86	16	55,17	9	36,00	8	22,86	12	42,86	57	27,01
Teacher-R							4	14,29	4	13,79	1	4,00					9	4,27
Teacher-I													7	20,00			7	3,32
Book-R							1	3,57	4	13,79							5	2,37
Book-I																	0	0,00
School-Life-R							4	14,29	3	10,34	4	16,00	1	2,86			12	5,69
School-Life-I							2	7,14							4	14,29	6	2,84
Experiment-Demo-R							1	3,57	5	17,24	2	8,00					8	3,79
Experiment-Demo-I											2	8,00			8	28,57	10	4,74
Implicit	15	78,95	20	83,33	23	100,00	12	42,86	13	44,83	4	16,00	9	25,71	16	57,14	112	53,08
Implicit-R			17	70,83	9	39,13	9	32,14	13	44,83	4	16,00	5	14,29			57	27,01
Implicit-I	15	78,95	3	12,50	14	60,87	3	10,71					4	11,43	16	57,14	55	26,07
Total	19	100	24	100	23	100	28	100	29	100	25	100	35	100	28	100	211	100
None (No Justifications)	2	9,52															2	0,94

F. The variation of justification source types across phases 1, 3, 4, and 6 for each of the eight tasks

The variation of justification source types across phases 1, 3, 4, and 6 of Task 1: Weighing

	Task 1: Weighing											
	Phase 1			Phase 3			Phase 4			Phase 6		
Source Types	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%
Daily Life Experience		6	28,57		13	61,90		0	0,00		4	19,05
Real-Exper-R			0,00			0,00			0,00			0,00
Real-Exper-I			0,00			0,00			0,00			0,00
Illusi-Exper-I	D-1 F-1 G-1 L-1 O-1 W-1	6	28,57	B-3 A-3 D-3 E-3 F-3 H-3 I-3 G-3 L-3 O-3 S-3 W-3 X-3	13	61,90			0,00	B-6 A-6 D-6 R-6	4	19,05
Daily Life Observation		1	4,76		0	0,00		0	0,00		0	0,00
Real-Obser-R			0,00			0,00			0,00			0,00
Real-Obser-I			0,00			0,00			0,00			0,00
Illusi-Obser-I	A-1	1	4,76			0,00			0,00			0,00
Media-Obser-R			0,00			0,00			0,00			0,00
Media-Obser-I			0,00			0,00			0,00			0,00
School		12	57,14		8	38,10		0	0,00		0	0,00
Teacher-R			0,00			0,00			0,00			0,00
Teacher-I	N-1	1	4,76	N-3	1	4,76			0,00			0,00
Book-R			0,00			0,00			0,00			0,00
Book-I			0,00			0,00			0,00			0,00
School-Life-R			0,00			0,00			0,00			0,00
School-Life-I	B-1 R-1 T-1 V-1 K-1 H-1 Z-1 C-1 M-1 S-1 X-1	11	52,38	R-3 T-3 V-3 K-3 Z-3 C-3 M-3	7	33,33			0,00			0,00
Experiment-Demo-R			0,00			0,00			0,00			0,00
Experiment-Demo-I			0,00			0,00			0,00			0,00
Implicit		0	0,00		0	0,00		12	57,14		15	71,43
Implicit -R			0,00			0,00			0,00			0,00
Implicit-I			0,00			0,00	D-4 T-4 V-4 K-4 H-4 G-4 Z-4 C-4 M-4 N-4 O-4 X-4	12	57,14	T-6 V-6 F-6 K-6 H-6 I-6 G-6 Z-6 C-6 L-6 M-6 N-6 O-6 W-6 X-6	15	71,43
Multiple Source Types												
Experience-Observation												
Real-Exper-R Media-Obser-R												
Real-Exper-I Media-Obser-I												
Experience-School		1	4,76									
School-Life-R Real-Exper-R												

School-Life-I Real-Exper-I	I-1	1	4,76									
Teacher-R Real-Exper-R												
Teacher-I Real-Exper-R												
Real-Exper-I School-Life-I Teacher-I												
Observation-School		1	4,76									
Teacher-R Media-Obser-R												
Teacher-I Media-Obser-I	E-1	1	4,76									
School-Life-I Media-Obser-I												
School-Life-I Teacher-I Illusi-Obser-I												
School-School												
Teacher-R Book-R												
Teacher-I Book-I												
Book-I School-Life-I												
School-Life-R Experiment-Demo-R												
School-Life-I Experiment-Demo-I												
School-Implicit												
School-Life-R Implicit-R												
Experiment-Demo-I Implicit-R												
Implicit-Implicit												
Implicit-R Implicit-I												
Observation-School- Implicit												
Teacher-R Media-Obser-R Implicit-R												
None (No Justifications)							B-4 A-4 R-4 E-4 F-4 I-4 L-4 S-4 W-4	9	42,86	E-6 S-6	2	9,52
Total		21	100		21	100		21	100		21	100

