Supporting Science Teachers' Agentic Practice in the Pedagogy of Scientific Argumentation

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Declaration

I, **Zeynep Guler,** confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that the thesis has indicated this.

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Abstract

Examination of existing science curricula and school science practices reveals that scientific argumentation, among other approaches, in teaching science is effective for developing students' scientific enquiry and reasoning. However, much research has shown that science teachers have struggled to integrate it into science learning and teaching.

This thesis explores science teachers' pedagogical development of scientific argumentation through sustained collaborative work and reflection. The study adopted an embedded case study approach and involved the generation of qualitative data from three science teachers working in a comprehensive school in London (through lesson planning, lesson observations, reflective interviews, and students' written work). This thesis also utilised the concept of agency to examine teachers' pedagogical development.

The comparative analysis of teachers' practice showed that their initial approach to implementing scientific argumentation evolved, with variations according to teachers' characteristics, values and emphasis on teaching science, approaches and scaffolding scientific argumentation processes, timing and the organisation of their students for discussions. Reflection on practice and collaborative work with colleagues helped them construct a better understanding of scientific argumentation and its value for learning science. Additionally, the variations in students' written work provided insight into the differences in their teachers' scientific argumentation approach. The results indicate the need for better support for teachers in planning and incorporating scientific argumentation into their practice through more focused professional learning. Additionally, this study examined changes in teachers' pedagogical development through the lens of agency, specifically in the components of sense of purpose, mastery, autonomy to act, and reflexivity, and identified factors that seemed to support or hinder the development of agency. The findings of this thesis contribute to a better understanding of how scientific argumentation is incorporated into teaching science and how the concept of

agency may be useful to examine teachers' pedagogical development of new teaching approaches.

Impact statement

The results of this research directly impact both inside and outside academia. This thesis provides a comprehensive understanding of three science teachers' pedagogical development of scientific argumentation as a new approach and the critical features of their classroom practices. It contributes to understanding the value of professional learning opportunities for teachers focused on collaborative work with colleagues and researchers and reflections on practices, which builds on previously developed resources and strategies. These processes helped the teachers construct a better pedagogical understanding of scientific argumentation and its value in understanding science. Additionally, the thesis uses the concept of teacher agency to interpret teachers' developing pedagogy.

Additionally, this study sheds light on the impact of researcher-practitioner partnerships, teacher collaboration, reflections on practice within educational innovations, and teachers' professional, personal, and social growth in the field of science education. Additionally, the results may affect teacher professional learning activities by providing educators with valuable examples from the participating teachers. These examples may be utilised to encourage teachers to collaborate on lesson planning, share their practice and experience with colleagues, and reflect on their own practice. Additionally, the results of this research have the potential to significantly influence the development of teacher agency, as an academic field.

Finally, living through a pandemic while engaged in the generation of scientific knowledge has emphasised the challenges that global leaders and policymakers have when critically evaluating scientific evidence and engaging with scientific information. Thus, science education, incorporating scientific argumentation into science education in particular, has a crucial role in addressing these challenges. This study has the potential to influence policies aimed at guiding teachers toward more efficient classroom practices with effective scientific approaches, such as scientific argumentation and assisting them in improving them in their teaching practice.

This study was educational research; it inevitably aimed to affect educational settings outside academia. I was particularly interested in exploring the contributions made by examining teachers' practice in scientific argumentation through the lens of teacher agency. This is an area that has recently emerged in academic studies on the critical nature of strengthening teachers' agentic practices in science teaching. Throughout this research, relevant and essential findings for school science stakeholders (i.e. science teachers, school community and curriculum developers) have been highlighted, and specific teaching and learning plans for scientific argumentation have also been developed, implemented, and disseminated.

To enhance the academic impact of my PhD study, I presented the results and implications of this study orally to researchers and educational practitioners at international and national academic conferences. I presented a paper at the British Educational Research Association (BERA) conference in 2019 and at the National Association for Research in Science Teaching (NARST) conference in 2021. In 2019, I attended the European Science Education Research Association (ESERA) summer school to present my study to other PhD students and researchers in science education. I plan to publish my research findings in the near future to increase the impact of my research.

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List of Abbreviations

AMS: Argument-focused Metacognitive Scaffolding

AT: Attainment Targets

CER: Claims, Evidence, and Reasoning

CPD: Continuous Professional Development

DfE: Department of Education

HSW: How Science Works

IDEAS: Ideas, Evidence, and Argument in Science

IOE: Institute of Education

KS3: Key Stage 3

KS4: Key Stage 4

MoNE: Ministry of National Education in Turkey

NC: National Curriculum

NRC: National Research Council

OFSTED: Office for Standards in Education

PD: Professional Development

PhD: Doctor of Philosophy

RQ: Research Question

SSI: Socio-Scientific Issue

SAP: Scaffolding Argumentation Pedagogy

TAP: Toulmin's Argumentation Pattern

UCL: University College London

UK: United Kingdom

Y7: Year 7

Chapter 1: Introduction

In this introductory chapter, I begin by outlining the motivation behind the direction and design of my PhD research into scientific argumentation; I then briefly discuss the rationale of the research and introduce the research context (section 1.1). Following this, I present the research objectives and questions that I aim to address in this research (section 1.2). This chapter continues by examining the potential significance of this research (section 1.3) and finally includes details of the organisation of the thesis (section 1.4).

1.1 The rationale of the research

Typically, traditional science education entails students passively memorising distinct facts and theories, as well as carrying out predetermined experiments to test a variety of scientific concepts (Osborne, 2010). Several science educators and curriculum reformers have long been concerned about how science is taught in schools. To remedy the concern expressed, many arguments have been proposed suggesting the need for a closer relationship between the practice of science learning and the applications of scientific knowledge in real-world situations (Duschl, Schweingruber, & Shouse, 2007). One way to address the need is for science teachers to incorporate scientific practices, such as scientific argumentation, the focus of my study, into their pedagogies by encouraging students to actively engage with and participate in these practices.

Two primary factors motivated me to conduct this research. First, I had experienced certain problems arising from the practices involved in teaching science over the four years of my career as a science teacher. I was expected to teach science, applying a range of teaching strategies and approaches, including scientific argumentation, in accordance with Turkey's science curriculum (Ministry of National Education in Turkey (MoNE), 2013). The intention is to enable students to engage collaboratively in the social construction of their knowledge and promote critical thinking with regard to scientific concepts and methods. When incorporating scientific argumentation as I had been taught at university, I always valued the process of engaging in classroom discussions with my students and constructing their knowledge collaboratively.

However, I was rarely able to incorporate classroom discussions and the process of social construction into my lessons due to a lack of time and the volume of science content that had to be taught throughout an academic year. I also had limited understanding of how to encourage my students to participate actively in discussions, facilitate small group and whole-class discussions, and determine what types of questions to ask to support their science learning. I rarely asked critical questions, such as ‘How do you know that?’, ‘Why do you think that?’, ‘How do you justify your answer?’ which might subsequently have prompted my students to evaluate their responses. Nor did I routinely encourage my students to evaluate their initial responses to the topics addressed. I rarely offered them opportunities that would enable them to construct their knowledge collaboratively.

I always had the impression that some pedagogical element was missing. To address this, I took a few short courses on new approaches and strategies to improve my own pedagogical knowledge so that I could teach science efficiently. Personally, I had seen that changes in my practice rarely happened when 'experts' presented knowledge to me as a teacher. I took extensive notes and listened attentively but seldom changed anything when I returned to my classroom. I also did not have the opportunity to collaborate with colleagues since I was the only science teacher in my school. Perhaps, suppose we have received additional support from experts or colleagues regarding a certain strategy over a period of time. In that case, we might have developed our knowledge and pedagogy by incorporating this specific strategy into practice. Once we take charge of our own learning, we begin to develop our pedagogy as teachers, identifying and advocating for change in our setting. I also learned that having agency as a teacher refers to recognising the critical pedagogy used to implement strategies, identify learning barriers, and then work to overcome these barriers, as well as engage more in my learning process. Additionally, I began to see collaborative work and reflection in teacher learning as critical components for fostering learner ownership as teachers pursue their educational objectives.

We, as science teachers, are required to include a range of teaching strategies and approaches in our practices, with the curriculum resources providing essential guidance. I had often wondered if we all used the same materials, resources and plans, including the activities for the academic year, in the same way. I had also questioned whether we demonstrated comparable or dissimilar instructional approaches while incorporating similar strategies into our science lessons. Additionally, I wanted to know if reflection and collaboration with colleagues would assist us in developing a new pedagogy and agency in our teaching practices. This study is primarily concerned with addressing these queries.

Whilst exploring the background literature that informs this research, I found that there has been an increased and sustained interest in science education research on understanding teaching and learning science through scientific argumentation (e.g., Lin, Lin, Potvin, & Tsai, 2019). This interest stems principally from extensive research data that supports the argument that scientific argumentation has become a critical and fundamental component of science education in schools (Driver, Newton, & Osborne, 2000; Henderson, McNeill, González-Howard, Close, & Evans, 2018; Jiménez-Aleixandre & Erduran, 2008). Consequently, international reform documents (e.g., Jiménez-Aleixandre, Mauriz, Gallástegui Otero, & Blake, 2010) and national curriculums (e.g. MoNE, 2013; National Research Council (NRC), 2012) have focused mainly on the nature of science practices and emphasised the value of scientific argumentation in science education as one of the primary objectives of science teaching and learning, demanding that students and teachers need to be encouraged to utilise this approach in science classrooms (McNeill, González-Howard, Katsh-Singer, & Loper, 2016). In England, the term ‘scientific argumentation’ has not been used explicitly in the National Curriculum (NC) for science. Nevertheless, the importance of critical thinking and the justification of claims have been acknowledged as educational objectives of science teaching for several years, as evidenced in the *Ideas and Evidence (2004)* and *How Science Works (HSW) (2007)* components of the NC for science. Scientific argumentation is related to the *'Working*

Scientifically' component of the current NC for science, specifically to the 'development of scientific thinking' and 'analysis and evaluation' (DfE, 2014, p. 214).

The general argument made by those arguing for the integration of scientific argumentation in school science is that in order for students to develop their scientific inquiry and literacy skills (Cavagnetto, 2010; Jiménez-Aleixandre, Rodriguez, & Duschl, 2000) and enhance their capacity to construct a scientific argument. Students must be given opportunities to debate, persuade or convince their peers, pose questions, engage with alternative viewpoints, critique other arguments, practice reasoning and articulate reasons for supporting a particular view (Driver et al., 2000; McNeill et al., 2016). Previous studies have shown that scientific argumentation is considered an essential science practice in science learning; however, it rarely appears in science lessons, as Osborne (2010) argued, and remains a considerable challenge for both science teachers and students (Henderson et al., 2018). To address this challenge, the literature is wide-ranging, and my own study draws on previous studies to frame this research that focuses on the development of science teachers' pedagogy and instructional strategies of scientific argumentation through designing professional development (PD) workshops (e.g., McNeill & Knight, 2013; Osborne, Simon, Christodoulou, Howell-Richardson, & Richardson, 2013; Simon, Erduran, & Osborne, 2006). More recent studies have focussed on supporting teachers in developing their pedagogy of scientific argumentation through teaching resources, such as technology-enhanced learning materials and resources (Marco-Bujosa, McNeill, González-Howard, & Loper, 2017; Simon & Davies, 2019).

It has been emphasised throughout the literature how essential it is for teachers to gain an understanding of the underlying philosophy to develop adequate pedagogical knowledge and skills for teaching science through scientific argumentation (Erduran & Aleixandre, 2008; Osborne et al., 2013). Therefore, understanding the philosophy underlying this scientific practice is vital for teachers to know how to design argumentation activities, how to organise students' groups, how to structure argumentation lessons, how to motivate students to participate in group discussions, and how to evaluate students' work to implement this approach in science classrooms (Berland & McNeill, 2010).

However, previous studies have acknowledged that enhancing scientific practice through scientific argumentation may be challenging due to teachers' hesitancy to implement this approach into science classrooms (Osborne et al., 2013; Sampson & Blanchard, 2012; Simon et al., 2006). Several factors might lead to science teachers' hesitancy. One potential factor is that science teachers have lacked the pedagogical knowledge required to design scientific argumentation lessons or the resources necessary to acquire the skills required to mediate the classroom settings for scientific argumentation (Duschl, 2008; Erduran, Simon, & Osborne, 2004). A further factor is that science teachers often have limited experience and knowledge about learning and teaching science through scientific argumentation in their classrooms (McNeill & Knight, 2013; Osborne et al., 2013) and insufficient understanding of the value of utilising it for science teaching (Sampson & Blanchard, 2012). The implementation of this approach on a superficial level has also resulted in 'pseudo argumentation' (Berland & Hammer, 2012a; McNeill et al., 2016), with the result that students are unable to engage in this practice productively.

To overcome the difficulties mentioned above, Duschl and Osborne (2002) highlight a need for teachers to be guided and supported in their approach to scientific argumentation and assisted by the resources that help them develop their pedagogy and moderate the classroom environment. Osborne et al. (2013) also suggest that teachers need a well-articulated justification to understand its value, video representations of expert use of this practice, identification of important aspects of this approach, and a procedure for providing feedback that assists teachers in identifying both success and failure. Teachers also require a variety of practice opportunities to incorporate new knowledge and pedagogy into practice. McNeill et al. (2016) argue that teachers' experiences with scientific argumentation must go beyond simply defining and describing argumentation practices. These researchers highlight that the emphasis should be on particular teaching skills challenges and difficulties, such as planning instructional strategies that reflect students' needs, organising students to facilitate group discussion, encouraging students to sustain group discussion. To gain a better understanding of the challenges and difficulties teachers face, as well as the various approaches involved in integrating scientific argumentation into science classrooms, more details about teachers' challenges and difficulties, as well as teachers' plans and approaches for incorporating this approach into science classrooms, is still needed.

The substantial literature on scientific argumentation stated before has informed the direction and design of my own study, particularly the work entitled *Enhancing the Quality of Argument in School Science* (Osborne et al., 2004a, 2004b; Erduran et al., 2004; Simon et al., 2006). They focused on developing science teachers' pedagogical knowledge and instructional strategies of scientific argumentation across a two-year period. They also investigated science teachers' argumentation approaches, focusing on the characteristics of their oral contributions that encouraged and supported students' argumentation abilities. However, there is little data about how science teachers planned their lessons either collaboratively or individually to implement them in their classrooms. Other studies have focused on variations in teachers' instructional practice when implementing scientific argumentation in science classrooms (Berland, 2011; McNeill & Pimentel, 2010; Pimentel & McNeill, 2013). For instance, Pimental and McNeill (2013) investigated three science teachers' approaches to whole-class discussion with the goal of enhancing student participation in scientific argumentation. These studies demonstrated that science teachers implement this approach in a variety of ways. However, they only provided limited insight into how science teachers structure their lessons and scaffold argumentation pedagogy throughout their lessons. Understanding diverse emphasises and approaches of scientific argumentation is vital to influence existing classroom practices and incorporate this approach into science teaching. Therefore, I felt the need to extend those studies that focus on teachers' pedagogical development of scientific argumentation by examining how science teachers develop their pedagogy of scientific argumentation and scaffold this approach in their practice over a period of time.

Developing any new pedagogy and teaching practice cannot be accomplished simply by enforced curricular recommendations or through top-down development of teaching activities to be delivered to teachers. Change may be accomplished not only by providing teachers with the materials, resources, and knowledge necessary to engage with this practice but also by actively and collaboratively constructing this practice with them, as well as taking their reflections on their practice into account. Therefore, professional learning initiatives have become more dynamic and peer-based in nature to support teachers in developing effective instructional strategies and facilitating discussion and reflective practice as critical components of professional learning and change (Avalos, 2011). My goal throughout this research was not just to present the underlying pedagogy of scientific argumentation to science teachers but also to collaborate with them on lesson planning by taking their knowledge, thoughts and reflections into consideration.

Teachers may have challenges in evaluating the effectiveness of their instructions and identifying their strengths and weaknesses (Danielson, 2009). Teacher insufficient experience with reflection after implementing a lesson prevents teachers from participating in reflective practice required to develop pedagogy. Therefore, teachers need to enhance and enforce reflective practices to address these challenges after implementing a new instructional strategy in their practice (Danielson, 2009). Teachers may utilise this process to evaluate their planning and instructional strategies, drawing on their strengths and resolving the weaknesses in their practice (Jaeger, 2013). It is necessary to provide opportunities for teachers to reflect while implementing a new pedagogy in practice. In my own study, I focused on how science teachers develop their practices in light of their reflections, emphasising a process known as reflexivity. According to Feucht, Lunn Brownlee, and Schraw (2017), one approach for promoting practice-oriented reflection (reflection for action) is reflexivity, which has the potential to promote in-depth professional learning and long-lasting improvements in education.

Additionally, considering the underlying literature on teacher professional learning, which influences my own study, I found that there has been an increased interest in teacher agency as an emergent and necessary component for teachers' professional learning (Jones & Charteris, 2017). This concept is based on the belief that teachers should be empowered to determine their own learning, leading to more meaningful and effective engagement in instructional improvement processes (Calvert, 2016). During these processes, teachers act purposefully and constructively to direct their own professional learning and also contribute to their colleagues' professional learning.

This concept is considered a valuable tool for evaluating the effective implementation of new innovative teaching strategies (King & Nomikou, 2017). Therefore, it is critical to include this concept in teacher professional learning. However, previous studies take an oversimplified and uncritical approach to the relationship between teacher agency and teacher learning, assuming that teacher agency may necessarily result in positive outcomes, such as enhanced teacher capacity and improved instruction and student learning, as argued by Biesta, Priestley and Robinson (2015). Researchers have recently started to investigate the significance of teacher agency in the context of teacher learning, for instance, by attempting to characterise and understand the elements of teachers' agentic practices (e.g., van der Heijden, Geldens, Beijaard, & Popeijus, 2015; King & Nomikou, 2017; Lu, Leung, & Li, 2021; Pantić, 2015). The results of studies on teacher agency and teacher learning indicate a complex connection between teacher agency and learning in instructional contexts, wherein teacher agency may take a variety of forms and be used to resist or approve new innovations and change or, perhaps most commonly, maintain practices. Therefore, to better assist teachers in pedagogical learning, such as planning and implementing a new instructional approach in their practice, we need to understand the concept of teacher agency and its implications for implementing this new approach.

Previous literature on teacher agency has influenced my own study's rationale and conceptualisation of this concept, particularly the work of Pantić (2015) and van der Heijden et al. (2015). Taking these scholars' conceptualisations of teacher agency into account, I described teacher agency as consisting of four components: a teacher’s sense of purpose (the belief that a particular practice is valuable in terms of achieving a specific outcome), mastery (understanding how to influence the desired outcome in practice), autonomy to act (ability to take risks and make a difference within a given context), and reflexivity (capacity to monitor, evaluate and change one's own practices). Studying these interconnected four components of teacher agency simultaneously and thus examining teacher professional learning through the lens of teacher agency may help us not just in understanding the processes and results of professional learning but also in developing a more nuanced understanding of what occurs when science teachers develop their knowledge and pedagogy for a new approach.