The variation of justification source types across phases 1, 3, 4, and 6 of Task 2: Inclined Plane 1

	Task 2: Inclined Plane 1											
	Phase 1			Phase 3			Phase 4			Phase 6		
Source Types	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%
Daily Life Experience		3	12,50		1	4,17		3	12,50		4	16,67
Real-Exper-R	L-1	1	4,17	L-3	1	4,17	A-4 G-4 L-4	3	12,50	A-6 G-6 L-6 R-6	4	16,67
Real-Exper-I	F-1 V-1	2	8,33			0,00			0,00			0,00
Illusi-Exper-I			0,00			0,00			0,00			0,00
Daily Life Observation		0	0,00		0	0,00		0	0,00		0	0,00
Real-Obser-R			0,00			0,00			0,00			0,00
Real-Obser-I			0,00			0,00			0,00			0,00
Illusi-Obser-I			0,00			0,00			0,00			0,00
Media-Obser-R			0,00			0,00			0,00			0,00
Media-Obser-I			0,00			0,00			0,00			0,00
School		13	54,17		14	58,33		0	0,00		0	0,00
Teacher-R			0,00			0,00			0,00			0,00
Teacher-I	D-1	1	4,17			0,00			0,00			0,00
Book-R			0,00			0,00			0,00			0,00
Book-I	R-1	1	4,17	R-3	1	4,17			0,00			0,00
School-Life-R			0,00			0,00			0,00			0,00
School-Life-I	G-1 B-1 C-1 O-1 U-1 H-1 Q-1 N-1 M-1 P-1	10	41,67	G-3 B-3 C-3 O-3 U-3 H-3 Y-3 N-3 M-3 P-3	10	41,67			0,00			0,00
Experiment-Demo-R			0,00			0,00			0,00			0,00
Experiment-Demo-I	X-1	1	4,17	D-3 W-3 X-3	3	12,50			0,00			0,00
Implicit		0	0,00		1	4,17		21	87,50		20	83,33
Implicit -R			0,00	Q-3	1	4,17	O-4 H-4 Q-4 Y-4 W-4 X-4 S-4 T-4 M-4 P-4	10	41,67	B-6 C-6 O-6 U-6 H-6 Q-6 Y-6 Z-6 D-6 W-6 X-6 S-6 T-6 F-6 M-6 P-6 V-6	17	70,83
Implicit-I			0,00			0,00	R-4 B-4 C-4 U-4 Z-4 D-4 N-4 I-4 K-4 F-4 V-4	11	45,83	N-6 I-6 K-6	3	12,50
Multiple Source Types												
Experience-Observation												
Real-Exper-R Media-Obser-R												
Real-Exper-I Media-Obser-I												

Experience-School		7	29,17		8	33,33						
School-Life-R Real-Exper-R												
School-Life-I Real-Exper-I	A-1 Y-1 I-1 K-1 S-1 T-1	6	25,00	A-3 I-3 K-3 S-3 T-3 F-3 V-3	7	29,17						
Teacher-R Real-Exper-R												
Teacher-I Real-Exper-R												
Real-Exper-I School-Life-I Teacher-I	Z-1	1	4,17	Z-3	1	4,17						
Observation-School												
Teacher-R Media-Obser-R												
Teacher-I Media-Obser-I												
School-Life-I Media-Obser-I												
School-Life-I Teacher-I Illusi-Obser-I												
School-School		1	4,17									
Teacher-R Book-R												
Teacher-I Book-I												
Book-I School-Life-I	W-1	1	4,17									
School-Life-R Experiment-Demo-R												
School-Life-I Experiment-Demo-I												
School-Implicit												
School-Life-R Implicit-R												
Experiment-Demo-I Implicit-R												
Implicit-Implicit												
Implicit-R Implicit-I												
Observation-School-Implicit												
Teacher-R Media-Obser-R Implicit-R												
None (No Justifications)												
Total		24	100		24	100		24	100		24	100

The variation of justification source types across phases 1, 3, 4, and 6 of Task 3: Pulley KLM

	Task 3: Pulley KLM											
	Phase 1			Phase 3			Phase 4			Phase 6		
Source Types	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%
Daily Life Experience		0	0,00		0	0,00		0	0,00		0	0,00
Real-Exper-R			0,00			0,00			0,00			0,00
Real-Exper-I			0,00			0,00			0,00			0,00
Illusi-Exper-I			0,00			0,00			0,00			0,00
Daily Life Observation		1	4,55		3	13,64		0	0,00		0	0,00
Real-Obser-R			0,00			0,00			0,00			0,00
Real-Obser-I	S-1	1	4,55	N-3 Z-3 S-3	3	13,64			0,00			0,00
Illusi-Obser-I			0,00			0,00			0,00			0,00
Media-Obser-R			0,00			0,00			0,00			0,00
Media-Obser-I			0,00			0,00			0,00			0,00
School		14	63,64		14	63,64		0	0,00		0	0,00
Teacher-R			0,00			0,00			0,00			0,00
Teacher-I	E-1 Z-1	2	9,09			0,00			0,00			0,00
Book-R			0,00			0,00			0,00			0,00
Book-I	R-1	1	4,55	R-3	1	4,55			0,00			0,00
School-Life-R			0,00			0,00			0,00			0,00
School-Life-I	B-1 X-1 G-1 K-1 M-1 N-1 P-1 Q-1 O-1 T-1 U-1	11	50,00	A-3 B-3 E-3 X-3 G-3 K-3 M-3 P-3 Q-3 O-3 T-3 U-3 Y-3	13	59,09			0,00			0,00
Experiment-Demo-R			0,00			0,00			0,00			0,00
Experiment-Demo-I			0,00			0,00			0,00			0,00
Implicit		3	13,64		2	9,09		18	81,82		21	95,45
Implicit -R			0,00			0,00	B-4 L-4 N-4 P-4	4	18,18	K-6 L-6 R-6 N-6 P-6 Q-6 O-6 U-6	8	36,36
Implicit-I	A-1 D-1 L-1	3	13,64	D-3 L-3	2	9,09	E-4 X-4 D-4 C-4 I-4 K-4 M-4 R-4 S-4 O-4 T-4 U-4 W-4 Y-4	14	63,64	A-6 E-6 X-6 D-6 C-6 G-6 I-6new M-6 Z-6 S-6 T-6 W-6 Y-6	13	59,09
Multiple Source Types												
Experience-Observation												
Real-Exper-R Media-Obser-R												
Real-Exper-I Media-Obser-I												
Experience-School		1	4,55		1	4,55						
School-Life-R Real-Exper-R												

School-Life-I Real-Exper-I	I-1	1	4,55	I-3	1	4,55						
Teacher-R Real-Exper-R												
Teacher-I Real-Exper-R												
Real-Exper-I School-Life-I Teacher-I												
Observation-School		2	9,09		1	4,55						
Teacher-R Media-Obser-R												
Teacher-I Media-Obser-I												
School-Life-I Media-Obser-I	C-1	1	4,55	C-3	1	4,55						
School-Life-I Teacher-I Illusi-Obser-I	Y-1	1	4,55									
School-School		1	4,55		1	4,55						
Teacher-R Book-R												
Teacher-I Book-I	W-1	1	4,55	W-3	1	4,55						
Book-I School-Life-I												
School-Life-R Experiment-Demo-R												
School-Life-I Experiment-Demo-I												
School-Implicit												
School-Life-R Implicit-R												
Experiment-Demo-I Implicit-R												
Implicit-Implicit											1	4,55
Implicit-R Implicit-I										B-6	1	4,55
Observation-School- Implicit												
Teacher-R Media-Obser-R Implicit-R												
None (No Justifications)							A-4 G-4 Q-4 Z-4	4	18,18			
Total		22	100		22	100		22	100		22	100

The variation of justification source types across phases 1, 3, 4, and 6 of Task 4: Dynamometer