According to Buchanan (2015), agency may be enacted in various ways in practice. Therefore, expanding our understanding of teacher agency by moving beyond an analysis of teachers' perceptions of agency to including an analysis of teacher agency in action would help us better understand the relationship between teacher agency and teacher pedagogical learning. Based on the current literature, there is a research gap in the relationship between the concept of agency and teacher learning. To fill the gap, my study aims to address this argument by examining how science teachers develop their agency over time when implementing scientific argumentation as a new instructional approach and which factors support/hinder the development of agency. I believe that it would be valuable to investigate teachers' pedagogical learning of scientific argumentation through the lens of teacher agency. The way I designed my study with research objectives, and particular questions arise from my understanding of what agency might look like in practice. I have chosen a particular research design that looks at specific ways science teachers have taken on the new practices. My study may lead us to understand how this concept can be useful in a school where teachers are willing to learn and interested in developing their pedagogy but with limited knowledge of how to accomplish this.

1.2 Context of the study

My study was conducted in the setting of a comprehensive secondary school in London, with a particular emphasis on science teaching and learning at the Key Stage Three (KS3) level. At the time of this investigation (between 2017 and 2019), the participating school was implementing a new national curriculum (DfE, 2014), with the first year of instruction scheduled for 2016.

The introduction of scientific argumentation pedagogy in this situation was informed by a two-year study of science teachers' plans and implementations of this approach and students' engagement with this practice. Throughout this investigation, lesson observations were conducted with the purpose of observing a variety of science lessons implemented by three science teachers with their Year 7 (Y7) students over a two-year period to inform the development of scientific argumentation pedagogy through an embedded case study design. The teachers were introduced to teaching science through scientific argumentation and provided with resources for planning and designing argumentation lessons. The argumentation lessons were planned collaboratively by the participant teachers and researcher (myself). Following classroom observations, reflective interviews with the participant teachers on their practice were conducted. A qualitative-interpretive approach was used to analyse the data generated during this study, and the main results will be presented and discussed throughout this thesis. In the following sections, I set out the research objectives formulated, then substantiate my stated purpose and the relevance of my study.

1.3 The objectives of the study

Although scientific argumentation is a significant objective in science education, incorporating it into science classrooms can be a long-term process for teachers and students (Osborne et al., 2004a; Sampson, Enderle, & Grooms, 2013). One solution that has been adopted to address this issue is to provide teachers with resources to help them mediate the learning environment and improve their use of scientific argumentation through collaborative work with colleagues and reflections on their practice over time. It is acknowledged to be essential to provide teachers with some ideas as starting points and assist them when planning and implementing scientific argumentation in their practice.

The main three objectives of this study were as follows:

- To investigate how secondary school science teachers develop their pedagogy of scientific argumentation in the process of planning and implementing argumentation lessons.
    - To compare the scaffolding of argumentation pedagogy of three science teachers as they plan and implement the same argumentation lessons in their classrooms and to emphasise the variations in their practices, approaches and pedagogy.
    - To compare the scaffolding of argumentation pedagogy of two science teachers as they plan and implement the same two argumentation lessons and observe their changes in their pedagogy and practice across two years.
    - To compare one science teacher’s pedagogical changes in her argumentation pedagogy and her students’ written work over a year.
- To investigate how students' written work provides insight into their science teachers' argumentation approaches.
- To investigate how (if at all) science teachers develop their agency and agentic practice in this regard.

1.4 Significance of the study

This study benefits from its unique context as a long-term professional learning initiative through collaborative work and reflection to explore how science teachers develop their pedagogy of scientific argumentation and develop their agency in this regard. Previous studies provided vital information on what science teachers might need to know to incorporate scientific argumentation effectively into their lessons to assist science teachers in improving their pedagogy in this approach. However, the critical issue about these studies is whether teaching science through scientific argumentation involves a fundamental change in teachers’ pedagogies while incorporating this approach into their pedagogy (Osborne et al., 2013; Simon et al., 2006; Zohar, 2008). These studies targeted at improving teachers' ability to teach argumentation-based science lessons must address other fundamental points in constructing knowledge and pedagogy, such as which instructional strategies science teachers use (Zohar, 2008).

This study was conducted over a two-year period to give science teachers the opportunities to provide sustained practice through collaborative work and reflection. The argumentation lessons were planned collaboratively with the aim of expanding science teachers' knowledge and pedagogy regarding scientific argumentation in order for them to integrate it into their instructional practices successfully. Given the importance of this type of sustained practice, I believe that this study offers important implications and an understanding of professional learning needs to assist teachers in developing a new instructional strategy. Research on how teachers incorporate scientific argumentation in their classrooms is still an area that needs further exploration (as provided in this study). Our background knowledge from teacher learning through collaborative work and reflections on practice.

Another potential contribution of this study is theoretical. It not only adds to our understanding of how science teachers plan and implement argumentation lessons through collaborative work with their colleagues and myself as a researcher but also how the concept of agency in practice provides insights into teacher learning. Teacher agency assists us in examining how science teachers develop their pedagogy of scientific argumentation and incorporate this approach in their practice. This study sought to consider the concept of teacher agency and how the development of agency has implications for teachers' professional learning. To support teacher agency in professional learning, it is crucial that we further expand our understanding of the connection between teacher learning, teacher agency, and teachers' pedagogical development, informing our efforts to support teachers in the future.

Currently, we have limited insights into variations in how science teachers develop their knowledge and understanding of scientific argumentation, how science teachers scaffold the pedagogy of scientific argumentation, what they emphasise in their instructions while implementing this approach in their practice or of the degree to which they are able to develop this approach through collaborative work and reflection on their own practices. The further significance of this study is that it contributes to our understanding of teachers' values and perspectives, as well as the challenges and difficulties they experienced and the emphasis they placed on scientific argumentation in science teaching while incorporating scientific argumentation. The values of the participating teachers are especially significant since they have previously volunteered to enhance their understanding and practice and have voluntarily engaged in this development.

1.5 Structure of the thesis

Following this introductory chapter, I will review the five main fields that inform my own study in chapter 2: I will examine the main discussions and ideas generated in the field of science education in England, scientific argumentation in science education, students' argumentation practice, teachers' pedagogical development of scientific argumentation and teachers' practice in scientific argumentation, teacher pedagogical learning, collaboration and reflection in particular, as well as teacher agency in teacher learning and practice.

Chapter 3 will describe the proposed research design, focusing on my research aims and questions, the philosophical perspectives, and ethical considerations that underpin this study. Additionally, this chapter will include detailed information about the research settings and participant teachers, as well as describe the chosen methods and instruments of data generation and analysis.

Chapter 4 will include the main findings generated from the participant teachers' lesson plan meetings and their classroom practices, as three embedded cases: (1) a comparison of three science teachers' argumentation practices in the same lesson within a scientific and socio-scientific issue (SSI) context, (2) a comparison of two science teachers' argumentation practices and pedagogical changes in scientific argumentation across the two years, and (3) lastly a comparison of one science teacher's pedagogical changes in scientific argumentation and her students' written work over a year, and students' written work from each argumentation lesson as an indication of teachers' argumentation approaches.

Chapter 5 will examine the participant teachers' pedagogical development of scientific argumentation using the lens of teacher agency with the purpose of identifying the development of agency in the component of a sense of purpose, mastery, autonomy to act and reflexivity, and the factors that support/hinder the development of teacher agency and agentic practice.

In Chapter 6, I will draw upon the relevant literature to investigate the findings generated by my own study. In addition, this chapter will reflect on the limitations of the study regarding its methodological design, including sampling processes and methods of data generation. Implications from this study's findings, descriptions of possibilities for future research, future teacher learning through collaborative work and reflection, teacher agency in practice, and future development of school practices in scientific argumentation will also be explored.

Chapter 2: Literature Review

A number of science educators and curriculum reformers in England have expressed concerns about teaching science in schools, including what content should be taught and how it is taught. The issue they address is that students are not given the opportunity to see various ways of thinking and the generation of scientific knowledge. This has highlighted the need to bring together conceptual, epistemological, and social objectives to teach students how to construct scientific knowledge, as well as strengthen the connection between science learning and the construction of scientific knowledge. I consider that one solution to the issue of students' access to scientific knowledge and different ways of thinking is for science teachers to incorporate scientific argumentation into their pedagogies, providing opportunities for understanding the processes through which scientific knowledge is generated. My study, therefore, examines the support required by science teachers to develop their pedagogy of scientific argumentation (i.e. professional learning experiences consistent with pedagogical shifts). Additionally, teacher agency has been shown to be essential because agency is necessary for evaluating teachers' decision-making process. Therefore, it might be valuable for evaluating teachers' pedagogical learning in the context of educational practice through the lens of teacher agency.

Consequently, this chapter discusses various fields to contextualise my own study, including gaps in the existing research I will contribute. Firstly, there is a critical examination of the development of science education in secondary schools in England. In section 2.1, I provide a review of the literature with a particular emphasis on the evaluation of science education in England and emerging ideas for teaching and learning scientific argumentation, as well as its implementation in science education. Secondly, in section 2.2, I examine the literature focusing on the significance and implications of scientific argumentation for students in scientific practice. Thirdly, in section 2.3, I undertake a review of the literature about how science teachers develop their pedagogy of scientific argumentation and incorporate it into their classroom instructions. Fourthly, in section 2.4, I focus on the literature exploring teacher professional learning, particularly the components of reflection and collaboration supporting teacher learning and pedagogical development. Finally, in section 2.5, I explore and critique the concept of teacher agency, highlighting how the academic literature emphasises the importance of teacher agency in evaluating teacher pedagogical learning and practice.

2.1 Science education and scientific argumentation

2.1.1 Science education in England

Curriculum innovations are viewed as critical for educational reforms throughout the contemporary period of educational change (Fullan, 2007). For instance, in England, curriculum innovations occurred a significant shift in the practice of science education in schools as known the ‘Public Understanding of Science’, with the aim of creating a scientifically literate society (Duschl, 2008). Revision of the contents and form of such pedagogical approaches have been viewed as significant, supporting the thought that the goals of science education should be connected to practical applications of knowledge in real-world situations (Duschl et al., 2007).

Since the 1980s, the current England NC has undergone six major revisions, with the latest being across all KS in 2013, rolled out from September 2014. One of the objectives of the 1989 NC for Science was the provision of a programme for all students aged between five and sixteen, known as ‘Science for All’, which included both ‘methods of science’ and the development of ‘knowledge and understanding of principles and facts’. The curriculum was structured “around seventeen Attainment Targets (AT) and included the exploration of science (knowledge and understanding of science communication and the application and implications of science report” (Department of Education and Skills, 1989, p. 1). AT1 and AT17 thus ‘bookended’ ATs with the processes and nature of science, including an evaluation of scientific evidence and the history of scientific ideas (Department of Education and Skills, 1989, p. 3) along with an understanding of the various aspects of ‘scientific enquiry’. Both the content and its place within the curriculum have evolved. In 1991, the structure of the NC for Science was simplified. The simplified structure was based on five rather than seventeen AT and labelled Scientific Investigation (Department of Education and Science/Welsh Office, 1991).

Millar and Osborne (1998) undertook a detailed five-year examination of NC for Science Education, including its development to suit the requirements of twenty-first-century learners. This examination resulted in an influential review, entitled *Beyond 2000: Science Education for the Future: A Report with Ten Recommendations*. An essential criticism was that NC for Science Education had been inadequate in developing ‘scientific literacy’, with students receiving a great deal of scientific content knowledge but a limited understanding of the nature of science and its application to their daily lives. This essential criticism led to an improvement of NC to include considerable information on how science works and encourage students to think creatively, draw on various sources of data, and examine the implications of scientific developments in more detail. For example, students at KS3 (aged between eleven and fourteen) were required to learn about “the interplay between empirical questions, evidence and scientific explanations using historical and contemporary examples” (Department for Education and Employment/ Qualifications and Curriculum Authority, 1999, p. 28). Such a change in science education required a commensurate development of pedagogy, including emphasising social construction, encouraging discussion and negotiation, and refocusing attention on how students utilise evidence in constructing arguments, linking data and scientific theories (Erduran et al., 2004).

In 2004, NC for science was updated for students in KS4, placing a greater focus on HSW, organised around two main ideas: firstly, canonical knowledge (i.e. scientific content), and secondly, ‘key concepts/key processes’ (Department for Education and Skills/ Qualifications and Curriculum Authority, 2004). NC for KS3 received similar revisions around 2006, with the strand on ‘key concepts/key processes’ encompassing learning about: ‘applications and implications of science’; ‘critical understanding of evidence’; ‘scientific thinking'; 'communication skills' and 'collaboration with others'. It was launched in 2008, placing even greater importance on HSW. NC developed the phrase HSW to emphasise that 'scientific enquiry' should include not only experimental skills but also an awareness of how scientific knowledge is generated. NC situated scientific argumentation inside the HSW component, emphasising how evidence is gathered through data collection and interpretation in order to support (or reject) concepts and hypotheses. Thus, since then, incorporating scientific argumentation into science education has been considered essential for students to develop their scientific enquiry and literacy. In addition, the justification of claims with evidence has been recognised as an educational purpose, as shown by the *Ideas and Evidence (2004)*[1] and *HSW (2007)*[2]. Osborne et al. (2004a) indicated that NC for science refers to the teaching of ideas, evidence and argument as HSW, arguing that students should understand how scientific knowledge is generated, as well as a more nuanced recognition of the nature of scientific knowledge (i.e. how ideas are generated, analysed, and modified) while acknowledging that the way science in schools reflects the products of science is frequently far too clear-cut, without taking account of any controversy or argument involved in their development.

When I conducted my own study (i.e. between 2017 and 2019) in the context of comprehensive secondary science education and focusing on KS3, the participant school was in the process of implementing the most recent NC for science (DfE, 2014, p. 169), which had removed the terms 'key concepts/key processes' and 'HSW', referring to scientific enquiry as 'Working Scientifically', including teaching: 'scientific attitudes'; 'experimental skills and investigations'; 'analysis and evaluation'; and 'measurement' (DfE, 2014, p. 201). This still entails engaging with scientific processes, including (1) understanding scientific questions; (2) designing experiments; (3)

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[1] Department for Education and Skills and Qualifications and Curriculum Authority, England, and Wales. (2004). Science. The National Curriculum for England. HMSO.

[2] Qualifications and Curriculum Authority (2007). How Science Works. http://curriculum.qcda.gov.uk/key stages 3 and 4/subjects/key stage 3/science/Level descriptions/index.aspx

understanding forms of reasoning; (4) arguing using scientific evidence; and (5) analysing and interpreting data (DfE, 2014). Moreover, Government reports have attributed positive benefits to scientific enquiry, stating that in "schools which showed clear improvement in science subjects, key factors in promoting students' engagement, learning and progress were more practical science lessons and the development of the skills of scientific enquiry" (Ofsted, 2011, p. 6). Therefore, the incorporation of scientific argumentation into science teaching and learning has begun to be seen as essential for accomplishing these objectives, as addressed in more detail in the following section.

2.1.2 Scientific argumentation in science education

This section evaluates the existing body of research associated with the practice of scientific argumentation in science education to provide a context for my discussion of the importance of incorporating this scientific practice into science teaching and learning and its contribution to science learning and teaching.

Bringing together conceptual, epistemological, and social objectives in science education have been recognised as an essential element in science learning (Duschl, 2008), including focusing on scientific practices, such as scientific argumentation. Incorporating scientific argumentation into science teaching and learning then has become a common objective in science education in some countries (MoNE, 2013; NRC, 2012) and has been taken up by various educational organisations and international policy documents (Jimenez-Aleixandre et al., 2010). The science curriculum in Turkey, for instance, has highlighted the importance of incorporating scientific argumentation into science teaching (MoNE, 2013). However, the science curriculum for England has not yet explicitly used the term 'scientific argumentation', although the justification of claims with evidence and arguing using scientific evidence has been acknowledged as educational goals (as previously examined in detail).

Science in schools had been traditionally taught as a collection of distinct facts and theories (Driver et al., 2000) and predetermined experiments to test a variety of scientific concepts, separated from the process of knowledge construction (Osborne, 2005). This approach had failed to offer students opportunities to develop science and acquire scientific knowledge and ways of thinking (Osborne, 2005). This practice has frequently left students unable to understand different interpretations of scientific concepts or evaluate their validity (L. Kuhn & Reiser, 2006). On the other hand, students in classrooms with scientific argumentation approaches are able to propose, support, criticise, modify, justify, and defend their positions on specific scientific opinions, as well as acquire higher-level critical thinking skills (Llewellyn, 2013). However, this demands a different classroom culture and discourse that is distinct from traditional science classrooms (Duschl, 2008).

Before discussing the objectives of incorporating scientific argumentation into science education, I acknowledged the need to define argument and scientific argumentation. Various frameworks and theoretical perspectives define scientific argumentation in a varied manner in teaching and learning science (Jimenez-Aleixandre & Erduran, 2008). For instance, Erduran and Jiménez-Aleixandre (2008) describe scientific argumentation as a form of discourse in which knowledge claims are constructed and evaluated individually and collaboratively in light of empirical or theoretical evidence. Similarly, Duschl et al. (2007) describe scientific argumentation as a dialogical process in which knowledge claims are made, accompanied by supportive evidence, followed by being challenged through listening, talking and writing. Osborne et al. (2004a) also describe an argument as 'the artefact students create to articulate and justify claims or explanations' and argumentation as 'their complex generation process' (p. 998).

I also examined several theoretical perspectives associated with the nature of scientific argumentation in science classrooms, including as: (1) a practice of structuring arguments (McNeill, 2011; Osborne et al., 2004a) ; (2) a process of developing an understanding of scientific literacy (Cavagnetto, 2010; Chen, Park, & Hand, 2016); (3) a process of learning methods of scientific enquiry and literacy (Duschl & Osborne, 2002; Erduran et al., 2004; Jimenez-Aleixandre et al., 2000; Zohar & Nemet, 2002); (4) a process of justification, persuasion, and sense-making (Berland & Reiser, 2009; Sampson, Grooms, & Walker, 2011); (5) a practice of reasoning (Kim & Roth, 2018); (6) a practice of critical thinking (Giri & Paily, 2020); (7) a discussion of controversial and SSI (Kahn & Zeidler, 2019; Sadler, 2004) and (8) an activity promoting critical reasoning and decision-making (Cavagnetto & Hand, 2012; Venville & Dawson, 2010). In my own study, I define scientific argumentation as a social interaction process in which knowledge claims are constructed through discussion and supported by evidence, and an argument as an artefact created by students individually or collaboratively, combined with a practice of discussing science in scientific and SSI contexts and structuring scientific arguments (McNeill, 2011; Osborne et al., 2004a).

While reviewing the background literature that informs my own study, I noticed that there had been an increased and continuous interest in educational research investigating and understanding science teaching and learning through scientific argumentation (Lee, Wu, & Tsai, 2009; Lin et al., 2019; Lin, Lin, & Tsai, 2014). This has resulted in substantial research supporting claims that scientific argumentation has emerged over previous decades as an essential component of science education in schools (Driver et al., 2000; Erduran & Jiménez-Aleixandre, 2012; Erduran, Ozdem, & Park, 2015; Faize, Husain, & Nisar, 2017; Jiménez-Aleixandre & Erduran, 2008; Jiménez-Aleixandre et al., 2010; McNeill, Marco-Bujosa, González-Howard, & Loper, 2018; Osborne et al., 2004a). That is why it is still necessary to investigate teaching and learning science through scientific argumentation as an essential component of science education.