	Task 4: Dynamometer											
	Phase 1			Phase 3			Phase 4			Phase 6		
Source Types	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%
Daily Life Experience		2	8,70		2	8,70		0	0,00		0	0,00
Real-Exper-R			0,00			0,00			0,00			0,00
Real-Exper-I	L-1 X-1	2	8,70	L-3 X-3	2	8,70			0,00			0,00
Illusi-Exper-I			0,00			0,00			0,00			0,00
Daily Life Observation		1	4,35		0	0,00		0	0,00		0	0,00
Real-Obser-R			0,00			0,00			0,00			0,00
Real-Obser-I	D-1	1	4,35			0,00			0,00			0,00
Illusi-Obser-I			0,00			0,00			0,00			0,00
Media-Obser-R			0,00			0,00			0,00			0,00
Media-Obser-I			0,00			0,00			0,00			0,00
School		9	39,13		10	43,48		6	26,09		6	26,09
Teacher-R			0,00			0,00			0,00			0,00
Teacher-I			0,00			0,00			0,00			0,00
Book-R			0,00			0,00			0,00			0,00
Book-I			0,00			0,00			0,00			0,00
School-Life-R	P-1 K-1	2	8,70	P-3 A-3	2	8,70	E-4 H-4 P-4 A-4	4	17,39	E-6 H-6 P-6 A-6	4	17,39
School-Life-I	B-1 E-1 H-1 C-1 I-1	5	21,74	B-3 E-3 H-3 C-3 I-3	5	21,74	C-4	1	4,35	C-6	1	4,35
Experiment-Demo-R	O-1	1	4,35	O-3	1	4,35	O-4	1	4,35	O-6	1	4,35
Experiment-Demo-I	T-1	1	4,35	T-3 D-3	2	8,70			0,00			0,00
Implicit		6	26,09		6	26,09		10	43,48		12	52,17
Implicit -R			0,00			0,00	Q-4 B-4 L-4 S-4 K-4 I-4	6	26,09	Q-6 B-6 L-6 X-6 S-6 R-6 K-6 F-6 I-6	9	39,13
Implicit-I	M-1 Q-1 A-1 S-1 F-1 N-1	6	26,09	M-3 Q-3 S-3 F-3 N-3 K-3new	6	26,09	T-4 M-4 D-4 F-4	4	17,39	T-6 M-6 D-6	3	13,04
Multiple Source Types												
Experience-Observation												
Real-Exper-R Media-Obser-R												
Real-Exper-I Media-Obser-I												
Experience-School		3	13,04		3	13,04		3	13,04		3	13,04
School-Life-R Real-Exper-R												
School-Life-I Real-Exper-I	U-1 R-1	2	8,70	U-3 R-3	2	8,70	U-4	1	4,35	U-6	1	4,35
Teacher-R	Z-1	1	4,35	Z-3	1	4,35	Z-4 N-4	2	8,70	Z-6 N-6	2	8,70

Real-Exper-R												
Teacher-I Real-Exper-R												
Real-Exper-I School-Life-I Teacher-I												
Observation-School		1	4,35		1	4,35		2	8,70		1	4,35
Teacher-R Media-Obser-R	Y-1	1	4,35	Y-3	1	4,35	Y-4 R-4	2	8,70	Y-6	1	4,35
Teacher-I Media-Obser-I												
School-Life-I Media-Obser-I												
School-Life-I Teacher-I Illusi-Obser-I												
School-School		1	4,35		1	4,35		1	4,35		1	4,35
Teacher-R Book-R	W-1	1	4,35	W-3	1	4,35	W-4	1	4,35	W-6	1	4,35
Teacher-I Book-I												
Book-I School-Life-I												
School-Life-R Experiment-Demo-R												
School-Life-I Experiment-Demo-I												
School-Implicit												
School-Life-R Implicit-R												
Experiment-Demo-I Implicit-R												
Implicit-Implicit												
Implicit-R Implicit-I												
Observation-School-Implicit								1	4,35			
Teacher-R Media-Obser-R Implicit-R							X-4	1	4,35			
None (No Justifications)												
Total		23	100		23	100		23	100		23	100

The variation of justification source types across phases 1, 3, 4, and 6 of Task 5: Pulley XY

	Task 5: Pulley XY											
	Phase 1			Phase 3			Phase 4			Phase 6		
Source Types	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%
Daily Life Experience		1	4,17		2	8,33		0	0,00		0	0,00
Real-Exper-R			0,00			0,00			0,00			0,00
Real-Exper-I	O-1	1	4,17	O-3 D-3	2	8,33			0,00			0,00
Illusi-Exper-I			0,00			0,00			0,00			0,00
Daily Life Observation		0	0,00		0	0,00		0	0,00		0	0,00
Real-Obser-R			0,00			0,00			0,00			0,00
Real-Obser-I			0,00			0,00			0,00			0,00
Illusi-Obser-I			0,00			0,00			0,00			0,00
Media-Obser-R			0,00			0,00			0,00			0,00
Media-Obser-I			0,00			0,00			0,00			0,00
School		19	79,17		18	75,00		9	37,50		7	29,17
Teacher-R			0,00			0,00			0,00			0,00
Teacher-I	Z-1	1	4,17	Z-3	1	4,17			0,00			0,00
Book-R			0,00			0,00			0,00			0,00
Book-I			0,00			0,00			0,00			0,00
School-Life-R	K-1	1	4,17	K-3	1	4,17	K-4 Y-4 C-4	3	12,50	K-6 C-6	2	8,33
School-Life-I	I-1 R-1 T-1 A-1 E-1 G-1 N-1 Y-1 C-1 P-1 H-1	11	45,83	I-3 R-3 T-3 A-3 E-3 G-3 N-3 Y-3 C-3 P-3 H-3	11	45,83			0,00			0,00
Experiment-Demo-R	S-1 Q-1	2	8,33	S-3 Q-3	2	8,33	S-4 I-4 O-4 D-4 Q-4 F-4	6	25,00	S-6 O-6 D-6 Q-6 F-6	5	20,83
Experiment-Demo-I	D-1 U-1 B-1 X-1	4	16,67	U-3 B-3 X-3	3	12,50			0,00			0,00
Implicit		3	12,50		3	12,50		12	50,00		12	50,00
Implicit -R	L-1	1	4,17	L-3	1	4,17	L-4 E-4 U-4 G-4 V-4 R-4 N-4 P-4 B-4 X-4 H-4	11	45,83	L-6 E-6 U-6 G-6 V-6 R-6 I-6 N-6 P-6 B-6 X-6 H-6	12	50,00
Implicit-I	V-1 F-1	2	8,33	V-3 F-3	2	8,33	Z-4	1	4,17			0,00
Multiple Source Types												
Experience-Observation												
Real-Exper-R Media-Obser-R												
Real-Exper-I Media-Obser-I												

Experience-School												
School-Life-R Real-Exper-R												
School-Life-I Real-Exper-I												
Teacher-R Real-Exper-R												
Teacher-I Real-Exper-R												
Real-Exper-I School-Life-I Teacher-I												
Observation-School												
Teacher-R Media-Obser-R												
Teacher-I Media-Obser-I												
School-Life-I Media-Obser-I												
School-Life-I Teacher-I Illusi-Obser-I												
School-School		1	4,17		1	4,17		3	12,50		4	16,67
Teacher-R Book-R	W-1	1	4,17	W-3	1	4,17	W-4 T-4 A-4	3	12,50	W-6 T-6 Z-6 A-6	4	16,67
Teacher-I Book-I												
Book-I School-Life-I												
School-Life-R Experiment-Demo-R												
School-Life-I Experiment-Demo-I												
School-Implicit											1	4,17
School-Life-R Implicit-R										Y-6	1	4,17
Experiment-Demo-I Implicit-R												
Implicit-Implicit												
Implicit-R Implicit-I												
Observation-School- Implicit												
Teacher-R Media-Obser-R Implicit-R												
None (No Justifications)												
Total		24	100		24	100		24	100		24	100

The variation of justification source types across phases 1, 3, 4, and 6 of Task 6: Inclined Plane 2

	Task 6: Inclined Plane 2											
	Phase 1			Phase 3			Phase 4			Phase 6		
Source Types	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%
Experience		6	27,27		9	40,91		12	54,55		12	54,55
Real-Exper-R	E-1 G-1 L-1	3	13,64	E-3 Y-3 T-3 P-3 G-3 C-3 I-3 L-3	8	36,36	E-4 Y-4 X-4 T-4 P-4 G-4 C-4 N-4 B-4 I-4 L-4 F-4	12	54,55	E-6 Y-6 X-6 T-6 P-6 G-6 C-6 N-6 B-6 I-6 L-6 F-6	12	54,55
Real-Exper-I	X-1 T-1 I-1	3	13,64	X-3	1	4,55			0,00			0,00
Illusi-Exper-I			0,00			0,00			0,00			0,00
Observation		3	13,64		2	9,09		0	0,00		0	0,00
Real-Obser-R			0,00			0,00			0,00			0,00
Real-Obser-I	Y-1 R-1	2	9,09	R-3	1	4,55			0,00			0,00
Illusi-Obser-I	F-1	1	4,55	F-3	1	4,55			0,00			0,00
Media-Obser-R			0,00			0,00			0,00			0,00
Media-Obser-I			0,00			0,00			0,00			0,00
School		6	27,27		6	27,27		6	27,27		4	18,18
Teacher-R	Z-1	1	4,55	Z-3	1	4,55	Z-4	1	4,55	Z-6	1	4,55
Teacher-I	N-1	1	4,55	N-3	1	4,55			0,00			0,00
Book-R			0,00			0,00			0,00			0,00
Book-I			0,00			0,00			0,00			0,00
School-Life-R	Q-1	1	4,55	Q-3	1	4,55	Q-4 H-4	2	9,09	Q-6 H-6	2	9,09
School-Life-I	A-1 H-1	2	9,09	A-3 H-3	2	9,09			0,00			0,00
Obser-Demo-R			0,00			0,00			0,00			0,00
Obser-Demo-I	S-1	1	4,55	S-3	1	4,55	S-4 A-4 R-4	3	13,64	S-6	1	4,55
Implicit Intuition		1	4,55		1	4,55		2	9,09		3	13,64
Intuition-R	V-1	1	4,55	V-3	1	4,55	V-4 W-4	2	9,09	V-6 A-6 W-6	3	13,64
Intuition-I			0,00			0,00			0,00			0,00
Multiple Source Types												
Experience-Observation												
Real-Exper-R Media-Obser-R												
Real-Exper-I Media-Obser-I												
Experience-School												
School-Life-R Real-Exper-R												
School-Life-I Real-Exper-I												