Driver et al.'s (2000) seminal paper entitled *Establishing the norms of scientific argumentation in classrooms* highlighted two main reasons for integrating scientific argumentation in teaching and learning science. This resulted in subsequent studies concluding that, in order to encourage engagement with scientific argumentation, students should first acquire an accurate picture of science, including the social construction of scientific knowledge and the ability to offer explanations and evaluate evidence (Duschl & Osborne, 2002). Second, they should acquire competence in generating and analysing relevant arguments for controversial issues, as well as developing the capacity to think scientifically about and comprehend scientific practice relating to daily problems (Newton, Driver, & Osborne, 1999). This suggests that science education should improve students' capacity to understand and practice scientific argumentation in a scientific manner, as well as recognise both the strengths and weaknesses of arguments in scientific and SSI contexts (Erduran, Osborne, & Simon, 2005). This concurs with Osborne et al.'s (2004a) suggestion that considering scientific argumentation as a fundamental component of science teaching serves two primary purposes: first, a practical function, relating to learners' engagement in conceptual and epistemic objectives and second, ensuring students' scientific thinking and reasoning becomes observable, so enabling instructors or teachers to carry out formative assessments. This, therefore, forms an essential underlying purpose of teaching science through scientific argumentation (Duschl & Osborne, 2002). These studies have helped me understand that the incorporation of scientific argumentation into science lessons is essential for students’ engagement with science and the assessment of their learning.

The practice of scientific argumentation provide a major contribution to science learning and teaching from a variety of perspectives, such as (1) enhancing understanding of the epistemological foundations of science (Driver et al., 2000; Manz, 2015); (2) improving the conceptual understanding of science (Dawson & Venville, 2010; Osborne, 2005; Zhou, 2010); (3) assisting students in becoming accustomed to the practices of current scientific culture (Jiménez-Aleixandre & Erduran, 2008); (4) encouraging students' involvement in the cognitive, social, and epistemic aspects of scientific thinking and reasoning, in order to understand how knowledge is constructed collectively (Jiménez-Aleixandre & Crujeiras, 2017; Osborne, 2010); (5) assisting students in understanding how scientific knowledge is constructed and modified over a period of time (Bricker & Bell, 2008; Jiménez-Aleixandre & Erduran, 2008); (6) developing conceptual learning and skills related to scientific argumentation (McNeill & Pimentel, 2010; Sampson, Enderle, Grooms, & Witte, 2013; Venville & Dawson, 2010); (7) helping students become scientifically literate (Duschl et al., 2007); (8) encouraging students to discuss their reasoning with their peers and identify inconsistencies in their own, and others' reasoning (Aydeniz, Pabuccu, Cetin, & Kaya, 2012; Bricker & Bell, 2008); (9) enabling students to acquire scientific thoughts, provide evidence for their explanations, and evaluate alternatives (Sampson, Grooms, & Walker, 2009); (10) helping students become aware of the variable nature of scientific knowledge and the prominent role of empirical data (Maloney & Simon, 2006).

As mentioned earlier, one advantage of incorporating scientific argumentation into science teaching is that it supports students in improving their conceptual understanding of science. Venville and Dawson's (2010) investigation of the role of scientific argumentation in science teaching found a significant improvement in high school students' conceptual understanding of genetics. Their study identified an improvement in the sophistication of students' argumentation skills through practice and the use of explicit instructions. It is indicated that explicit instructions in scientific argumentation strengthen students' argumentation skills to participate in argumentation through the construction, evaluation, and criticism of scientific knowledge, using a variety of reasoning processes and practices (Ford, 2015). Scientific argumentation also enhances their ability to act scientifically, provide evidence for a claim, as well as critique claims, evidence and methods (Ford, 2015). The above studies support the claims that scientific argumentation provides a significant contribution to the teaching of science. However, it rarely appears in science classrooms, as Osborne (2010) argued. Therefore, it is necessary to investigate why scientific argumentation rarely occurs in science teaching and learning.

Certain factors should be addressed while teaching and learning scientific argumentation. According to Dawson and Venville (2010), two factors are critical for enhancing scientific argumentation: the writing frames utilised to guide student thinking and the context in which argumentation is addressed. Similarly, Duschl and Osborne (2002) suggested two primary criteria for successfully implementing scientific argumentation in the science classroom. Firstly, students must be given appropriate resources (i.e. a writing frame, template and/or sentence starters) to assist them in developing their arguments, including information and data to support or refute a claim. Secondly, science lessons should be designed to allow students to engage with and participate in discussion, with several attempts to support scientific argumentation focusing on providing scaffolding for students' understanding of the form of a strong argument, in order to emphasise the importance of scientific evidence (Erduran et al., 2004; Sandoval & Reiser, 2004; Zohar & Nemet, 2002). These attempts demonstrate that scaffolding can assist students while producing their written work, i.e. scientific explanations (McNeill et al., 2006; Sampson & Clark, 2009).

Firstly, as Dawson and Venville (2010) emphasise, the writing frames were utilised to guide student thinking and inform students about scientific argumentation in my study. I considered this point as fundamental for not only recording students' written work, with the writing frames acting as a reference for recognising their opinions on scientific and SSI contexts but also for identifying teachers' approaches to scientific argumentation. Examining how science teachers scaffold their scientific argumentation lessons is also critical for gaining a deeper understanding of how (and whether) students' written work varies, and yet there is no evidence to support this claim in the literature.

Secondly, the science context, either scientific or SSI, in which scientific argumentation is addressed needs to indicate a purposeful choice. Despite students being provided with resources (i.e. a writing frame or template) for constructing arguments, less attention has been paid to the contexts that motivated this practice (Manz, 2015). As noted by Osborne et al. (2004a, p. 997) "just giving students scientific or socio-scientific context to discuss is not sufficient to ensure the practice of valid argumentation". This indicates that the classroom environment should be structured to facilitate students' engagement with this practice and participation in discussion as well as the negotiation of differing opinions to achieve an agreement when working collaboratively on a scientific or SSI context. Therefore, it is necessary to pay close attention to how context influences the emergence of scientific argumentation in science education and how science teachers choose context to incorporate this approach into their practice. Osborne et al.'s (2004a) study showed that implementing scientific argumentation in a scientific context is more challenging than implementing it in an SSI context. This has been considered due to SSI settings including informal thinking, being often open-ended, lacking distinct correct answers, and creating an atmosphere for discussion and decision-making (Chen & Xiao, 2021; Sadler, 2004; Sadler & Donnelly, 2006). Thus, students can argue their views using personal experiences, ethical ideals, and scientific data, prompting them to relax when discussing these issues (Dawson & Venville, 2009). Khishfe (2014) and Sadler (2004) highlighted increased attention being placed on the use of SSI in science classrooms due to their creation of an engaging learning environment in which students can practice scientific argumentation. SSI-based teaching has been validated as a successful strategy for fostering students' scientific literacy (Duschl et al., 2007; Erduran et al., 2005), including the ability to make sense of science and make informed decisions in everyday situations (Chen & Xiao, 2021; Sadler, 2004).

However, a significant limitation of utilising SSI discussions in science classrooms concerns the potential for students to lack the adequate scientific knowledge to make appropriate decisions when there is no correct answer (Lewis & Leach, 2006). According to Cavagnetto (2010), students involved in SSI discussions have fewer opportunities to participate in authentic scientific practice through controlling variables, designing experiments, and gathering data to support their arguments. By contrast, scientific contexts are based on entirely scientific knowledge. Students may need a deeper understanding of science knowledge to engage with this practice. Therefore, I consider it essential to examine the reason behind the teachers' context choices by determining how science teachers implement a scientific and SSI context in the classroom, focusing on their approach and emphasis, as well as the background knowledge of their students.

It is vital to highlight that scientific argumentation is not simply a verbal activity but also entails selecting: (1) relevant knowledge; (2) suitable materials and sources; and (3) appropriate skills in argumentation (Erduran & Jiménez-Aleixandre, 2012). Students are more likely to acquire these if they are integrated into the curriculum and explicitly addressed through modelling and providing a task structure (Erduran & Jiménez-Aleixandre, 2008; Osborne et al., 2004a). This suggests providing opportunities for students to engage with and participate in scientific practices and discussions in order to acquire a greater depth and breadth of knowledge in specific areas.

Although previous studies have shown that scientific argumentation has long been a goal of science education and provide a major contribution to the learning and teaching of science, it rarely appears in science classrooms (Osborne, 2010). It remains a significant challenge for teachers and students (Henderson et al., 2018). There remain a number of issues when it comes to its incorporation into science classrooms, which can therefore prove a long process for both teachers and students (Osborne et al., 2004a; Sampson et al., 2013). The following sections evaluate first the literature on students' practice of scientific argumentation, focusing in particular on their engagement with and participation in scientific argumentation, including both their capabilities and challenges, and then on teachers' practice of scientific argumentation, with a particular focus on their pedagogical development and practice, including their knowledge, beliefs and challenges.

2.2 Students' practices of scientific argumentation in science classrooms

This section explores the body of research on promoting students' practice of scientific argumentation to contextualise my discussion of students' engagement with scientific argumentation. Firstly, I review research on instructional strategies for supporting students' practice in developing their argumentation abilities. Secondly, I examine how students engage with and participate in scientific argumentation, concluding with a discussion of their skills and challenges in scientific argumentation.

As previously mentioned, students' engagement with scientific argumentation has been highlighted as fundamental for science education; such as in developing their understanding of central science concepts and epistemic procedures (Bricker & Bell, 2008; Duschl, 2008; Manz, 2015) and improving understanding of how scientific knowledge is constructed (Jiménez-Aleixandre & Crujeiras, 2017; Osborne, 2010). As a result, considerable research has been conducted on how to increase students' engagement with these practises, for example, by developing appropriate instructional strategies to utilise science lessons (Berland & Hammer, 2012b; Osborne et al., 2004a); proposing instructional approaches to assist students in improving their argumentation skills (Jiménez-Aleixandre et al., 2000; Sampson & Clark, 2009); supporting students' oral and written argumentation skills through instructions (Berland & McNeill, 2010; Chen, Hand, & Park, 2016); and developing students' critical thinking skills through instructions (Giri & Paily, 2020).

Several aspects must be addressed when it comes to the development of students' argumentation skills, with Duschl (2008) arguing that scientific argumentation for school science should emphasise two convergent aspects: "social negotiation (e.g., how to critique, debate, and evaluate an argument) and epistemic understanding of an argument (e.g., what counts as data, evidence, and claim, and the relationships between these components)" (p. 277). Students are required to support their claims with evidence, as well as give explanations for their connections between their claims and evidence (Berland & Hammer, 2012a; Erduran et al., 2004; McNeill et al., 2006; Sampson et al., 2011; von Aufschnaiter, Erduran, Osborne, & Simon, 2008). Students need explicit instructions to identify what counts as a claim and evidence, the relationships between these components. This allows students to subsequently understand the relationship between evidence and claim and the importance of justification in a scientific argument when engaging with scientific argumentation (Simon, 2008) as students often sought accurate answers rather than undertaking the process of making claims, presenting evidence, and reasoning (McNeill & Pimentel, 2010). Additionally, the social negotiation process helps students identify their weaknesses in the construction of an argument, so it facilitates the strengthening of an argument and, ultimately the conceptual understanding of a topic. Thus, these two forms of language can help teachers assess their students' development of argumentation abilities in social and epistemic contexts.

Further aspects, which are talk and writing as two critical components of argumentation practice, should be established in science lessons (Berland & McNeill, 2010; Chen et al., 2016; Chen, Park, & Hand, 2016; Ford, 2012). These two components are required for scientific argumentation since they are acquired through a series of discussions and writing-to-learn experiences (Chen et al., 2016). While examining students' abilities in talk and writing, the quality of students' written arguments is typically slower to develop than that of their verbal communication (Berland & McNeill, 2010). When students focus only on oral communication, they learn science superficially (McNeill & Pimentel, 2010). Therefore, it is significant to establish these two aspects in argumentation practice.

These aspects mentioned above may be addressed by providing continuous instructional support, sufficient assistance, and opportunities for students to develop their argumentation skills. Continuous instructional support over time strengthens students' capacity for argumentation practice and their comprehension of epistemic requirements for scientific reasoning (Ryu & Sandoval, 2012). However, D. Kuhn, Zillmer, Crowell, and Zavala (2013) argued that time alone does not ensure that students acquire argumentation skills. By providing sufficient assistance, and opportunities for students, they are able to develop their argumentation skills; even young students are capable of participating in scientific argumentation (McNeill, 2011; Reznitskaya et al., 2007; Ryu & Sandoval, 2012). For example, McNeill's (2011) examination over a school year of 5th-grade students' views of argument, evidence and explanation found that adequate assistance allows them to acquire an understanding of scientific reasoning and the ability to create evidence-based explanations. Transferring science lessons from activity-based to argument-based is also essential to enable students to understand fundamental scientific practices and develop an understanding of disciplinary ideas through the use of questions, data collection and claim generation in response to evidence (Duschl, 2008; Ryu & Sandoval, 2012, 2015; Sampson et al., 2011).

It is also essential to provide students with sufficient scaffolding to assist them in expressing their opinions supported with evidence in talk and writing. Implementing instructional strategies with the appropriate scaffolding is crucial for pedagogical effectiveness in order to facilitate scientific argumentation. For instance, Jin and Kim's (2021) study examined how two types of Argument-focused Metacognitive Scaffolding (AMS), i.e. questioning and prompting, and modelling of thinking, helps students' argumentation in an elementary science classroom. They found that AMS assisted students in engaging in argumentation by promoting awareness of the objectives and evidence-related norms of argumentation and their ability to participate in metacognitive practice. In addition, they found that when AMS was progressively decreased, students were able to maintain their argumentation and metacognitive skills. There is still a need to investigate how science teachers scaffold their argumentation lessons by examining their argumentation pedagogy and how students' responses, such as their written work, provide insight into their teachers' approaches and scaffolding of argumentation during the argumentation lessons.

Berland and Hammer (2012b) argued that, even when students may not have formal preparation in scientific argumentation, students are capable of making claims, supported with evidence and reasoning, as well as challenging each other's views and employing prior knowledge to construct new understandings. This point argues that it is reasonable to expect students to utilise their knowledge to constitute effective evidence, as well as explanations for their claims to argue, analyse, defend, and refute (Duschl, 2008; Ryu & Sandoval, 2012, 2015; Sampson et al., 2011). Therefore, it is necessary to investigate further the relationship between teachers' instructional strategies and scaffolding of argumentation pedagogy and students' argumentation, such as their written argumentation.

Students may be unaware of the importance of justification and epistemic understanding of argumentation, i.e. perceiving it as a means of assessment rather than an activity for collaboratively constructing knowledge (Erduran & Jiménez-Aleixandre, 2008; Ryu & Sandoval, 2015). Therefore, science teachers should clarify this practice as a means of activity for collaboratively constructing knowledge. It is also essential for students to understand the importance of justifying claims with evidence and scientific reasoning (González-Howard, McNeill, Marco-Bujosa, & Proctor, 2017; McNeill, Gonzalez-Howard, Katsh-Singer, & Loper, 2017). For example, McNeill et al. (2017) noticed that teachers offer time for students to explore the use of data to support a claim by asking, "What is your evidence?" to help students see the value of supporting claims with evidence. Another study by González-Howard et al. (2017) observed science teachers using language supports (i.e. modelling around the use of evidence) to justify students' claims as an epistemic aspect of the argument. These processes help students engage with scientific argumentation.

As mentioned earlier, students' argumentation skills are strengthened by sustained practices, explicit instructions, and scaffolding. The fact that it continues to be a significant challenge for students (Henderson et al., 2018) as students have difficulties in (1) justifying their claims both in talk and writing

(Erduran et al., 2004); (2) defining and evaluating evidence (McNeill & Krajcik, 2007; Sadler, 2004) and offering convincing evidence (Berland & Reiser, 2009; McNeill, 2011); (3) justifying their use of data in written arguments (Bell & Linn, 2000; Walker & Sampson, 2013); (4) differentiating and connecting every day and scientific language (Yore & Treagust, 2006); (5) establishing a connection between verbal and written argumentation practices to enhance knowledge construction and critique (Berland & McNeill, 2010); and (6) struggling to transfer their oral and written argumentation abilities from one context to another, arguing that ‘‘knowledge of argumentation discourse may not readily transfer, because it may depend on feedback from conversational partners’’ (Reznitskaya, Anderson, & Kuo, 2007, p. 455).

In summary, the above studies helped me develop a more nuanced understanding of students’ argumentation practices across different contexts, over time, and students’ abilities and struggles. I set out to explore Osborne et al.’s (2004a) and Sampson et al.’s (2011) claim that, in order to facilitate engagement with scientific argumentation, teachers need to develop scientific argumentation pedagogies through a combination of explicit instructions, continuous support, appropriate contexts and scaffolding. Therefore, scientific argumentation supported by explicit instructions, sustained support, and scaffolding needs further research to improve understanding of effective ways of assisting students in improving their capacity to engage with and participate in scientific argumentation. This suggests a need to examine how science teachers scaffold their argumentation lessons and how science teachers’ approaches influence students’ argumentation, such as students’ written work in this practice in my own study.

To support students in developing argumentation skills, there is the need for a fundamental change in teachers’ pedagogy to teach science through scientific argumentation (Simon et al., 2006). Teachers are expected to establish an environment appropriate to questioning, evaluate how students engage, and establish the structure and components of an argument (Chin & Osborne, 2010; Venville & Dawson, 2010). Additionally, teachers are required to encourage student-student interactions, develop students' argumentation, provide evidence-based practice in either scientific or SSI context and give attention to opposing lines of argument (Osborne et al., 2004a). To accomplish this, science teachers have been provided with professional learning opportunities to improve their knowledge and understanding of teaching science through scientific argumentation. In the following section, I will critique the literature on how science teachers develop their pedagogy of scientific argumentation and incorporate it into their classroom instructions.

2.3 Teachers' pedagogical development and practice of scientific argumentation

This section reviews the body of research on teachers' pedagogical development of scientific argumentation and their instructional strategies in this practice. The literature provides context for the examination of science teachers' pedagogical knowledge and understanding of scientific argumentation, as well as their values, beliefs, and challenges in this approach. First, I address PD designed in England with the aim of assisting teachers' pedagogy of scientific argumentation. Second, variations in teachers' practice are evaluated to give a deep understanding of how science teachers implement this pedagogy in their classrooms, with an emphasis on teachers' values, beliefs, and challenges in scientific argumentation. I conclude this section by examining what is required to support teachers in their pedagogical development and practices.

2.3.1 Teachers' pedagogical development of scientific argumentation

Over previous decades, great emphasis has been dedicated to science teachers' pedagogical development and instructional strategies of scientific argumentation through PD initiatives/workshops focusing on strategies of scientific argumentation (McNeill & Knight, 2013; Osborne et al.,, 2013; Simon et al., 2006) and teaching resources, including technology-enhanced learning tools (Simon & Davies, 2019; Marco-Bujosa et al., 2017). Various courses also have been designed to enable both pre-service and in-service science teachers to practice and analyse the instructional strategies of scientific argumentation (Ozdem Yilmaz, Cakiroglu, Ertepinar & Erduran, 2017). There are also PD workshops for other teachers working in elementary schools to assist them with their professional development of scientific argumentation (Martin & Hand, 2009; Osborne, Borko, Fishman, Gomez, Rafanelli, Reigh, …. & Berson, 2019).