Teacher-R Real-Exper-R												
Teacher-I Real-Exper-R												
Real-Exper-I School-Life-I Teacher-I												
Observation-School		1	4,55									
Teacher-R Media-Obser-R												
Teacher-I Media-Obser-I												
School-Life-I Media-Obser-I	C-1	1	4,55									
School-Life-I Teacher-I Illusi-Obser-I												
School-School		5	22,73		4	18,18		2	9,09		2	9,09
Teacher-R Book-R												
Teacher-I Book-I	W-1	1	4,55	W-3	1	4,55						
Book-I School-Life-I												
School-Life-R Obser-Demo-R	K-1	1	4,55	K-3	1	4,55	K-4 U-4	2	9,09	K-6 U-6	2	9,09
School-Life-I Obser-Demo-I	P-1 B-1 U-1	3	13,64	B-3 U-3	2	9,09						
School-Science											1	4,55
School-Life-R Science-R												
Obser-Demo-I Science-R										R-6	1	4,55
Science-Science												
Science-R Science-I												
Observation-School- Science												
Teacher-R Media-Obser-R Science-R												
None (No Justifications)												
Total		22	100		22	100		22	100		22	100

The variation of justification source types across phases 1, 3, 4, and 6 of Task 7: Circular Motion

	Task 7: Circular Motion											
	Phase 1			Phase 3			Phase 4			Phase 6		
Source Types	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%
Daily Life Experience		6	24,00		7	28,00		6	24,00		8	32,00
Real-Exper-R	U-1 P-1 V-1	3	12,00	U-3 O-3 P-3 V-3	4	16,00	A-4 U-4 W-4 O-4 P-4 V-4	6	24,00	A-6 N-6 U-6 W-6 I-6 O-6 P-6 V-6	8	32,00
Real-Exper-I	L-1 X-1	2	8,00	L-3 X-3	2	8,00			0,00			0,00
Illusi-Exper-I	A-1	1	4,00	A-3	1	4,00			0,00			0,00
Daily Life Observation		0	0,00		0	0,00		0	0,00		0	0,00
Real-Obser-R			0,00			0,00			0,00			0,00
Real-Obser-I			0,00			0,00			0,00			0,00
Illusi-Obser-I			0,00			0,00			0,00			0,00
Media-Obser-R			0,00			0,00			0,00			0,00
Media-Obser-I			0,00			0,00			0,00			0,00
School		9	36,00		8	32,00		3	12,00		4	16,00
Teacher-R			0,00			0,00			0,00			0,00
Teacher-I	E-1 Z-1	2	8,00	E-3 H-3 Z-3	3	12,00	Z-4 B-4	2	8,00	Z-6 B-6 S-6	3	12,00
Book-R			0,00			0,00			0,00			0,00
Book-I			0,00			0,00			0,00			0,00
School-Life-R	T-1	1	4,00	T-3	1	4,00	T-4	1	4,00	T-6	1	4,00
School-Life-I	C-1 H-1 B-1 S-1 K-1 O-1	6	24,00	C-3 B-3 S-3 K-3	4	16,00			0,00			0,00
Experiment-Demo-R			0,00			0,00			0,00			0,00
Experiment-Demo-I			0,00			0,00			0,00			0,00
Implicit		3	12,00		3	12,00		7	28,00		3	12,00
Implicit -R	F-1	1	4,00	F-3	1	4,00	F-4 H-4 S-4 I-4 X-4	5	20,00	H-6 X-6	2	8,00
Implicit-I	M-1 N-1	2	8,00	M-3 N-3	2	8,00	M-4 E-4	2	8,00	M-6	1	4,00
Multiple Source Types												
Experience-Observation		2	8,00		2	8,00		3	12,00		3	12,00
Real-Exper-R Media-Obser-R	G-1	1	4,00	G-3 D-3	2	8,00	G-4 D-4 L-4	3	12,00	G-6 D-6 L-6	3	12,00
Real-Exper-I Media-Obser-I	D-1	1	4,00									
Experience-School		4	16,00		4	16,00		4	16,00		4	16,00
School-Life-R Real-Exper-R	Q-1	1	4,00	Q-3	1	4,00	Q-4	1	4,00			
School-Life-I	R-1 I-1	2	8,00	R-3 I-3	2	8,00						