There have been a few PD projects in England dedicated to assisting science teachers with their professional development of scientific argumentation. The first project (which served as a foundation for my own study) entitled *Enhancing the Quality of Argument in School Science* (Erduran et al., 2004; Osborne et al., 2004a, 2004b; Simon et al., 2006). This project placed particular emphasis on teachers' pedagogical development to use scientific argumentation as instructional practice in science classrooms. This study evaluated the quality of scientific argumentation provided by science teachers at the beginning and end of the year and identified higher-quality argumentation in students' arguments. This project identified several successful instructional strategies and revealed that the teacher's initial understanding of argumentation significantly impacted their pedagogical development (Simon et al., 2006). However, this project focused exclusively on developing teachers' use of the argumentation approach without providing any insights into teachers' beliefs about the value of this approach in their practice or teachers' lesson plans while implementing this approach in different science contexts. The second project designed by them aimed to produce a pack of resources, called Ideas, Evidence, and Argument in Science (IDEAS) (Osborne et al., 2004b). These researchers collaborated with science teachers for a year to develop these materials to assist them in incorporating scientific argumentation into science classrooms.

Another PD project, entitled *Minding Gaps in Argument* (Erduran & Yan, 2009), involved a series of workshops led by researchers in collaboration with secondary science teachers. The objective was to bridge the gap between educational policy, research, and practice in scientific enquiry and argumentation due to these topics emerging through the HSW component of NC. This project encouraged teachers to reflect on their own practice and collaborate with both colleagues and researchers (Erduran & Yan, 2009).

A further PD project, *Talking to Learn, Learning to Talk in Secondary Science* (Osborne et al., 2013), attempted to help science teachers adopt a dialogic pedagogical approach. The project placed particular focus on developing the ability of science teachers to use scientific argumentation instructional practices in science classrooms. They asked lead science teachers to collaborate with their colleagues over a two-year period to integrate scientific argumentation into science lessons. The importance of integrating collaboration and reflection were highlighted as essential elements for advancing teachers’ pedagogical development in this project (Osborne et al., 2013). However, there is no available publication from this project detailing the changes in science teachers’ practices over two years as a consequence of collaborative work and reflection. Therefore, there is a need to investigate how science teachers develop their pedagogy of scientific argumentation through collaborative work and reflection on practice over time.

A recent PD project focused on teachers’ pedagogical development of scientific argumentation through providing online resources for teachers (Simon & Davies, 2019). This project examined two components of teachers' pedagogical development: (1) teachers’ relationship with web-based resources in their own learning and (2) teacher pedagogical development of scientific argumentation through online materials (which also served as a foundation for my own study). The multimedia representations of scientific argumentation in actual classrooms proved critical for supporting teachers' professional learning, particularly by promoting reflection on their practices.

Notably, all these projects emphasise the need to assist teachers in: (1) developing argumentation pedagogy for its implementation in practice; (2) understanding the underlying philosophy of scientific argumentation and instructional practices; (3) appropriating its norms in science classrooms. These projects revealed that teachers' understanding and development of this pedagogy, as well as its application in classroom practice, varied considerably. Therefore, it is essential to evaluate variations in teachers’ pedagogical development of scientific argumentation and their classroom practice in different science contexts and over time.

2.3.2 Teachers' practice of scientific argumentation

One area of research emphasised mainly how science teachers incorporate scientific argumentation into their lessons. Science teachers use a variety of teaching strategies, including both traditional classroom procedures and scientific argumentation, while implementing this practice in their lessons. Therefore, it is critical to investigate a variety of instructional approaches for scientific argumentation to improve current classroom practices and encourage scientific argumentation (Berland, 2011).

Several researchers have examined how classroom communities adopt argumentation strategies in science lessons (Berland, 2011; Berland & Reiser, 2009). For example, Berland and Reiser (2009) found that, despite using similar instructional activities, different classes employed a variety of ways in response to variations in teachers' understanding of the purpose of argumentation. Pimental and McNeill (2013) investigated five scientific teachers' strategies for facilitating whole-class discussions in order to enhance students' involvement with argumentation. They found variations in teachers' structuring of whole-class discussions and their movement throughout the discussions, which seemed to reinforce the limited nature of the students' responses. They also found that teachers rarely used probing questions. As stated previously, Simon et al. (2006) investigated science teachers' scientific argumentation strategies to identify the characteristics of their oral contributions, emphasising those that encouraged and supported scientific argumentation across a two-year period. They found that some teachers incorporated various argumentation processes into their teaching practice; however, others failed to evolve their scientific argumentation practices. Sandoval, Enyedy, Redman, and Xiao (2019) examined teachers' efforts to encourage effective scientific argumentation in primary school science lessons. As a result, they identified differences in teachers' use of discourse movements to help students become aware of their contributions during classroom discussions.

These publications mentioned above indicate a broad range of variations in the argumentation strategies implemented by teachers, which influence students' engagement with this practice. Their findings demonstrated the various ways in which science teachers use scientific argumentation in their classrooms. However, no research has been conducted to examine factors that contribute to the variations, such as in teachers' use of scientific argumentation across contexts (both scientific and SSI contexts) and years, teachers' belief about the value of scientific argumentation, approaches, and challenges in scientific argumentation. These factors are addressed in further detail in my own study.

Teachers' beliefs concerning the value of scientific argumentation for promoting students' learning relates to their instructional decisions (McNeill et al., 2013; Sampson & Blanchard, 2012; Simon et al., 2006). In other words, teachers' values are often mirrored in their instructions. For example, a teacher who views science as a collection of pure facts and theories may struggle to lead argumentation activities as a means of understanding how scientific knowledge is constructed and criticised over time (Ryu & Sandoval, 2012). When teachers consider scientific argumentation valuable for encouraging students' critical thinking, communications and interactions with each another (McNeill et al., 2013; McNeill & Krajcik, 2008), they can identify the distinctions between traditional and argumentation-based science lessons (Berland & Reiser, 2009) and thereby understand the benefits of teaching science through scientific argumentation. However, previous research shows that most teachers have unsophisticated beliefs regarding the value of teaching science through scientific argumentation (Sampson & Blanchard, 2012; Simon et al., 2006). A recent study by Simon and Connolly (2020) aimed to help teachers develop a new set of values concerning teaching science through scientific argumentation by addressing their existing beliefs about the teaching of science and providing new ideas for improving their practices. Their study encouraged teachers to enhance their recognition of the social and epistemic objectives of argumentation activities, such as effective group work.

Examining what teachers emphasise in their lessons while implementing scientific argumentation in practice and how students respond to their teacher's approaches while engaging with and participating in this practice is essential to understanding teachers' pedagogical strategies. Erduran (2008) presented a taxonomy for categorising the pedagogical strategies used by teachers to teach scientific argumentation. It indicated that teachers who emphasise interaction and listening tended to prioritise modelling and exemplification by positioning themselves within an argument and justifying their position with evidence, constructing and evaluating arguments, combined with counterargument and debate, and reflecting on argumentation. This study also aims to examine these aspects.

Moreover, teachers' views of their students' abilities are another factor influencing their instructional strategies in scientific argumentation. Katsh-Singer, McNeill and Loper (2016) indicated that teachers undermine scientific argumentation goals by emphasising information transmission above other instructional objectives. Consequently, teachers' engagement in scientific argumentation varies according to their views about their students' abilities and socioeconomic status. Teachers are also concerned with their students' prior experience, knowledge and motivation to engage in and extend classroom discussion and their own capacity to manage discussions (Pimentel & McNeill, 2013). These factors affect teachers' scientific argumentation practices. To eliminate these factors, teachers must change their underlying beliefs and values regarding science teaching and learning and their understanding of pedagogical knowledge (Zohar, 2008). Additionally, teachers must recognise the value of teaching science through scientific argumentation, including scientific argumentation's role in creating a classroom where students can engage and participate in argumentation (McNeill, 2009; McNeill & Pimentel, 2010). Teachers' beliefs concerning the use of scientific argumentation must be examined over time to identify any changes in their beliefs, particularly as they may also affect their instructional decisions (Katsh-Singer et al., 2016; Sampson & Blanchard, 2012).

Teachers' knowledge of scientific argumentation also affects how they incorporate this approach into practice. McNeill and Knight (2013) argued that, even after participating in an intensive PD for scientific argumentation, teachers frequently exhibited a limited understanding of both the structural components and epistemic knowledge of argumentation. Thus, teachers must understand argumentation to improve classroom discussions by emphasising, firstly, the structural aspect (e.g. what counts as a claim or evidence, how to decide if evidence is supporting or refuting a specific claim) and, secondly, epistemic aspects (e.g. the construction, justification and evaluation of arguments).

Additionally, they demonstrate various levels of competency in their pedagogical content knowledge of scientific argumentation, with some experiencing difficulties in choosing appropriate questions and analysing classroom discussions for both structural and epistemic features of argumentation (McNeill & Knight, 2013). This also highlights that teachers should not only understand this practice in terms of both the structural and epistemic aspects but also be able to assess student responses accurately and instantly and provide an immediate response.

According to Ryu and Sandoval (2012), a teacher's continuous use of epistemic questions (e.g. "How do you know?" or "How do you persuade others?") assists students in recognising the importance of argumentation standards and negotiating their meaning. The use of complex and open-ended questions allows teachers to encourage their students to produce multiple claims (Berland & Reiser, 2009). Those teachers who understand the importance of using epistemic questions and creating a scientific argument can develop the argumentation skills of their students. These teachers also utilise questions to promote discussion: “Can anyone think of anything that somebody might say to oppose that? What might someone say which makes that argument a bit flawed?” (Simon et al., 2006, p. 252). Pimentel and McNeill (2013) found that many teachers also tend to use questions eliciting basic phrases or short sentence responses rather than encouraging students to challenge and defend one another.

Teachers have been introduced to a variety of different forms of argumentation activities and pedagogical strategies and encouraged to develop their pedagogical approaches and incorporate this into their practice (e.g. Simon et al., 2006; Simon, Richardson, Howell-Richardson, Christodolou & Osborne, 2010). They were also provided with the pedagogical knowledge necessary to implement scientific argumentation into their practices through PD workshops, curricula and online resources. Yet, teachers still find it challenging to incorporate this approach into science classrooms (Henderson et al., 2018; Osborne et al., 2004a; Osborne et al., 2013). Thus, it is crucial to explore why scientific argumentation is a challenge for teachers.

Additionally, it is also vital to cultivate science teachers’ pedagogical knowledge and their attitudes towards, and evaluation of, the practice of scientific argumentation (Beyer & Davis, 2008; McNeill et al., 2017; Pimentel & McNeill, 2013; Sampson & Blanchard, 2012; Simon et al., 2006). For example, science teachers may lack adequate knowledge, experience and understanding of scientific argumentation and thus are hesitant to incorporate it into their classrooms. Some have argued that many science teachers lack the pedagogical knowledge required to design argumentation lessons and the resources necessary to acquire the skills to mediate the classroom environment for scientific argumentation (Duschl, 2008; Erduran et al., 2004). Another reason concerns a lack of pedagogical experience, the demands of the curriculum, and preventing teachers from engaging students in the construction of knowledge through both whole-class and small-group discussions (Newton et al., 1999), particularly as this requires an understanding of educational reforms and argumentation strategies (Zembal-Saul, 2009; Zohar, 2008). It has been indicated that teachers tend to lack either familiarity with teaching science through scientific argumentation (Jiménez-Aleixandre, 2008) or the confidence to change classroom practices and promote scientific argumentation (Sampson & Blanchard, 2012). They may feel uncomfortable with this approach, given that it requires a fundamental shift in their current pedagogies and practices (Simon et al., 2006; Zohar, 2008). Although teachers improve their ability to discuss specific aspects of their students' arguments, they do not enhance their use of scientific argumentation in classroom discussions. Some studies have shown that teachers' prior experiences (McDonald & Heck, 2012) and the objectives teachers set for their students and their own understanding of scientific argumentation practice (McNeill et al., 2016) tend to affect their classroom practices and instructional strategies for argumentation.Therefore, teachers require a variety of pedagogical strategies and resources which offer practical guidance to address these challenges and support the integration of scientific argumentation into their lessons (Duschl & Osborne, 2002; Erduran et al., 2004; Osborne et al., 2004a; Zohar, 2008).

Any attempt to teach science through scientific argumentation must be followed by continuous efforts to encourage and support teachers in developing their instructional strategies to include scientific argumentation since this approach differs from most teaching practices (Martin & Hand, 2008;

Osborne et al., 2013; Simon et al., 2006). Martin and Hand (2009), for instance, conducted a case study as part of a two-year research project focusing on a fifth-grade science teacher as she attempted to include scientific argumentation into her regular teaching practices. They identified that a teacher-centred strategy predominated up until the final six months of the PD programme, emphasising the challenges to effective pedagogical change. It is critical to allow teachers time to practice and gradually improve their scientific argumentation skills according to their current approaches, abilities and/or knowledge of argumentation.

Duschl and Osborne (2002) argued that teachers must be guided and supported in their approach to scientific argumentation and assisted via resources to help them develop their pedagogy and moderate the learning environment. Furthermore, Osborne et al. (2013) suggested that teachers require a well-articulated justification for the practice to comprehend its value. This could include video representations of expert use of the practice, identification of critical aspects of this approach, and a feedback procedure that assists teachers in identifying both the teacher’s success and failure to implement scientific argumentation. Effective resources may be required to successfully teach science through scientific argumentation (Simon et al., 2006; Zohar, 2008). Additionally, teachers need practice opportunities to integrate new instructional strategies and methods into their classroom instruction. According to McNeill et al. (2016), teachers' interactions with scientific argumentation must go beyond simply identifying and explaining scientific argumentation processes. They emphasised the need to develop certain teaching abilities, such as developing instructional strategies relevant to students' needs, organising students to encourage group discussion, analysing the quality of argumentation, and encouraging students to maintain group discussions (McNeill et al., 2016).

Moreover, Osborne et al. (2013) emphasised that PD for teachers should not only focus on the acquisition of new skills but also on improving their understanding of the theoretical justification for any pedagogy. This highlights the need for additional research into instructional strategies for engaging in scientific argumentation tasks and designing activities to address science teachers' lack of confidence and competence in this area (McNeill et al., 2016;

Osborne et al., 2013). Teachers need to not only recognise the importance of scientific argumentation but also understand how it can be planned and integrated into classroom practice. Simon and Richardson (2009) contended that a more analytical approach to activity planning is required to accomplish the purposes of scientific argumentation and increase students' science knowledge. This is vital as, in the absence of teachers with the appropriate skills, students are unlikely to acquire a sophisticated understanding of the argumentative character of science or engage in effective argumentation. Kolsto and Ratcliffe (2008) emphasised the importance of teachers' awareness of the complexity of scientific argumentation context, particularly its use of dialogue between various individuals (e.g., student-student, teacher-student, small groups and whole-class) concerning a variety of phenomena. Teachers must, therefore, be able to demonstrate the application of scientific argumentation in a variety of contexts and offer opportunities for students to express the cognitive processes involved in these activities (Zohar, 2008).

The difficulties experienced by teachers in implementing such strategies, particularly as this demands that they: firstly, share their values and experiences with a community and be willing to take risks (Loucks-Horsley, Stiles, Mundry, Love & Hewson, 2010), secondly, desire to change their current practices; thirdly, have opportunities for action; fourthly; have the capacity to reflect in order to understand emerging patterns of change fully; and finally, can extend their personal knowledge and experience (Hoban, 2002). It is indicated that it takes at least eighteen months to effectively incorporate scientific argumentation into science teaching (Martin & Hand, 2009); however, this finding is uncommon in the research and thus can be concluded as not necessarily true in practice (Benus et al., 2013). Thus, developing competency in implementing new teaching approaches takes time, recognising that teachers should be supported with continuous reflection and feedback (Clarke & Hollingsworth, 2002; Zohar, 2008) as sustaining professional learning in conjunction with collaboration and reflection can assist teachers in developing more effective strategies and incorporating scientific argumentation into practice. Additionally, it is critical to ascertain teachers’ skills in planning and implementing scientific argumentation in their classrooms, as well as how they acquire the relevant pedagogical knowledge for development (Desimone, 2009), which should be created collaboratively by colleagues and informed by teachers' own practices. To explore these points in detail, the following section focuses on the current literature examining teachers professional learning, emphasising the importance of reflection and collaboration.

2.4 Teachers' professional learning

This section evaluates the existing body of research associated with teachers' professional learning to provide a context for my discussion of teacher learning. The literature offers a background for the discussion of science teachers as reflective and collaborative learners. Firstly, I discuss the use of different terms, i.e. PD and professional learning in teacher education and then evaluate several theories of teacher learning to provide a foundational understanding of how teachers can develop a new pedagogy (section 2.4.1). I conclude with a focus on the necessity of reflection (section 2.4.2) and collaboration (section 2.4.3) in teacher learning.

2.4.1 Teacher professional learning in teacher education

Several researchers have promoted approaches that account for the complex relationship between teacher learning and practice (e.g., Opfer & Pedder, 2011, Boylan, Coldwell, Maxwell, & Jordan, 2018). The dominant discourse on teacher learning and practice continues relatively linear and process and product-focused (Opfer & Pedder, 2011). These linear approaches presume that teachers have full agency to account for their learning, affecting how we support teachers and students access to high-quality teaching and learning (e.g., Opfer & Pedder, 2011). Consequently, the value of placing emphasis on developing teachers' pedagogical knowledge and practice was the main objective of PD, which is often conceived as workshops, seminars, programmes, and training (Calvert, 2016). While reviewing a considerable number of studies emerging from an extensive search of recent literature to define features of 'effective' PD for teachers, Darling-Hammond, Hyler, and Gardner (2017) identified that it should: "(1) be content-focused; (2)

incorporate active learning based on adult learning theory; (3) support collaboration, usually in job-embedded contexts; (4) utilise models and modelling for effective practice; (5) provide coaching and expert support; (6) offer opportunities for feedback and reflection; and (7) be of sustained duration" (pp. v-vi). They concluded that successful PD should include the majority of these components and that one-off workshops were ineffective. Many researchers have accepted these PD elements and integrated them into a number of ways by educators to assist teachers in their professional learning.

Studies that have opposed the 'one-off' version of PD, recognising that this structure of PD can: (1) be passive; (2) be frequently external to a school; (3) lack a specific focus on instructional practice; and (4) fail to provide opportunities for reflection (Camburn, 2010). Clarke and Hollingsworth (2002) also argued that traditional models of PD are inherently flawed because they fail to allow for the construction of new thinking or to value existing knowledge and experience, and thus presumes that teachers can enact new knowledge from external factors and apply it directly to their personal and professional domains. This is the main reason PD has generally proved ineffective (Clarke & Hollingsworth, 2002). Despite its suggested ability to offer individual and school improvement, teachers also consider PD a one-size-fits-all and isolated approach, disconnected to individual needs (Coggshall, 2012). Thus, in this approach to PD, teachers have only limited control over the concepts presented and can lack guidance for their implementation (Varela, 2012).

To address this, O'Brien and Jones (2014) suggested that the term 'professional learning' be more effective in capturing the critical characteristics of reflective practice, critical evaluation and continuous learning. This has led me to use the term 'professional learning' in my own study to exemplify the essential characteristics of reflective practice and continuing professional learning because the majority of current perspectives argue that successful professional learning should be: firstly, intense, ongoing, and linked to practice (Darling-Hammond et al., 2017); secondly, allocate sufficient time and opportunity for collaboration and reflective practice; and thirdly, monitored and assessed continuously to ensure teachers are able to incorporate ideas into their classroom practice (Loucks-Horsley et al., 2010).

One advantage of professional learning may be the opportunity for teachers to continue their learning in their own classrooms. Therefore, the length of professional learning appears to impact both teachers and students' learning due to the incorporation of practice-based applications facilitated by study groups and/or coaching over a period of time (Darling-Hammond, Wei, Andree, Richardson, & Orphanos, 2009). This process is characterised as a continuous process that assists teachers in developing and sustaining their understanding of classroom practices through engagement with various classrooms (Simon & Campbell, 2012; Wallace & Loughran, 2012), as well as allowing for principles such as "teacher ownership, focus on practice, coherence, collegiality, active learning and systemic support" (Wallace & Loughran, 2012, p. 303). The process of designing and organising professional learning should include a commitment to objectives such as goal settings, planning, choosing, implementation, and evaluating the outcomes, as the current study took these arguments into account.

To theorising the nature and process of professional learning for teachers, Boylan et al. (2018) contrasted various analytical models of teacher learning, focusing on the relevant: (1) components; (2) aim and scope; (3) explicit and implicit theories of learning; (4) processes of change and agency; and (5) philosophical foundations. Boylan et al. (2018) indicated that, unlike other models of teacher learning, Clarke and Hollingsworth's (2002) Interconnected Model of Teacher Professional Growth emphasises teachers' agency, including the prioritisation of different classroom outcomes i.e. student motivation or classroom management. Emphasising the concept of teacher agency in teacher learning is significant to evaluate the development and implementation of a new pedagogy. A more in-depth discussion of this concept will be provided in the next section (section 2.5).

It is essential to acknowledge the voices and perspectives of individual teachers engaging in professional learning (Simon & Campbell, 2012). Teachers' desire for change contributes to their learning experience, understanding of the theoretical underpinnings of the curriculum, and concurrent teaching strategies, as well as recognition of perceived advantages for students. Research into individual learning indicates that this motivates teachers to improve their own and their students' learning to overcome the obstacles associated with new strategies (Simon & Campbell, 2012). Teachers' beliefs are also vital as teachers may have differing perceptions of the effectiveness of new approaches, depending on their initial beliefs and experience. Clarke and Hollingsworth's work exemplified the continuous cycle of learning and development, showing that teachers can: (1) change their beliefs but not their practices: (2) modify their practices but not their beliefs; and (3) improve their practices but not their students' results. Thus, Clarke and Hollingsworth (2002) highlighted that, in order for teachers to develop or learn, it is vital that change takes place in various areas of influence. Specifically, successful strategies for changing teachers' beliefs and practices include learning new ideas from colleagues, as well as trying out new ideas in classrooms followed by reflection (Ketelaar, Beijaard, Boshuizen & Den Brok, 2012). I, therefore, built into my study the opportunity for teachers to be thoughtful in their articulation and dissemination of their learning experience and look for approaches to relate theory to practice.

A consistent learning process also supports teacher learning through fostering a collaborative culture of professional learning and "follow up, feedback from colleagues, and reflection" (Coggshall, 2012, p. 4). Therefore, teacher learning should integrate the development of teachers' knowledge with their professional learning in school and classrooms, as well as their social growth, which includes collaboration with others in similar contexts (Simon & Campbell, 2012). Thus, teacher learning is intended to foster personal and professional development to promote effectiveness, and collaboration is essential for advancing pathways for gaining knowledge and enabling teachers to evaluate their own progress and encourage student outcomes. My own study examined these perspectives, embodying the underlying assumption concerning the beneficial impact of collaboration with others and reflections on practice.

I, therefore, conclude from the literature that it is vital to provide opportunities for teachers to interact, including through professional meetings (such as the collaborative lesson planning meetings that I held in my own study) and the design of instructional materials (Wallace, 2003; Wallace & Loughran, 2012). I also agree with Wallace's (2003) viewpoint that professional learning activities for teachers should take place in various contexts, including classrooms and collaboration with other members of the school, school, or the broader education community (Wallace, 2003). This suggests that teacher learning is socially generated and includes collaborative learning, and thus needs to provide diverse opportunities for teachers to participate in communities and share innovative insights into the development of teaching and learning (Wallace, 2003).

According to Loughran (2002), risk-taking is an “important principle of learning and teaching, explaining that learning about teaching required a pushing of boundaries of practice” (p. 64). Thus, teachers continually shape and reshape their understanding and their practice; in this way, “teachers construct concrete, detailed knowledge, develop and store in relation to the specific learner, classroom and activity contexts, and access for use in similar situations” (Hennessey, 2014, pp. 6-7) by continually attempting to put theory into practice, while simultaneously using practice to refine the theory. The nature of teaching necessitates teachers to constantly make connections between those aspects they learn outside of any formal instruction and those aspects they discover during instruction, thus bridging the gap between theoretical and practical knowledge. It also requires teachers to implement new strategies to challenge their comfort level and enhance their learning. This indicates that integrating new approaches into instruction is an evolutionary process dependent on the specifics of the context, i.e. the teacher’s prior experience, his/her beliefs concerning the instructional approach and the available resources.

An extensive examination of these professional learning approaches has led to a consensus concerning the beneficial impact of active engagement, teacher voice, collaboration, and reflection. This indicates that it is critical to establish an atmosphere where teachers feel comfortable sharing ideas, learning from one another, reflecting on their practices, and making adjustments to improve student outcomes. The purpose of this current study was to provide science teachers with the opportunity to design argumentation activities collaboratively, both with their colleagues and a researcher (myself), and then implement them in their classrooms as a new pedagogical practice, followed by reflecting on their practices both individually and collaboratively.

The following sections evaluate the importance of collaboration and reflection in both teacher learning and pedagogical development.

2.4.2 Teacher reflection for professional learning

As noted above, reflection forms one of the essential components of professional learning and is a complex phenomenon characterised by several theories. In this section, I first discuss different types of reflections and their relationship to teacher learning. Secondly, there is a brief description of reflection within the learning process. Finally, there is a focus on this study's discussion of individual and collaborative reflection on practice.

Various scholars, including Dewey (1933) and Schön (1984), have linked reflection to education and teacher learning. *How We Think* (Dewey, 1933), along with Schön's (1984) emphasis on the importance of knowledge in action, has recognised reflection as a critical learning process for teachers. Dewey (1933) viewed reflection as an aspect of the educational process, enabling the learner to make sense of personal experience on a deeper level of understanding through concentration and careful consideration. The process of reflection is considered to be an "active, persistent, and careful consideration of any belief or supposed form of knowledge, in the light of the grounds that support it, and the further conclusions to which it tends" (Dewey, 1933, p. 6). In addition, Dewey's (1933) introduced the concept of reflective thinking by arguing that individuals are unable to reach conclusions about a concept until they have investigated alternative thought processes and solutions. Reflective thinking transfers individuals away from recurring thoughts and behaviour towards thoughtful and planning activities, facilitating the possibility of further development (Dewey, 1933).

Schön (1983) suggested two levels of reflection: (i) reflection-in-action and (ii) reflection-on-action, partly based on Dewey's (1933) work. Reflection-on-action describes how teachers utilise reflection to inform their instructions, i.e. their daily practice, including the lessons taught and student participation. This is a critical skill for teachers as they plan lessons and consider the development of their students. By contrast, reflection-in-action refers to teachers who reflect throughout the process of their instructions. The optimum time for reflection-in-action is within the lesson or activity. Schön (1983) considered that, over time, the practitioner builds up a repertoire of examples, skills and connections. The range of previous experience also facilitates understanding of the unfamiliar as both similar to and different from issues the individual has already explored. Thus, teachers draw on this fund of practical knowledge as they continuously balance their intended lessons against their actual classroom. Reflection-for-action is the process of considering future actions with the objective of enhancing or changing practice. This sort of reflection requires teachers to anticipate what will happen during a lesson and to reflect on their previous experiences before a lesson occurs (Farrell, 2013).

Critical reflection is emphasised as the most in-depth and advanced form of reflection (Brookfield, 2015; Hatton & Smith, 1995) and thus a critical component of teacher learning, resulting in changes to understanding and instructional practices (Brookfield, 2005). It is employed by teachers when they make connections to philosophical understanding while examining instructional practices to align their teaching with the various learning styles represented in the classroom (Hatton & Smith, 1995). It incorporates an examination of thoughts and beliefs through the examination of current values, information, assumptions, perceptions, interpretations, and expectations while making connections between ideas, experiences and knowledge, as well as the ways these form an individual's practice. A critically reflective teacher does not depend only on assumptions but considers the possible outcomes of each scenario (Shandomo, 2010). Furthermore, critical reflection enables teachers to reject the most straightforward answer and dig deeper, challenging their assumptions (Brookfield, 2015). Thus, it allows teachers to acquire and act on new ideas and improve their instructional practices.

Reflection is also considered as a means of improving instruction (Camburn, 2010). Each of the three forms of reflection-for-practice, reflection-in-practice, reflection-on-practice described above as fundamental to teachers' professional learning needs to be adaptive before, during and following instruction. However, the challenges of capturing thinking taking place during activity mean that, in my own study, it was more effective for me to investigate reflection before and after instruction, i.e. reflection-for-action and reflection-on-action. This suggests that teachers can use reflection to assist them in:

firstly, making decisions (i.e. prior to giving a lesson); secondly, planning interactive decisions (as a consequence of reflecting-for-action); and thirdly, evaluation decisions (made as a result of reflecting-on-action).

However, Feucht, Lunn Brownlee, and Schraw (2017) argued that reflection alone does not ensure effective practice. One way of fostering action-oriented reflection (i.e. reflection-for-action) is to emphasise reflexivity, which uses the reflection process as a trigger for the next action. Reflexivity has the potential to promote in-depth professional learning and so generate sustained educational change (Feucht et al., 2017). Reflection becomes reflexivity when it is informed by recent experience, whereby an intentional internal dialogue results in changes to educational strategies, expectations, and beliefs, which then affects the following action. In my own study, the lesson planning meetings served as a space for teachers' reflection both before and following instruction (reflection-for-action), while the subsequent interviews allowed teachers to reflect after instruction and use this reflection to plan future lessons. Additionally, reflexivity is a component of agency. Therefore, it is essential to evaluate the relationship between teacher agency and teacher learning in teacher pedagogical development.

As previously stated, reflection forms a critical component of professional learning to improve teachers' practice and serve as a catalyst for change (Clarke & Hollingsworth, 2002). Thus, initiating the type of change sought by my own study was also dependent on the participants' efforts to incorporate scientific argumentation into their science teaching, including (1) sharing their experiences, including their successes and failures; (2) discussing the strengths and weaknesses of their instructions; and (3) reflecting on their practices. However, any lack of consistent reflective practice prevents them from effectively evaluating how their students responded to their instructional strategies, along with the strong and weak points of the lesson (Danielson, 2009). Therefore, it is important for teachers to create time after applying a new instructional strategy in their lessons in order to enhance and implement reflection.

In my own study, the participant teachers were asked to reflect on their practice following each implementation of the argumentation lessons. However, this was not necessarily a routine process due to teachers' lack of awareness of the benefits of reflection after teaching (Danielson, 2009). Datnow, Park and Kennedy-Lewis (2013) noted that many secondary school science teachers do not actively reflect due to a lack of adequate time. As was the case with my participant teachers as well, teachers were often faced with issues of time constraints. This implies that teachers would be less able to determine which aspects are successful in the delivery of lessons. I, therefore, consider that, since reflection forms a significant component of the teaching practice, along with individual enrichment, science teachers need to take appropriate action to develop their reflective skills. I also argue that while teachers may be hesitant to spend more time away from planning and teaching, reflective strategies can offer support in developing a more successful approach.

The significance of becoming a 'reflective practitioner' has been emphasised in the Teaching Standards (DfE, 2013), supported by the framework for beginning teacher education (Ofsted, 2015). Recent England government policy (DfE, 2016) has placed additional emphasis on the need for teachers to reflect on their practice while at the same time explicitly encouraging a collaborative approach. Despite this, both Ofsted (2016) and policymakers (DfE, 2016) have recognised a shortage of ongoing professional learning facilitating such reflection.

The literature discussed above suggests that the advancement of instructional practices can be accelerated and improved through the use of reflective practices, particularly in conjunction with colleagues (Colbert, Brown, Choi, & Thomas, 2008) as professional learning opportunities (Clarke & Hollingsworth, 2002; Varela, 2012). Colbert et al. (2008) noted that teacher reflection and collaboration during professional learning opportunities result in the more significant application of the acquired pedagogy. Thus, as previously mentioned, collaboration is another crucial element of teacher learning. Therefore, the following section examines the significance of collaboration as an aspect of teacher learning.

2.4.3 Teacher collaboration for professional learning

A distinct body of literature has been devoted to the discussion of collaboration in teacher learning, including the establishment of communities of practice. As mentioned in section 2.4, collaboration is often considered to be vital for teachers' professional learning (Stoll, Bolam, McMahon, Wallace, & Thomas, 2006; de Vries, Jansen, & van de Grift, 2013). The current forms of teacher collaboration primarily emphasise dialogue and the sharing of ideas, as well as focus on enhancing teaching practice (Hargreaves & O'Connor, 2017). Taking this emphasises into account, this current study touched on how collaborative lesson planning meetings were beneficial for improving teachers' scientific argumentation teaching practices.

Research has shown that teachers tend to collaborate with their peers and share their teaching practices when given the opportunity (Danielson, 2009). Collaborative work enables teachers to (1) share their pedagogical knowledge; (2) reflect on their teaching practices; (3) provide collaborative support or peer feedback; and (4) design teaching methods in a collaborative manner (Vangrieken, Dochy, Raes & Kyndt, 2015).

Over the previous decades, professional learning communities (PLCs) have gained the attention of academics engaged with professional teacher learning. Darling-Hammond et al. (2017) viewed PLCs as exemplary forms of PD and learning. Stoll et al. (2006) proposed five essential criteria in the promotion of PLCs: (1) shared values and visions; (2) collective accountability; (3) reflective professional enquiry; (4) collaboration; and (5) group and individual learning. PLCs consist of groups of teachers meeting regularly, systematically, and continuously to participate in learning cycles to develop their individual and collective capacity for teaching and enhancing student outcomes (Hairon, Goh, Chua & Wang, 2017; Stoll et al., 2006). These processes allow a group of teachers to establish environments conducive to continuous, sustained professional learning (Vangrieken, Meredith, Packer, & Kyndt, 2017), including (1) developing competence and confidence in the practice's knowledge base; (2) utilising this to make and justify their decisions; and also (3) establishing professional agency and identities. Therefore, it is essential to create a collaborative professional learning culture in schools

(Hargreaves & Fullan, 2012). After considering the characteristics of PLCs, I argue that teachers should be given opportunities to provide input into defining their individual development needs and time for small learning communities to investigate challenges faced in the classroom and reflect on results through collaborative work.

I further examine one of the advantageous outcomes of teacher collaboration: teachers' greater opportunity to overcome challenges and improve their teaching practice. However, in order to encourage effective collaboration, including facing challenges, schools need to provide time for both professional learning and collaborative practices (Reeves, 2006). Like other studies, my own study has identified that teachers are currently given insufficient time or opportunity for collaboration with their colleagues, which forms a significant barrier to professional learning in the workplace (Lohman, 2006). Teachers rarely observe each other's lessons or collaborate on creating lesson plans in order to advance their pedagogical learning (Kwakman, 2003).

However, a lack of collaborative opportunities for learning has been identified as detrimental to the development of schools (Bakkenes, Vermunt & Wubbels, 2010; Kwakman, 2003). Teachers rarely use the professional community or their students as resources for their own learning and agency (Pyhältö, Pietarinen & Soini, 2012; Soini, Pietarinen, Toom, & Pyhältö, 2015). When teachers recognise students and colleagues as essential resources, they are able to perceive themselves as accountable and significant participants in a reciprocal collaborative learning community (Kwakman, 2003). Furthermore, Bevins and Price (2014) emphasised the value of collaboration between academics and teachers in teacher professional learning. It is also essential to provide an environment where teachers and academics can work collaboratively and create collaborative relationships.

As previously emphasised, PLCs has been explicitly linked to the development of teacher agency because they support agency, which leads to enhanced learning, responding to, and driving reform (Lipponen and Kumpalainen 2011), with Soini et al. (2015) identifying peer support as essential for the development of agency. Spending time collaboratively with colleagues and experienced facilitators/experts can strengthen teacher agency over time (Philpott & Oates, 2017). To assist teachers in understanding and developing new pedagogy, the literature suggests that academics need to obtain a greater understanding of experiences of agency, which influence how (and to what extent) teachers interpret and implement instructional and pedagogical innovations (King & Nomikou, 2017).

Teachers should recognise the need to engage their colleagues' support to facilitate change, and those able to manage their new learning intentionally and responsibly at both the individual and community level (i.e. as being agentic) perceive themselves as pedagogical experts (Vähäsantanen, 2013). Similarly, van der Heijden et al. (2015) observed that agentic teachers understand the benefits of collaboration for peer support and, more significantly, for implementing change. Therefore, collaboration is essential for developing teacher learning and agency, which supports pedagogical knowledge and practice. The following section examines the conceptualising of teacher agency, its role in professional teacher learning, and evaluating teachers' pedagogical development.

2.5 Teacher agency

There has been little attention paid to the role of teacher agency and its significance for initiating change theoretically or empirically in education (Biesta et al., 2015). The primary reason is that the concept has generally lacked clarity of definition in terms of its core meaning. It is multidisciplinary and abstract, encompassing various understandings from different disciplines. Thus, firstly, I start with discussing some of the more common understandings of agency to clarity my own definition of this concept (section 2.5.1). Secondly, I examine teacher agency from various perspectives, including how I conceptualise teacher agency in this current study (section 2.5.2). Finally, in section 2.5.3, I outline this concept in relation to teacher learning in the context of pedagogical development.

2.5.1 Different theoretical conceptualisations of agency

The concept of agency has now emerged as a central element in the social science discussion, being conceptualised from a range of disciplinary viewpoints (Archer, 2000; Biesta & Tedder, 2007; Emirbayer & Mische, 1998; Giddens, 1984). Numerous scholars have argued on how agency should be defined.

Giddens (1984) defined agency as the ability ‘to intervene in the world, act otherwise, make a difference and exercise some sort of power (p. 14). According to Giddens (1984), some of the main features of agency consist of intentionality, which is influenced by ‘knowledgeability' and the human capacity for reflexive monitoring of the self and social contexts. Individuals are *purposeful agents* engaging in intentional acts they know or believe will lead to a specific quality or result. This is achieved through their understanding of their actions (*competence*), with competent actors able to rationalise and motivate both their own actions and those of and others. Another feature of human agency concerns the degree of power actors can mobilise within social systems that assume *autonomy* and interdependency. The extent to which agents' intent, knowledgeability, and reflexivity are exercised is determined by their degree of authority and autonomy within specific frameworks (Giddens, 1984). This necessitates an examination of the impact of various structural variables on teachers' agentic practice, *i.e. a sense of purpose, competence, the scope of autonomy, and reflexivity*. I argue that examining these components of agency over a period of time may assist in understanding key insights into how teachers develop their agency to achieve their learning. Additionally, examination of these components of agency can assist in understanding a fundamental question concerning the ways teachers direct their individual and collective agency towards achieving their professional responsibilities, including in the face of enormous constraints. Giddens (1984) views agentic action as evident in performing in a varied manner (and consciously) in a circumstance in which an individual has the option to make a different choice. In addition, the significance of Giddens's (1984) theory is that it implies that social (or organisational) systems may change throughout time as a result of the action of individual and collective agents.