Real-Exper-I												
Teacher-R Real-Exper-R												
Teacher-I Real-Exper-R	Y-1	1	4,00	Y-3	1	4,00	K-4 Y-4 R-4	3	12,00	K-6 Y-6 R-6 Q-6	4	16,00
Real-Exper-I School-Life-I Teacher-I												
Observation-School												
Teacher-R Media-Obser-R												
Teacher-I Media-Obser-I												
School-Life-I Media-Obser-I												
School-Life-I Teacher-I Illusi-Obser-I												
School-School		1	4,00		1	4,00						
Teacher-R Book-R												
Teacher-I Book-I	W-1	1	4,00	W-3	1	4,00						
Book-I School-Life-I												
School-Life-R Experiment-Demo-R												
School-Life-I Experiment-Demo-I												
School-Implicit												
School-Life-R Implicit-R												
Experiment-Demo-I Implicit-R												
Implicit-Implicit								1	4,00		3	12,00
Implicit-R Implicit-I							C-4	1	4,00	C-6 E-6 F-6	3	12,00
Observation-School- Implicit												
Teacher-R Media-Obser-R Implicit-R												
None (No Justifications)							N-4	1	4,00			
Total		25	100		25	100		25	100		25	100

The variation of justification source types across phases 1, 3, 4, and 6 of Task 8: Atwood Machine

	Task 8: Atwood Machine											
	Phase 1			Phase 3			Phase 4			Phase 6		
Source Types	Participant	n	%	Participant	n	%	Participant	n	%	Participant	n	%
Daily Life Experience		0	0,00		0	0,00		0	0,00		0	0,00
Real-Exper-R			0,00			0,00			0,00			0,00
Real-Exper-I			0,00			0,00			0,00			0,00
Illusi-Exper-I			0,00			0,00			0,00			0,00
Daily Life Observation		0	0,00		0	0,00		0	0,00		0	0,00
Real-Obser-R			0,00			0,00			0,00			0,00
Real-Obser-I			0,00			0,00			0,00			0,00
Illusi-Obser-I			0,00			0,00			0,00			0,00
Media-Obser-R			0,00			0,00			0,00			0,00
Media-Obser-I			0,00			0,00			0,00			0,00
School		12	50,00		13	54,17		4	16,67		4	16,67
Teacher-R			0,00			0,00			0,00			0,00
Teacher-I	Z-1	1	4,17	Z-3	1	4,17			0,00			0,00
Book-R			0,00			0,00			0,00			0,00
Book-I			0,00			0,00			0,00			0,00
School-Life-R			0,00			0,00			0,00			0,00
School-Life-I	T-1 E-1 G-1 H-1 M-1 V-1	6	25,00	E-3 G-3 D-3 H-3 V-3	5	20,83			0,00			0,00
Experiment-Demo-R			0,00			0,00			0,00			0,00
Experiment-Demo-I	U-1 D-1 B-1 X-1 L-1	5	20,83	T-3 U-3 P-3 B-3 X-3 L-3 F-3	7	29,17	L-4 F-4 Z-4 N-4	4	16,67	L-6 F-6 Z-6 N-6	4	16,67
Implicit		4	16,67		5	20,83		14	58,33		16	66,67
Implicit -R			0,00			0,00			0,00			0,00
Implicit-I	A-1 S-1 F-1 N-1	4	16,67	A-3 S-3 N-3 Q-3 W-3	5	20,83	U-4 P-4 Q-4 A-4 E-4 G-4 D-4 K-4 C-4 V-4 X-4 R-4 W-4 S-4	14	58,33	T-6 U-6 P-6 Q-6 A-6 E-6 G-6 D-6 M-6 K-6 C-6 V-6 X-6 R-6 W-6 S-6	16	66,67
Multiple Source Types												
Experience-Observation												
Real-Exper-R Media-Obser-R												
Real-Exper-I Media-Obser-I												
Experience-School												
School-Life-R Real-Exper-R												
School-Life-I												

Real-Exper-I												
Teacher-R Real-Exper-R												
Teacher-I Real-Exper-R												
Real-Exper-I School-Life-I Teacher-I												
Observation-School												
Teacher-R Media-Obser-R												
Teacher-I Media-Obser-I												
School-Life-I Media-Obser-I												
School-Life-I Teacher-I Illusi-Obser-I												
School-School		8	33,33		6	25,00		3	12,50		4	16,67
Teacher-R Book-R												
Teacher-I Book-I	W-1	1	4,17									
Book-I School-Life-I												
School-Life-R Experiment-Demo-R												
School-Life-I Experiment-Demo-I	P-1 Q-1 Y-1 I-1 K-1 C-1 R-1	7	29,17	Y-3 I-3 K-3 C-3 M-3 R-3	6	25,00	Y-4 I-4 B-4	3	12,50	H-6 Y-6 I-6 B-6	4	16,67
School-Implicit												
School-Life-R Implicit-R												
Experiment-Demo-I Implicit-R												
Implicit-Implicit												
Implicit-R Implicit-I												
Observation-School-Implicit												
Teacher-R Media-Obser-R Implicit-R												
None (No Justifications)							T-4 H-4 M-4	3	12,50			
Total		24	100		24	100		24	100		24	100