On the other hand, other scholars argue that agency encompasses more than an individual's capacity and willingness to act or resist. Archer's (2000) critical realism theory of agency rejected a clear distinction between structure and agency, instead emphasising the idea of 'culture’. According to Archer (2000), agency is always collective, while individuals change the environment through interaction with others, although not in the manner that any single agent intends. Their effectiveness is completely reliant on their interpretation of their environments. Human beings have agentic power because they are *capable of reflecting on* and evaluating social circumstances, as well as envisioning alternative futures and working with others to bring about change (Archer, 2000).

Emirbayer and Mische (1998) also conceptualised agency in a manner that overcomes the one-sidedness of current theories, which tend to focus either on the experience and expertise of individuals, the orientations guiding their work or on judgement i.e. decisions individuals make concerning ay potential action. Emirbayer and Mische (1998) argued that achieving agency requires a combination of past influences, future orientations, and engagement with the present. From this point of view, achieving agency considers the dynamic interaction of these three aspects and how it evolves depending on the structural context of action (Emirbayer & Mische 1998). In addition, context and structure are also important in Emirbayer and Mische’s (1998) view of agency as being “temporally constructed engagement with different structural environments” (p. 970). In practice, all three dimensions contribute to varying degrees, forming a ‘chordal triad of agency', in which all three aspects resonate as distinct (but not necessarily harmonic) tones (p. 972).

An ecological view of agency, like that of Emirbayer and Mische (1998), is based on action–theoretical perspectives conceptualised with an emphasis on how agents respond to challenging circumstances (Biesta & Tedder, 2007). Rather than emphasising human agency, the ecological perspective views it as developing through actor-situation interactions as a consequence of a situated combination of individual input, accessible resources, and contextual and structural effects (Biesta & Tedder, 2007). This situates agency inside those contexts in which agents act on their ideas, values, and attributes in response to a specific situation, while individuals develop agency through actively engaging with components of their contexts-for-action, including individual efforts, available resources, and other environmental circumstances. This approach understands agency as the potential to act within contexts-for-action in a temporal-relational setting. Therefore, agency should be conceptualised from an individual construction of life courses through choices and actions.

2.5.2 Conceptualising teacher agency

This section examines the increasing number of empirical studies focusing on teacher agency within an educational context, including understanding the components of agentic teachers' practices in educational development (Eteläpelto, Vähäsantanen & Hökkä, 2015; Eteläpelto, Vähäsantanen, Hökkä & Paloniemi, 2013; Hadar & Benish, 2019; van der Heijden et al., 2015; Kauppinen, Kainulainen, Hökkä & Vähäsantanen, 2020; King & Nomikou, 2017; Lu et al., 2021; Pantic, 2015; Priestley, Biesta & Robinson, 2015b; Rajala & Kumpulainen, 2017; Vähäsantanen 2013). The majority of these studies focused on various aspects of agency to describe teacher agency and analyse teachers' agentic practices in educational contexts in a variety of ways.

Priestley, Biesta and Robinson (2015a), for instance, conceptualised teacher agency from an ecological perspective and developed a model for understanding teacher agency concerning classroom activities by drawing on Emirbayer and Mische's (1998) temporal/relational conception of agency and Biesta & Tedder's (2007) ecological aspect of agency, taking into consideration that teacher agency is an emergent phenomenon of the ecological circumstances in which it is enacted. These researchers also emphasised the critical role of both individual capacity and contextual factors in shaping and enacting agency. This viewpoint integrates the concepts that agency is enacted in the present, shaped by prior experience and directed towards the future, taking into account both short- and long-term perspectives.

On the other hand, Eteläpelto et al. (2013) conceptualised professional agency from a subject-centred, socio-cultural perspective as "exercised when professional subjects and/or communities influence, make choices and take stances on their work" (p. 61). This suggests that it consists of (1) acting intentionally, (2) exercising control, (3) making decisions, (4) having the ability to influence the working environment, and (5) implementing practices. Additionally, they examined professional agency in terms of both individual and societal dimensions of human activity, aiming to gain better knowledge of the agentic manifestations that are relevant for examining professional learning in the workplace.

Pantić (2015) stated that there is currently only a limited understanding of the nature of teacher agency and how it works in schools and that it is, therefore, vital to identify contributing factors and those factors that support or prevent its implementation. This led her to develop a model for examining teacher agency based on established theories (Archer, 2000; Giddens, 1984) and suggesting recommendations and refinements for practical application. Pantić (2015) defined agency as intentionality or *a sense of purpose*, alongside *competence to accomplish an objective* and *some degree of autonomy*. She argued that these three components facilitate reflection on and recognition of potential improvements as a fourth component of reflexivity. I agree with her conclusion that teachers can make autonomous decisions about how they teach and manage their classrooms, and thus their agency remains social and context-dependent, rather than dependent on the application of research-generated knowledge. Thus, teachers' actions in a given context can be viewed as the result of complex connections between “their personal and professional beliefs and dispositions; degrees of autonomy and power; and interactions with other actors within the social contexts in which they work” (Pantić, 2015, p. 760). Teachers' individual and a collective sense of purpose, competency, the scope of autonomy, and reflexivity are all intertwined in her approach, as is the meaning-making of their current structures (i.e., roles and resources) and cultures, which Pantić describes as “complex interrelationships” (i.e., relational and ideational contexts).

van der Heijden et al. (2015), in a similar manner to Pantić (2015), identified similar components (reflection on practice, a strong foundation in practice-mastery, risk-taking and being collaborative), arguing that teacher agency is motivated by an internal need to reflect and external pressure to meet expectations. In distinguishing between internal and external factors, these authors conceptualise agency in ecological terms, in line with Emirbayer and

Mische's (1998, p. 969) suggestion that "actors are conceived not as atomised individuals, but as active respondents within nested and overlapping systems." Teachers with agentic practices should reflect on their behaviour consistently and systematically throughout their career and possess a strong foundation in their subject area and instructional practice to address any issues in their work and the wider environment (van der Heijden et al., 2015). Additionally, agentic teachers must take "creative risks" and be willing to question their current system, valuing collaboration both for peer support and for allowing a change in their school (van der Heijden et al., 2015).

The work of Pantić (2015) and van der Heijden et al. (2015) have influenced my own study's rationale and conceptualisation of this concept. Taking these scholars' conceptualisations of teacher agency into account, I described teacher agency as consisting of four components: a teacher's sense of purpose (the belief that a particular practice is valuable in terms of achieving a specific outcome), mastery (understanding how to influence the desired outcome in practice), autonomy to act (ability to take risks and make a difference within a given context), and reflexivity (capacity to monitor, evaluate and change one's own practices). Studying these interconnected four components of teacher agency simultaneously and thus examining teacher professional learning through the lens of teacher agency may help us not just in understanding the processes and results of professional learning but also in developing a more nuanced understanding of what occurs when science teachers develop their knowledge and pedagogy for a new approach.

2.5.3 Teacher agency in professional learning

The concept of teacher agency has become increasingly significant in discussions of professional teacher learning (e.g., Eteläpelto et al., 2013; Jones & Charteris, 2017; Philpott & Oates, 2017). There is a focus on enabling teachers to shape their own learning, resulting in more meaningful and effective engagement in teaching practice (Calvert, 2016). This concept is considered as a critical component of professionalism, suggesting that agency is necessary to maintain the (re)construction of the professional knowledge associated with practices (Jones & Charteris, 2017; Lai, Li & Gong 2016;

Oolbekkink-Marchand, Hadar, Smith, Helleve & Ulvik, 2017; Vähäsantanen, Hökkä, Paloniemi, Herranen & Eteläpelto, 2017). This point indicates that insights into teacher agency concerning teacher learning have the potential to clarify the processes and outcomes of professional learning (Evans, 2017), such as the pedagogy of scientific argumentation examined in my study in terms of the four components of teacher agency. Teachers exercise their agency in a variety of ways concerning their professional identity and practice, as well as view pedagogical practice with peer support as valuable (Kauppinen et al., 2020). Thus, teachers with agency do not passively respond to learning opportunities but are aware of their learning choices as a means of achieving their personal goals (Calvert, 2016).

Several studies have concentrated on determining the influence of teachers' personal backgrounds (e.g., beliefs and values) and dispositions on their agency (Biesta et al., 2015; Bonner, Diehl & Trachtman, 2020; Hadar & Benish-Weisman, 2019; van der Heijden et al., 2015; Tao & Gao, 2017). For example, Biesta et al. (2015) examined the impact of teachers' beliefs on their perceptions, judgements, decision-making and actions, namely engagement with the present and thoughts about the future (Biesta et al., 2015). Their findings, while recognising the need for collaborative learning and reflection, indicated that teachers' views exert a significant impact on their daily work. I concur with the view that teacher agency embodies personal values and beliefs and affects teachers' ability to self-regulate (Hadar & Benish-Weisman, 2019).

Studies on teacher agency have also tended to focus on self-*perception* (Buchanan, 2015; Lasky, 2005; Pyhältö et al., 2012, 2015; Vähäsantanen, 2015), without exploring its practice, which seems limited, particularly as teachers tend to negotiate their response to change with others. However, these studies leant towards adopting an oversimplified and uncritical approach to the relationship between teacher agency and teacher professional learning and assumed that increased agency would result in more positive teacher learning outcomes (Biesta et al., 2015). I, therefore, consider that moving beyond teachers' perceptions to an analysis of agency in action would be most beneficial in seeking to understand the connections between agency and professional learning. I further consider that, due to the critical role of teacher agency in professional learning, it is vital that such agency is supported in multiple ways, including through collaborative work (Philpott & Oates, 2017) and providing room for reflection (Jones & Charteris, 2017). It is also crucial to emphasise the advantages of developing teacher agency. This is the conceptualisation of teacher agency in teacher learning that I explore in my own study.

The development of teacher agency is, therefore, not simply a matter of professional learning aimed at improving abilities and expertise; it also requires a consideration of cultures and structures (Priestly, Robinson & Biesta, 2012). Priestly et al. (2012) considered the importance of social, cultural and environmental factors in the development of teacher agency, highlighting several key factors, including the influence of colleagues and students, collaboration and school culture. The quality and extent of teachers' professional relationships can significantly influence the achievement of agency (Priestley et al., 2015). In addition, Pantic's (2015) approach situates teacher agency within the context of the meaning-making processes that occur within their current structures (i.e. their roles and resources) and cultures (i.e. relational and ideational contexts).

While exploring the background literature that informs my study, several empirical studies have recently put an emphasis on the importance of teacher agency and teacher agentic practice in professional learning in the educational context (Eteläpelto et al., 2015; van der Heijden et al., 2015; Kauppinen et al., 2020; King & Nomikou, 2017; Lu et al., 2021; Quinn & Carl, 2015; Pantic, 2015; Rajala & Kumpulainen, 2017; Sannino, 2010). For instance, Rajala and Kumpulainen (2017) used an ecological perspective to explain teachers' agency in understanding and implementing educational changes, paying particular attention to teachers' agentic orientations as indicated in their accounts of their practices. They viewed agentic orientations as "teachers' critical evaluations and attempts to reconstruct their work condition" (p. 312) and teacher agency as a significant component of professionalism and educational change. They argued that it is necessary to encourage collaborative sense-making among school teachers through reflections on their agentic practices in terms of the interaction between the past, present and future aspects of agency and through reflections on their own agentic practices. King and Nomikou (2017) also examined the potential of using the concept of teacher agency for the evaluation of educational innovation (i.e., the science capital pedagogical approach), observing that teachers actively shape their practices in ways that go beyond changes to their pedagogy. Their results revealed that, while all teachers demonstrated some enhancement of their agency as a result of PD, some appeared less agentic due to an unwillingness to take risks and make decisions.

The improvement of teachers' resources through continuous professional learning remains an essential phase towards the development of agentic teacher professionalism (Biesta, Priestley & Robinson, 2017). It is essential to follow the teacher dynamic in practice over time and within a design that involves an evaluation of the requirements and plans necessary to access their judgements and intentions (Edwards, 2015).

Reflection on practice is viewed as a primary activity for assisting in the development of teachers' professional knowledge and agency (Jones & Charteris, 2017; Priestley et al., 2015). This suggests a need to provide opportunities for teachers to express their practical knowledge and justify their agentic decisions and actions (Pantić, 2015). In this way, teachers work as agents and reflect on their practices throughout their careers, demonstrating a strong mastery of both their subject specialisation and pedagogical practice (van der Heijden et al., 2015). This allows them to recognise issues in their work and acknowledge when certain solutions are required, undertaking creative initiatives and taking risks, both of which require a collaborative working environment.

Teacher agency is collaborative in nature since it is achieved in relation to others in the context of practice. Research on teacher agency has identified some common characteristics that seem to be most significant, including relationships and collaboration with others (van der Heijden et al., 2015; Priestley et al., 2012b; Soini, Pietarinen, Toom & Pyhältö, 2015). Agentic teachers are aware that they need support from their colleagues to implement change in practice (Vähäsantanen, 2013). It entails active participation in the collaborative direction and creation of work processes. This is accomplished through engaging in decision-making processes, impacting both individual and shared practices (Biesta et al., 2015; Vähäsantanen, 2015). This conceptualises teacher agency as a multifaceted phenomenon that encompasses both individual practices (e.g., different and varied approaches of scaffolding scientific argumentation in the classrooms) and shared decision-making, such as lesson plans and activities (e.g., collaborative lesson planning practices).

The above studies support the potential benefits of collaboration and reflection to support teacher agency, although they do not illuminate the nature and development of such agency in teacher learning while developing and implementing a new pedagogy in practice over a period of time. Studies examining teacher agency and professional learning have pointed to a complex relationship between the two in instructional reform contexts, where agency may be used to resist or approve a reform, change or maintain practices, or negotiate a middle ground. For instance, Buchanan (2015) and Pyhälto et al. (2015) used their findings to call for *additional* teacher agency in professional learning.

Furthermore, notwithstanding recent research examining the concept of teacher agency in a variety of contexts, there remains a lack of understanding of how teachers develop their agency in their practice over time and of the elements and processes that support or hinder its development. Further research should examine the conditions and instructional contexts that support the development of agency. To address this issue, the current study (which took place over two years) was designed to support teachers in developing their pedagogy of scientific argumentation using longitudinal qualitative data, focusing on lesson planning meetings, classroom practices and the reflective discussion of such practices. Therefore, the purpose of this study is to use the concept of agency as a tool for investigating teachers' pedagogical development to provide a more profound understanding of the development of a new pedagogy.

Overall, throughout this chapter, I addressed various studies to contextualise my study, including gaps in the existing research. Firstly, I reviewed the existing literature, focusing on evaluating science education in England and evolving approaches to teaching and learning scientific argumentation and its implementation in classroom settings. Secondly, I examined the significance and implications of scientific argumentation for students in science learning. Thirdly, I critiqued the relevant literature on how science teachers develop their pedagogy of scientific argumentation and incorporate it into their practice. Fourthly, I focused on the existing literature exploring teacher professional learning, with a particular emphasis on the components of reflection and collaboration that contribute to teacher professional learning. Finally, I examined and critiqued the concept of teacher agency, highlighting how the academic literature emphasises the importance of teacher agency in evaluating teacher pedagogical learning and practice. In the next chapter, I discuss and justify the research design and methodology adopted in my own study.

Chapter 3: Research Design and Methodology

This chapter discusses the research design and methodology adopted in this research and the reason behind its choice. Special attention is devoted to constructing the research design under a qualitative approach. This chapter is structured as follows. Section 3.1 presents the research focus, starting with the purposes of this study, emphasising its originality, and presenting the research questions (RQs). Section 3.2 then addresses the central philosophical and methodological perspectives informing the research methodology, my positioning and role in this study, an examination of reflexive thoughts, and ethical considerations. Section 3.3 presents research processes, including the research setting, the participant teachers, and research procedures. Next, section 3.4 focuses on the data generation procedures undertaken during this study. Section 3.5 then addresses issues regarding data analysis, including data selection and analysis procedures, validity, and reliability. Lastly, section 3.6 considers the trustworthiness of this study.

3.1 Research focus: purposes and research questions

As previously discussed in chapter 2, the incorporation of scientific argumentation into science learning and teaching is necessary for students to develop a more nuanced comprehension of the nature of science (Driver et al., 2000), to acquire a conceptual understanding of fundamental scientific concepts and epistemic practices (Duschl et al., 2007) and to encourage students' involvement in the cognitive, social, and epistemic aspects of scientific thinking and reasoning to understand how knowledge is constructed collaboratively (Jiménez-Aleixandre & Crujeiras, 2017; Osborne, 2010). Although scientific argumentation is an essential objective of science education, the results of the research show that it rarely appears in science classrooms (Osborne, 2010). As such, there is a need to continuously assist teachers in developing their pedagogy of scientific argumentation in relation to planning, implementation, and reflection on their teaching practices. This study aimed at responding to that call and investigated how science teachers develop their pedagogy of scientific argumentation and how they develop their agency and agentic practice in this regard over time through collaborative work and reflection. This study also examined how students engage in scientific argumentation and construct their written work while science teachers implement this approach in their teaching practice. This study was then developed around three main objectives:

- To investigate how secondary school science teachers develop their pedagogy of scientific argumentation through planning and implementing argumentation lessons.
- To investigate how students written work provides insight into their science teachers' argumentation approaches.
- To investigate if and how science teachers develop their agency and agentic practice in this regard.

Further specific objectives behind this investigation were:

- To identify argumentation lessons' objectives and procedures through audio recordings of the collaborative lesson planning meetings between the participant science teachers and researcher (myself)
- To investigate science teachers' practices and pedagogical changes regarding scientific argumentation over a period of time through audio and video recordings of argumentation lessons in KS3, Y7 classrooms in a secondary school in London/England.
- To identify instances of agency and agentic practice, and teachers' values, approaches, and understanding of teaching science through scientific argumentation through audio recordings of science teachers' reflective interviews
- To examine students' written work constructing either individually or collaboratively as an indicator of their teachers' argumentation approaches.

To achieve these main and specific purposes, this investigation endeavoured to answer the following RQs:

RQ1. How do science teachers develop their pedagogy of scientific argumentation in science classrooms?

- How do three science teachers plan and implement the same argumentation lessons based in a scientific and SSI context in their classrooms apart a year?
- How do two science teachers plan and implement the same two argumentation lessons based in the two scientific contexts in their classrooms across two years? To what extent do the two teachers' pedagogy of scientific argumentation change across the two years?
- How do one science teacher's scientific argumentation pedagogy and her student's written work change over a year?

RQ2. How does students' written work provide insight into their teachers' approaches in scientific argumentation?

RQ3. How (if at all) do science teachers develop their agency and agentic practice in this regard?

This study created knowledge that extends existing literature and understanding of teachers' pedagogical development of scientific argumentation. A research strategy was constructed to answer the RQs based not only on the primary purposes indicated above but also on my perspectives and position as a researcher in science education. The following section provides an outline of this research strategy, justifying a qualitative stance for designing and conducting this study.

3.2 Research design

3.2.1 Research paradigm: Qualitative research and interpretivism

My main focus was to investigate science teachers' pedagogical development of scientific argumentation in science classrooms (RQ1 and sub-questions) and how students' written work provided insight into teachers' approaches when they implemented a series of argumentation lessons in their classroom (RQ2). I was further interested in examining how science teachers develop their agency and agentic practices in this regard looking through the lens of teacher agency (RQ3).

Central to every investigation is the stance or lens adopted by a researcher to underpin the research process. Therefore, it is crucial to have clarity on my paradigm for this research. A paradigm is defined by Guba and Lincoln (1994) as 'the belief system or a world view that guides the investigation' (p.105). The choice of conducting classroom-based research (Erickson, 2012) resulted in the use of a qualitative approach. Such research is characterised by investigating meanings, explanations for specific contexts and/or experiences, descriptions of classroom practices and reflections on teachers' approaches around their investigated practices (Denzin & Lincoln, 2003). To carry out qualitative research, I, as a researcher, must address ontological assumptions that guide the epistemological view of the research and incorporate empirical methods for generating and analysing data (Denzin & Lincoln, 2008). Denzin and Lincoln (2003) and Creswell (2013) argued that there are a variety of research traditions, such as positivism, critical realism, interpretivism, and cultural studies within the qualitative approach. Additionally, they argued that there is a range of ontological assumptions, i.e. theories and beliefs about how we understand the nature of reality; epistemological assumptions, i.e. views and theories about how we understand the nature of knowledge about this reality; and axiological views, i.e. different assumptions about how we recognise our values as researchers affect our work. Different research paradigms and their assumptions influence not only how the data are generated and analysed but also findings, interpretation and writing up these findings.

In this study, the ontological assumption is relativism, which views reality as 'subjective experiences of reality and differs from person to person' (Guba & Lincoln, 1994, p.110). It assumes that multiple realities are constructed by the participant teachers (Patton, 2002). My understanding of the reality of classroom practices was what can be observed in science lessons while teachers implement scientific argumentation and heard in reflective interviews about the teachers' approaches and practices. Thus, I worked from an interpretivism paradigm because I was interested in investigating what was happening in the participant teachers' classrooms during the research process. This enabled me to develop a deep level of analysis (Merriam, 1994). Additionally, this paradigm helped me frame this study through understanding the changing and multiple realities in which the participant teachers implemented the argumentation approach in their natural settings over a period of time. The ontological position of relativism adopted in this study presupposes certain epistemological positions on how knowledge comes to be and, therefore, my epistemological position. Denzin and Lincoln (2005) argued that epistemological assumptions examine the relationship between the knower and knowledge, asking the question 'how do I know the world?' (p. 183). Subjectivist epistemology implies that I, as a researcher, make sense of data generated during my interactions with participant teachers through my own thinking. The knowledge is socially produced due to my real-world experiences in the natural settings examined (Punch, 2005).

The qualitative approach, conducted from an interpretive paradigm, emphasises ‘that all human actions are meaningful and have to be interpreted and understood within the context of social practices when we discuss how knowledge is gained. In order to make sense of the social world, the researcher needs to understand the meanings that form and arise from interactive social behaviour' (Scott & Robin, 1996, p.18). I, as a researcher, identified themes and patterns, but the goal was to understand the perspectives and practices on the ground. By employing a qualitative approach, I was able to construct research to better understand the participant teachers' practice in their real classroom settings. This meant that I needed to understand teachers' perspectives, the values associated with teaching science through scientific argumentation, their experiences in this practice, and their meaning to make a difference or achieve change (Merriam, 2009).

Additionally, in this study, I used various methods that are commonplace in the qualitative approach. These were audio recordings of the lesson planning meetings and reflective interviews on teachers' practices, field notes, audio and video recordings of teachers' practices, and students' written work obtained through activity sheets. Another advantage of this approach was the opportunity to comprehend the experiences of the participant teachers in their own settings. This was accomplished by functioning as a non-participant observer and observing events as they happened.

3.2.2 Research methodology

The methodology for this research is a case study, described by Stake (1995) as 'the study of a particularity and complexity of a single case, coming to understand its activity within important circumstances' (p. xi). The benefits of adopting a case study design derive from its inherent ability to enable examination of a particular situation within its natural context and promote a more in-depth knowledge of nuances. This, in turn, allows the identification of causal characteristics and connections that would otherwise be unachievable (Stake, 1995). The pedagogy of scientific argumentation was described as a case in this study. Applying case study as methodology also provides an in-depth description of a particular activity and situation, and thus, can be used to arrive at a deeper understanding of an individual or a group of individuals (Meriam, 1994). Particularly, this study placed emphasis on comprehending how a teacher does, why he or she does, and how behaviours evolve in response to the environment (Ary, Jacobs, Razavieh, & Sorensen, 2010).

Although identifying this study as a case study was relatively straightforward given the nature of the content, selecting the lens through which I attempted to examine the case study proved more challenging. This was due to the fact that I thought specific characteristics were critical to include and clearly define. The first reason was that I wanted an accurate representation of my perspectives as an educator in my own study. That is, I hoped to design a study in which participants' voices were heard in dialogues and in which they were positioned as co-creators of a collaborative effort rather than as subjects. The second reason was that I believed it was crucial to establish a study design that acknowledged my involvement with the partnership and openly acknowledged how it had unavoidably influenced my investigations. Finally, I wanted to conduct a study that recognised and acknowledged the complexity of science education. Therefore, the case study is beneficial for natural settings, e.g., classroom practices, where there is no influence over the behaviours of individuals and contexts (Creswell, 2013). It is also useful for showing analysed data to the participants from this study and enabling discussion to enhance the data's accuracy.

As for specific data generation methods, a case study is best performed by generating data from various sources. These included collaborative lesson planning meetings, classroom observations, reflective interviews, and field notes to secure more objective and reliable data. This enables an in-depth description of the participants' practice, views, approaches and reflections within this study. This study provided deep and detailed examinations of science teachers' practices with scientific argumentation over two years through a case study with a small number of participants. It enabled me to emphasise the real-world context surrounding the case, making it possible to examine complex social phenomena (Yin, 2013). Therefore, a case study was an appropriate methodology to acknowledge and portray the complexities underlying teachers' changes in their pedagogy and practices.

This study also contained an embedded-case design in which there are multiple sub-units of analysis (Yin, 2003). The data were explicated by the depth of the investigation into various units of analysis that concentrate on different aspects of the case (Scholz & Tietje, 2002). An embedded case was applied to explore the embedded case's uniqueness. The examination of the embedded case extended the explanation for the unique features of a selected case.

In this study, as previously mentioned, the pedagogy of scientific argumentation constitutes the central unit of analysis as a case. The teachers' practices from different aspects of the case constitute the sub-units of analysis as embedded cases, as follows:

- Case 1 is a comparison of the three science teachers' practices of scientific argumentation in the same argumentation lessons
- Case 2 is not only a comparison of two science teachers' practices of scientific argumentation across two years in two argumentation lessons but also an identification of their changes in their argumentation pedagogy and practices across different lessons and years
- Case 3 identifies changes in a science teacher's argumentation pedagogy and her students' written work in similar argumentation contexts over an academic year.

These individual sub-cases 'add significant opportunities for extensive analysis, enhancing the insights into the single case' (Yin, 2013, p. 56). Thus, considering the pedagogy of scientific argumentation as a case and sub-cases from three different aspects of this case contributed to my analysis of the research questions. In this study, each embedded case provided an in-depth investigation and detailed description. The selection of the embedded case is the main interest of this study to achieve an understanding of the phenomena (Stake, 2005). The embedded case study research approach was well-suited for digging into the complexities of a particular case, the pedagogical development of scientific argumentation, and enabled me to address the RQs from different aspects of this particular case mentioned above. Thus, these three embedded cases enabled the exploration of how science teachers develop their pedagogy in similar circumstances, whether teachers display different or similar practices in similar situations, and whether the development of scientific argumentation pedagogy and the composition of their agentic practices make changes over time. In this study, it was also important to examine how science teachers develop their agency in their practice of scientific argumentation to better understand teachers' pedagogical development of scientific argumentation through the lens of agency.

To ensure the validity and generalisation of the results of this study, which are challenging to achieve with case studies at times, I utilised the approaches recommended in the literature: detailed description (Guba & Lincoln, 1989) and triangulation of multiple datasets (Creswell & Miller, 2000). I offered a detailed description of the context in which the participant teachers' scientific argumentation practice in their classrooms over a period of time. I enabled what Guba and Lincoln (1989) referred to as ‘transferability judgments on the part of others who may wish to apply the study to their own situations (or situations in which they have an interest)’ by providing a detailed description of the classroom environment and activities, including the teachers’ scaffolding of scientific argumentation and students' written work (p. 242). A particular type of triangulation used to ensure the validity of research results is for qualitative researchers to give evidence gathered through multiple methods in order to discover patterns (Creswell & Miller, 2000). Thus, the detailed description included in my own study offers essential reference material for people interested in applying the research findings to other secondary science classrooms.

Viewpoints on the importance of generalisation in case studies vary — with discussions ranging from naturalistic generalisation (Stake, 1995) to holographic generalisation (Lincoln & Guba, 1985) to fuzzy generalisation (Bassey, 2001). This has been taken by some as implying that researchers should avoid making broad generalisations from case studies, preferring instead to let the example speak for itself. For example, Bassey (2001) states that ‘[...] argued that there were no empirical generalisations of use to teachers’ (p. 5). Thus he encouraged “[...] the proliferation of case studies of what teachers considered to be good practice”. He argues for using a ‘best estimate of trustworthiness’ approach. Fuzzy predictions with best-estimates-of-trustworthiness may be an efficient approach for researchers to engage with potential research participants and to establish a cumulative approach to educational theory building.

Additionally, this study considers an essentially a ‘fuzzy generalisation’—stating that some actions may result in certain outcomes, or, none at all in some instance, and which is dependent on making explicit the context of the statement and the evidence behind it. It provides a strong summary that may serve as a guide for professional action (Bassey, 2001). Additionally, the concept of relatability has been generated in response to the generalisability challenge in qualitative research. For practitioners, relatability, or the capacity of pedagogic research to identify issues and offer possible alternative options, is more significant than generalisability:

> '..an important criterion for judging the merit of a case study is the extent to which the details are sufficient and appropriate for a teacher working in a similar situation to relate his decision making to that described in the case study. The relatability of a case study is more important than its generalizability' (Bassey 1981, p 85).

When a case study is not conducted rigorously, subjectivity and even prejudice may enter. A researcher's assumptions may influence what behaviours to observe and how those findings are interpreted (Ary et al., 2010). In this study, I kept in mind the disadvantages of using a case study as a methodology. I investigated the embedded cases of the pedagogy of scientific argumentation implemented by science teachers in the specific lessons to understand the phenomenon. I generated data from multiple sources, and conclusions were made only when dispersive data converged. Additionally, it is significant to note that my choice of developing this study was linked to my time constraints as a sole researcher. Therefore, there was only one school involved in this study. However, my presence as an observer of science lessons enabled me to build a good relationship with the participant teachers. Still, I had to acknowledge the possible limitation of the data generated by this study due to its small-scale nature and to the choice of working with three KS3 science teachers who volunteered to take part.

3.2.3 My positioning and role in this study

It is crucial to acknowledge my position as a researcher in this study. I am a Turkish woman who attended public schools throughout my education. I graduated from a university in Turkey as a secondary school science teacher and worked as a science teacher in secondary schools in Turkey (from 5th to 8th grade, ages eleven-fourteen). However, my teaching subjects differed slightly from the participant teachers, as I did not have a specialised subject and did not teach science to older students. I completed a master's degree in Science Teaching at Abant Izzet Baysal University in Turkey and another master's degree in Educational Research at the University of Exeter in England. This aspect of my background helped me create a good relationship with the participant teachers and facilitate data generation throughout this study. In addition, as an international researcher with little experience of the

English educational system, this study supported my familiarisation with the research context, including school organisation, the science curriculum, and accountability processes. I maintained close contact with the participant teachers; therefore, reciprocal influences were unavoidable. As such, I used a notebook to organise the generated data and record my thoughts and reflections during each data generation process. The handwritten notebook not only helped me keep track of my general observations and thoughts but also assisted me in choosing relevant data to analyse. However, to make the results clear for the reader, I mainly provided data from the teachers and their students in the result chapters. Tracking my thoughts helped me ensure that I was not reading into the data something that was not there. I also ensured that I did not miss anything presented in the video and audio recordings of classroom practices and audio recordings of the lesson planning meetings and reflective interviews.

Although I was no longer a science teacher, I was an insider to this study in the sense that I came from science education and had the experience of teaching science in secondary schools (Flick, 2009; Patton, 2002). At the beginning of this study, I had a conversation with the teachers about my research, including the objectives of this study and their values and practices of teaching science and teaching science through scientific argumentation. By doing so, I hoped to establish a collegial relationship with the participant teachers, reassuring them that my objective was to collaborate and assist them in developing their pedagogy of scientific argumentation in their practices, rather than to criticise their approaches, opinions and teaching practices in general. I saw my role as offering a new vision of why this approach matters in science teaching and learning and how it might be taught in science classrooms through introductory sessions and lesson planning meetings. The sustainability of the teachers' motivations was also crucial to implementing argumentation lessons in their classrooms. I assisted the teachers in the processes of planning and designing the argumentation lessons and reflecting on their practices to recognise the strengths and weaknesses of their argumentation lessons. Throughout the planning meetings and reflection processes, I concentrated on interpreting the reality and experiences of the participant teachers, as well as myself as a researcher. This position inside this approach allowed me to act as both a researcher and a participant, examining both myself and the participant teachers (Schwartz-Shea & Yanow, 2012). It was difficult to distinguish between the researcher's and facilitator's responsibilities. I involved in discussions with the teachers and participated as a participant throughout the planning sessions, and offered my understandings, expertise, and experience with them. I also provided an environment for them to share their experiences with colleagues during the lesson planning processes.

3.2.4 Ethical considerations

Before any data were generated, clearance was obtained from UCL IOE Research Ethics Committee, and informed consent was obtained from parents/carers, students, and teachers, following British Educational Research Association guidelines. This was achieved through written forms, including opt-out forms for students and their parents/carers and opt-in forms for teachers. Teachers and students were continuously informed that they could withdraw their consent and/or choose not to answer specific questions. Besides these traditional social research ethical considerations, classroom-based investigations, where the choice of methods, approaches, and negotiations between the school and me was constructed continuously throughout this study, demanded specific ethical deliberations. These mainly concerned the outsider-insider dichotomy and working with students (Christensen & Prout, 2002). Care was taken to building rapport with teachers and students before any official data were generated (Punch, 2002).

Additionally, other important issues relating to classroom-based research were considered. These included access to research files, documents, reflections, and opinions (Tilstone, 1998, p.123). Access to files and documents produced by the participant teachers and their students as part of the argumentation lessons was available only to me, my supervisor (Prof Shirley Simon), and the participant teachers. Taber (2002) also emphasises that care needs to be taken while gathering data from learners. Therefore, data from this study, including students' written work, was reflected upon and carefully debated with the participant teachers to ensure it was relevant to their practice. All data generated were anonymised to preserve the privacy of the participants and used for my PhD study. I used pseudonyms for the school, the participant teachers, and their students.

At the beginning of this study, I intended to conduct a comparative study between England and Turkey. The participant teachers' willingness to continue this study with me for one more year helped me find a second direction. Therefore, during the data generation process, I realised that I needed to slightly alter my research focus and research questions and that the necessary adaptations could be easily applied.

3.3 Research process

3.3.1 Setting and participant teachers

This study was conducted at a secondary school in London/England, where my PhD university is located, during the school years of 2017/2018 and 2018/2019. This level of education was chosen due to both my scholarship requirements[3] and my previous experience as a secondary school science teacher in Turkey. The school was selected through convenience sampling, as well as willingness to participate. The school is an outstanding[4], mixed-sex school, specialising in Science, Technology, Engineering and Mathematics subjects. It has long-term experience in academic research. In this school, approximately 80-85% of the students have English as a second language and are mostly from working-class or low-income families. Around 850 students are enrolled in their KS3 and KS4 cycles. The school follows the KS3 curriculum in Y7 (aged eleven-twelve) and Y8 (aged twelve-thirteen), and the KS4 curriculum in Y9 (aged thirteen-fourteen), Y10 (aged fourteen-fifteen) and Y11 (aged

[3] I was awarded this scholarshop to pursue a PhD in secondary school level in accordance with the Turkish educational system.

[4] According to OFSTED (Office for Standards in Education, Children's Services and Skills), the English office responsible for inspecting and regulating services provided by educational institutions. An ‘outstanding’ rating is the highest in the current grading scale adopted by this office.

fifteen-sixteen). In Turkey, secondary school students are aged eleven to fourteen, which is equal to KS3 and early KS4. Therefore, the level of KS3 was a suitable level for this study. This choice was also made due to my interest in this stage of education.

Three secondary school science teachers (one male and two females) from KS3 volunteered to participate in the research after receiving my information sheet. The participating teachers, Ray, Mala, and Padma (pseudonyms), are described in Table 3.1. Ray had eight years of teaching experience, three of which were specifically science teaching experience. Mala had one year of science teaching experience, and Padma did not have any science teaching experience when this study was conducted. Additionally, the teachers had no previous experience or specific training in science teaching through scientific argumentation.

Table 3.1 The teachers' background information

Teacher	Gender	Year of experience of teaching Science	The highest level of education	Science Specialty
Ray	Male	3	BA	Physics
Mala	Female	1	BA	Physics
Padma	Female	0	MA	Physics

Discussions with the participant teachers led to the choice of students in Y7 in KS3 as the most suitable for this study due to the freedom from curriculum constraints and public examinations in this stage. In the first year of this study, I observed the three teachers and their two Y7 classes of mixed-abilities students, according to Standard Assessment Tests. Data from one class from each teacher was chosen because earlier data analysis revealed that their engagement in the argumentation lessons quite varied. Furthermore, some argumentation lessons, such as circuits and waves, were excluded from the data analysis due to the nature of the aims of this study. The chosen lessons are underlined in Appendix 3. In the second year of this study, Ray, Padma, and Mala only had one Y7 class (convenience sampling) of mixed-abilities students according to Standard Assessment Tests. Students' information in both years can be found in Appendix 2 (Tables 1 and 2).

3.3.2 Research procedure

The first year of this study involved contacting the school to gain access to their science department and science teachers. Contact was made with the help of my supervisor and one of her PhD students at UCL/IOE. An approach document was sent to the school to explain my research proposal and ask the teachers' interests. After the initial contact, the school agreed to receive me for informal observations of their science lessons and further discussion about my study. An official agreement for the development of my study was then reached with the school.

3.3.2.1 Teacher introductory sessions on scientific argumentation

In September 2017, before starting data generation, I briefly introduced this study and its objectives to the school's science department. Following this meeting, three science teachers who expressed an interest in participating in this study were invited to attend an introductory session with my supervisor, Prof. Shirley Simon as a guest speaker. I organised this session at the beginning of the school year. According to Murphy et al. (2018), Manzand and Renga (2017), and McNeill et al. (2006), teachers rarely receive introductory training sessions on how to incorporate scientific argumentation into science teaching. Therefore, this session entailed that I contributed toward filling this gap. During this session, the Ideas, Evidence, and Argument in Science (IDEAS) materials[5] (Osborne et al., 2004b) and Continuous Professional

[5] Osborne et al. (2004b) developed the IDEAS materials, which comprise a set of 15 lessons that include a range of frameworks, as well as examples based on the frameworks presented in the original study. The pack included a video and an instructional guide and materials for in-service training. The sessions, in sequence, are the introduction of argument; managing small group discussions; teaching argument; resources for argument; assessing argument; and modelling argument. The video includes recordings from science teachers discussing various elements of argumentation in a variety of contexts and on a variety of topics.

Development Units (CPD Units)[6] (Simon & Davies, 2019) online website[7] were presented and used to illustrate scientific arguments and the pedagogy of scientific argumentation, as well as to demonstrate how teachers are incorporating scientific argumentation into their science lessons. The IDEAS pack is a professional development programme and resource pack developed in England to assist teachers in teaching ideas and evidence in science classrooms.