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İlgi: İnsan Araştırmaları Etik Kurulu Başvurusu

Sayın Ömer Faruk ÖZDEMİR

Danışmanlığını yaptığınız **Özlem Aydın ŞENGÜLEÇ'in "Argümantasyon Temelli TGA (Tahmin et-Gözle-Açıkla) Uygulamalarında Ortaya Çıkan Argüman Türleri ve Birbirleriyle Etkileşimleri"** başlıklı araştırması İnsan Araştırmaları Etik Kurulu tarafından uygun görülmüş ve **033-ODTU-2020** protokol numarası ile onaylanmıştır.

Saygılarımızla bilgilerinize sunarız.

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Başkan

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EDUCATION

Degree	Institution	Year of Graduation
MS	METU, SSME, Physics Education	2007
BS	METU, SSME, Physics Education	2003
High School	Denizli High School, Denizli	1996

FOREIGN LANGUAGES

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WORK EXPERIENCES

2008-………	Research Assistance Zonguldak Bülent Ecevit University , Education Faculty
2004-2008	Physics Teacher METU College
2002-2004	Physics Teacher Vektör Dershanesi

PUBLICATIONS

1. Şengüleç Aydın, Ö., Bahçivan, E. & Azar, A. (2017). The Effect of the Argumentation on the Conceptual Understanding of Electricity. Karaelmas Journal of Educational Sciences, 5(2), 207-223

2. Büyükekşi, C., Şengüleç Aydın, Ö., Bahçivan, E. & Yavuz, S. (2017). An Experimental Study On The Development of Pre-Service Science Teachers' Conceptual Understanding in Chemistry Through The Argumentation. Karaelmas Journal of Educational Sciences, 5(2), 224-235.

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8. Çetin, A., Şengüleç Aydın, Ö., Özdemir, Ö.F. ve Azar, A. "Fen Bilgisi Öğretmen Adaylarının "Sezgiye Ters Fizik Problemleri" ve "Bilimsel Tartışma (Argümantasyon)" Kavramlarına İlişkin Metaforik Algılarının İncelenmesi", III. Ulusal Fizik Eğitimi Kongresi, 14-16 Eylül 2017, GAZİ-Eğitim Fakültesi, Ankara.

9. Bahçivan, E., Şengüleç Aydın, Ö., Alptekin, F. ve Azar A., "Fen Ve Teknoloji Öğretmen Adaylarının Argümantasyon Yoluyla Elektrikteki Kavramsal Anlamalarının Geliştirilmesi: Keşif Çalışması", 12. Ulusal Fen Bilimleri ve Matematik Eğitimi Kongresi, 28-30 Eylül 2016, KATÜ-Fatih Eğitim Fakültesi, Trabzon.

10. Şengüleç Aydın, Ö., Büyükekşi, C., Bahçivan, E., Yavuz S. ve Azar A., "Argümantasyonun Fen ve Teknoloji Öğretmen Adaylarının Kavramsal Anlamalarına Etkisi: Kaynama Örneği", 12. Ulusal Fen Bilimleri ve Matematik Eğitimi Kongresi, 28-30 Eylül 2016, KATÜ-Fatih Eğitim Fakültesi, Trabzon.

11. Çetin, A. Ve Şengüleç Aydın, Ö., "Lise Öğrencilerinin Fizik Kavramına Yönelik Metaforik Algılarının Okul Türü Ve Sınıf Seviyesi Değişkenlerine Göre İncelenmesi", 12. Ulusal Fen Bilimleri ve Matematik Eğitimi Kongresi, 28-30 Eylül 2016, KATÜ-Fatih Eğitim Fakültesi, Trabzon.

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17. Eryılmaz, A. ve Şengüleç Aydın, Ö. "10. Sınıf Öğrencilerinin Kinematik Grafiklerindeki Kavram Yanılgılarının Üç Basamaklı Test ile Belirlenmesi" 9. Ulusal Fen Bilimleri ve Matematik Eğitimi Kongresi, 23-25 Eylül 2010, 9 Eylül Üniversitesi-Buca Eğitim Fakültesi, İzmir.

18. Bahçivan, E., Eraslan, F.ve Şengüleç Aydın, Ö." İlköğretim Öğrencilerinin Bilimsel Epistemolojik İnançları ile Kişisel Epistemolojileri Arasındaki İlişkinin İncelenmesi: Bir Durum Çalışması" 9. Ulusal Fen Bilimleri ve Matematik Eğitimi Kongresi, 23-25 Eylül 2010, 9 Eylül Üniversitesi-Buca Eğitim Fakültesi, İzmir.

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