The purpose of this session with the teachers was to assist them in developing their theoretical knowledge of argument and scientific argumentation and their understanding of how scientific argumentation might be supported in the classroom. The session included a power-point presentation highlighting different aspects of teaching science through scientific argumentation using IDEAS pack materials (Osborne et al., 2004b), and online resources for CPD Units (Simon & Davies, 2019). An interactive discussion on how to effectively teach science through scientific argumentation took place between the teachers, my supervisor and me. I introduced scientific argumentation frameworks and the simplest version of the Toulmin's Argumentation Pattern (TAP) framework to help the teachers better understand written and verbal arguments (Erduran et al., 2004). The simplest version of TAP for evaluating students' arguments was better suited for teachers as it gave them a better structure for building their students' arguments. The participant teachers were required to use the IDEAS sources and the CPD website for two reasons. First, it provides a useful scaffold for teachers to engage in incorporating scientific argumentation into their classroom settings effectively. Second, video examples showing argumentation lessons present real classroom environments. Therefore, the

[6] Three Continuous Professional Development Units (CPD units) are available on the website, each containing video materials and supporting by professional development activities. The primary goal of developing these units is to support teachers for three main topics: group planning and organisation, the teacher's role in initiating and maintaining small group discussion, and the design and interpretation of curricular materials. The AstraZeneca Science Teaching Trust created this continuing professional development units for use by science teachers in the United Kingdom.

[7] As seen in https://pstt.org.uk/resources/cpd-units/argumentation

teachers were able to learn about argument structure and scientific argumentation pedagogy through these examples, which encouraged them to consider teaching science through scientific argumentation. In addition, argumentation activities were evaluated to help the teachers use the same frameworks to plan and design activities for other science contexts. Thus, the IDEAS pack provided a number of 'layers' for additional interpretation, including teaching objectives, science content, lesson procedures, student resources, group work strategies, and teacher support. It was critical to support teachers in doing in-depth planning and offer them a way of developing and modifying a variety of activities that addressed a broader set of instructional objectives.

3.3.2.2 Lesson planning meetings with the participant teachers

As mentioned earlier, it was essential to provide the participant teachers with ideas as starting points from which they could incorporate this practice into their science lessons and design further argumentation activities. Teachers who are new to scientific argumentation may begin with limited pedagogical knowledge and understanding of scientific argumentation; therefore, they may benefit from additional assist and support in understanding this pedagogy and the activity materials. This support was provided to the participant teachers through discussion with me and an expert (Prof. Shirley Simon) in the first session. Successful implementation of these materials requires teachers to have a good understanding of the frameworks/science, activity design and lesson plans. Simon and Richardson (2009) argued that task design should address the fact that teachers may not have a clear reason for planning and designing the argumentation lessons. The purpose of evaluating teachers' planning was to confirm studies indicating that teachers must be aware of pedagogy that encourages students to engage in scientific practices and then design lessons to include these practices (Driver, Asoko, Leach, Scott, & Mortimer, 1994).

Works from the pedagogy of scientific argumentation, such as Osborne et al. (2004a), Simon et al. (2006) and McNeill and Knight (2013), inspired my aim during the planning meetings. During the planning process, three critical features of argumentation pedagogy have been highlighted as key areas of concern for teachers (Simon & Richardson, 2009). The first of these is planning and organising small group discussions. Despite considerable guidance on how to organise students' groups, teachers often struggle to combine student-centred approaches with the need to manage classroom discussions. The second issue is to establish a distinct teaching role for initiating and sustaining small group discussions, as well as appropriate scaffolding that facilitates students' participation and argument construction. Additionally, teachers must be skilled at facilitating plenary discussions inside an argumentation lesson to assist students in evaluating accepted scientific explanations. The third obstacle to overcome is developing and interpreting materials for argumentation lessons (Simon & Richardson, 2009). Developing or modifying argumentation materials for science lessons needs an in-depth understanding of the activity's objectives, the science content, and potential forms of implementation, such as addressing science content, organising small group discussions. Thus, teachers must understand several components of activity – the methods and objectives, the science, the strategies for small group work, the time, and the teachers' directions as the activity progresses. All of these instructional characteristics need practice, support, and guidance. To accomplish that, the planning meetings provided opportunities for the teachers to develop their understandings and knowledge of scientific argumentation, share their experiences with their colleagues, and reflect on their practices. Moreover, this process assisted them in immediately incorporating scientific argumentation through activities while also providing opportunities for collaborative reflection and sharing. Each teacher implemented scientific argumentation based on their understanding of what was discussed in the introductory sessions and the planning meetings.

Taking all of the critical elements of scientific argumentation into account, the planning meetings involved the following topics: how science teachers incorporate scientific argumentation as a new educational approach into the science classroom, e.g., values and knowledge of teaching scientific argumentation; knowledge growth reteaching scientific argumentation; what teachers need to know about the pedagogy of scientific argumentation; and the pedagogical strategies related to argumentation, e.g., using reflections for future planning, and using different instructional strategies to increase student's engagement in argumentation. Furthermore, we had thoughtful discussions about the objectives of the tasks and procedures for each argumentation lesson, involving how scientific argument and scientific argumentation are introduced to students, how students are organised to facilitate small group discussions, how the lesson begins, how the activity and lesson come to an end, how the science is addressed through the resources used, and how the science and the positions of both teachers and students might all be resolved to achieve the objectives. Throughout this study, there were opportunities for addressing these points and engaging the participant teachers in the development of their knowledge and understanding of scientific argumentation. The teachers worked collaboratively and engaged in sharing and reflecting on their practices. Therefore, the discussions between myself and the teachers during the planning meetings were important to reconsider their values and understandings to plan further argumentation lessons.

In May 2018, I launched another overall planning session to re-emphasise the points discussed in the first session, including students' difficulties in engaging with argumentation and constructing their arguments, teachers' concerns about incorporating scientific argumentation into science lessons, and issues about planning and implementing this approach in science classrooms. In the second year of the study, the lesson planning meetings had reduced input from me, putting a greater emphasis on teacher-initiated procedures.

3.3.2.3 The procedures of lesson planning

During this study, the participant teachers were asked to incorporate scientific argumentation into their practice at the moment (Berland, 2011) as a new instructional practice. Thus, collaborative discussions with the teachers during the planning phase were crucial, not only to give the teachers an opportunity to discuss the new instructional practice but also to share their values, experiences, and understandings of teaching science through scientific argumentation and understand how their practice and knowledge have changed over time. The teachers interacted well during the lesson planning process, discussed how to incorporate this approach into their science classrooms and made changes in their practices. The collaborative approach allowed us to focus on issues that arose during the implementation processes, assisting the teachers with synthesising knowledge of teaching science through scientific argumentation from different perspectives and using novel resources, and how scientific argumentation lessons could be incorporated effectively. The responses from the teachers were positive and fuelled conversations about former experiences.

Additionally, these collaborative social interactions influenced how I planned meetings and assisted the teachers with their practice. My involvement served the purpose of supporting the teachers in developing their pedagogy of scientific argumentation. I organised the lesson plan meetings, elicited their opinions on how to plan argumentation lessons, that is, how to introduce argument and scientific argumentation, how to organise students' groups, how to sustain group discussion and how to reflect on their practices to help plan and design the future argumentation lessons. I was also a cheerleader, keeping the teachers motivated to share their experiences and continue their discussions. The teachers shared their experiences of incorporating scientific argumentation into their practice and the strengths and weaknesses of this approach in their practice. This was necessary to help the teachers develop the scientific argumentation approach through collaborative discussions and reflection on their practice.

The availability of time and resources, the teachers' instructions and strategies, and incentives impacted the effective uptake of teaching science through scientific argumentation. The teachers were free to adapt, transform, and enhance ideas to benefit their own practice and students and, if necessary, change their aims or develop their own activities. Thus, teachers could begin to own new practices and incorporate them into their existing strategies and approaches. This meant shifting from 'teacher-proof' activity design, which seeks to minimise teacher agency by providing highly detailed procedure-centric resources, to 'teacher-transparent' materials which support teachers in designing appropriate instructions by offering resources (Simon, Richardson & Amos, 2012, p. 100). Therefore, collaborative planning was also essential to help the teachers identify the strengths and constraints of their practice with scientific argumentation.

The activities for argumentation lessons were either taken directly from the IDEAS pack (Osborne et al., 2004b), or the IDEAS pack was used to select a framework to design and adapt new scientific argumentation activities to different contexts by using the NC for science as guidance at the middle school (lower-secondary) level. The lessons focus on scientific context (e.g., Dropping a box, Phases of the Moon and Food chain activities) or SSI context (e.g., Zoo and Leisure centre activities). These topics were chosen based on relevance both to the NC and to the students' everyday experiences. When the teachers and I planned and designed the activities together, we concentrated on finding an appropriate framework for the contexts and topics in the science NC and identifying the effective scientific argumentation strategy. We then adapted the various activity formats suggested in the IDEAS pack to the new scientific argumentation activities within the various contexts.

The articulation of lesson objectives and processes was also discussed during these sessions, which included visualising the lesson and how the activity may be carried out with classes. The teachers and I considered how lessons would be structured in terms of the following points: the rationale and purpose of activities; teaching points highlighting those aspects of background knowledge students needed to engage with and participate in the lesson; and a teaching sequence suggesting how the materials could be used in the lessons; how the lesson would begin; how scientific argument and scientific argumentation would be introduced to the students; how the students would be organised to facilitate small group discussion; how science would be addressed through the resources used; how the activity and lesson would be brought to an end; how the science and the positions of both the teachers and their students would be resolved to achieve the goals. Notes from the conversation between myself and the teachers provided details about their approaches and the resources they planned to use in the activity.

3.3.2.4 The implementation of scientific argumentation

The teachers were asked to implement argumentation lessons approximately once each half term during this study to assist them to develop the pedagogical understandings of scientific argumentation and agentic practice in this regard. However, sometimes the teachers were not available to implement these lessons because of their busy schedules, or they were sharing their science classrooms with another science teacher. As a result of heavy science content and these constraints, the teachers utilised fewer argumentation lessons in their classrooms than were asked. In follow-up reflective interviews, after implementing each argumentation activity, the teachers reflected on their practices, as well as the successes and challenges they experienced while integrating this approach into their classrooms. In reviewing teachers' implementation of scientific argumentation according to the three cases throughout this study, the teachers were expected to pro-actively shape their practices and agency in their classroom contexts.

3.4 Data generation

This study utilised a variety of methods to generate data, which are summarised in Table 3.2 below. The choice of a multi-method approach was due to the use of the case study approach (Stake, 2005; Yin, 2003, 2013) and classroom-based research (Erickson, 2012), which utilised a considerable number of data sources to address the RQs.

3.4.1 RQ1 - How do science teachers develop their pedagogy of scientific argumentation?

Data related to the first RQ were generated using audio recordings of the collaborative lesson planning meetings and my field notes from the meetings. This data consisted of seven audio recordings of lesson planning meetings over a two-year period. The presentation of these meetings was divided into three cases:

- Case 1: the planning meeting for Dropping a box and Zoo lessons

- Case 2: the planning meeting for Phases of the Moon and Food chain lessons twice across two years
- Case 3: the planning meeting with Mala for Leisure centre lesson

Details of the dates of the meetings across the two years can be found in Appendix 3. Each meeting was approximately 60 to 90 minutes in length, depending on the lesson itself.

Table 3.2 Outline of the methods of data generation and analysis

Research Questions (RQs)	*RQ1: How do science teachers develop their pedagogy of scientific argumentation?* • How do the three science teachers plan and implement the same argumentation lessons in their classrooms apart a year? • How do two science teachers plan and implement the same argumentation lessons across two years? To what extent do two science teachers differ in implementing the same argumentation lessons across two years and the lessons? • How does the practice of one science teacher in scientific argumentation change over a school year?	*RQ2: When science teachers implement argumentation lessons in their classrooms, How does students' written work provide insight into their teachers' scientific argumentation approaches?*	*RQ3: How do science teachers develop their agency and agentic practice in this regard?*
Methods of data generation	• Audio and video-recordings of teachers' practice • Field notes (Observations of the lessons, lesson planning meeting notes) • Audio-recordings of the collaborative lesson planning meetings	• Students' written work (Students' worksheet)	• Teachers' audio-recordings of reflection on their practices both individual and collaborative
Data analysis	Coding teachers' argumentation practice by using a theoretical framework developed by Simon et al. (2006) with field notes, Determination of themes for the lesson planning meetings	A descriptive analysis of students' written work	Determination of the instances of agency by drawing on studies by Pantic (2015) and van der Heijden et al. (2015)

3.4.1.1 Choice of scientific argumentation topics

The topics for the argumentation lessons were selected with the help of the participant teachers and based on empirical evidence found in the existing literature on argumentation (Ekborg, Ottander, Silfver & Simon, 2013; Osborne et al., 2004a). After evaluating the resources for the incorporation of scientific argumentation into science lessons, the teachers touched on the topics they felt to be closely connected with classroom discussions. Argumentation activities were either selected from the IDEAS resources (Osborne et al., 2004b), which were relevant to the science curriculum for England (DfE, 2014) or designed by the teachers and me working collaboratively according to the curriculum aims. These aims were drawn from curriculum documents and their interpretation of the theoretical perspectives of scientific argumentation. The teachers designed one of the argumentation activities called Food Chain, and others were adopted from the IDEAS pack (see all the argumentation lessons in Appendices 4,5,6,7,8). The activities to be implemented and the resources and materials to be utilised were chosen by the teachers and me through collaborative work and thoughtful discussions. The meetings between the teachers and me, and my notes provided details about the teachers' approaches and available resources planned to be used for these lessons.

3.4.1.2 Use of audio and video recordings and field notes

The second element of data generation to answer RQ1 and sub-questions included audio and video recordings of the teachers' classroom practices and field notes. Working closely with the participant teachers and observing their practices of scientific argumentation enabled me to investigate how the science teachers developed their pedagogy of scientific argumentation in terms of planning and scaffolding argumentation processes and supporting their students to engage with and participate in this practice. To gather data, two video cameras on the tripods were set up in the teachers' classrooms, one at the front to capture a general sense of the entire class and to catch students' engagement in the argumentation lessons, and the other at the back to capture the teachers' movements and interactions with students and the white board.

An audio recorder was wired to the teachers to capture their verbal contributions and their interactions with students. This choice of placing the audio recorder with the teachers, not with students, was due to the focus of data generation being on teachers' pedagogy and practices in scientific argumentation rather than tracking individual students' progress. Throughout this investigation, I kept a handwritten notebook and used it as needed for data analysis.

The audio and video recordings of the teachers' classroom practices in scientific argumentation were organised according to the three embedded cases as follows:

1. Six audio and video recordings of the lesson practices (40–55 min in length). Ray, Padma, and Mala implemented the argumentation lessons based on a scientific and SSI context. This case aimed to compare the three science teachers' pedagogy of scientific argumentation as they taught two argumentation lessons a year apart.

2. Eight audio and video recordings of the lesson practices (40–55 min in length) in which Padma and Mala implemented the same argumentation lessons in their classrooms across the two years. The focus, in this case, was to not only compare the pedagogy of scientific argumentation of the two science teachers teaching the same two argumentation lessons but also emphasise their change in their pedagogy across the two years.

3. Two audio and video recordings of the lesson practices (50–55 min in length) of Mala to compare her pedagogy of scientific argumentation in similar two SSI contexts to identify changes in her pedagogy and her students' written work over time. Mala was chosen due to the rich nature of the data generated through her practices with her students, which allowed for in-depth analysis and a deeper understanding of the changes in her practice over a year. Mala was observed utilising a wide range of argumentation lessons in her classroom to encourage her students in this approach.

The participant teachers were observed through non-participant observations, which allowed me to see and hear all aspects of their classroom practices and realities regarding teaching science through scientific argumentation. It must be acknowledged that the audio and video recording devices might have an impact on the teachers' practice and their students' behaviour at some points. Efforts to mitigate against such impact included building good relationships with me, the teachers, and their students.

3.4.2 RQ2 - How does students' written work provide insight into their teachers' scientific argumentation approaches?

I investigated how students construct their written work in each argumentation lesson to address this RQ. Students' written work was gathered from activity sheets utilised by the teachers. The writing frames served as a scaffold for students as they expressed their thinking and reasons for their opinions. Students produced their written work individually or collaboratively, depending on their teachers' approaches. Therefore, students' written work provided insight into teachers' argumentation approaches

3.4.3 RQ3 - How (and if at all) do science teachers develop their agency and agentic practice in this regard?

Audio recordings of the reflective interviews on teachers' practices and their practice were investigated to address RQ3. After each argumentation lesson, reflective interviews regarding the teachers’ practice were conducted. I spent time with the teachers discussing what they believed went well and what did not. These thoughts were then utilised to inform future lesson improvements and understand their knowledge of scientific argumentation. The interviews took place individually in the school, in a quiet, private room and were audio-recorded. Each interview was roughly 35 to 65 minutes long. The total number of interviews for each teacher was determined by the time available and the time it took to get through the entire set of main interview questions. In the first interview, the teachers were asked not only about their beliefs about the value of using scientific argumentation in science classrooms but also about their professional background and experience. The data were utilised to create a 'profile' of the teachers and establish a baseline for comparing changes in practice and their agency. Three interviews were conducted with Ray, seven with Padma, and eight with Mala.

I utilised the concept of agency as a lens to investigate science teachers' pedagogical development of scientific argumentation as a new scientific practice in order to gain a better understanding of what teachers need to develop their agency and agentic practice in this regard. Therefore, I paid particular attention to both the teachers' argumentation practice and their reflections on their practice.

3.5 Data analysis

The data analysis procedure was based on the qualitative approach involving the following stages: data reduction, data analysis and conclusion drawing (Miles & Huberman, 1994). Data reduction for this study included selecting the argumentation lessons to generate three embedded cases and gathering written work from students according to the cases. Then the collaborative lesson planning meetings, the teachers' reflective interviews, and audio and video recordings of argumentation lessons were transcribed verbatim. I carried out all transcriptions and considered this process an initial familiarisation with the data. Then, the data were organised, and further contextual information was added, such as field notes from the classroom observations. Following that, the data were coded and analysed qualitatively using Qualitative Data Analysis Software called NVivo 12. The use of NVivo 12 for the analysis of qualitative data allows for greater consistency across the themes developed, convenient storage and retrieval of data from different sources (Creswell, 2009).

3.5.1 Data analysis of the collaborative lesson planning meetings

As previously mentioned, the first dataset to answer RQ1 and sub-questions included transcribed audio recordings of the collaborative lesson planning meetings and my field notes from the meetings. Thematic analysis was utilised to analyse the data (Braun & Clarke, 2006; Nowell, Norris, White & Moules, 2017). Braun and Clarke (2006) argued that thematic analysis is a useful way to analyse the viewpoints of multiple participants, identify similarities and differences, and produce insights. Nowell et al. (2017) also noted that performing a comprehensive and trustworthy thematic analysis may benefit the subsequent interpretation and display of textual material. I approached the data with preconceived themes and ideas based on existing literature (Simon & Davies, 2019; Simon et al., 2006; Osborne et al., 2004a; 2004b). These themes included the planning and organisation of small group activities, the introduction of argument and scientific argumentation, sustaining small group discussions, teaching and modelling scientific argumentation, and the use of argumentation resources. This process could be considered a deductive approach (Braun & Clarke, 2006). Additionally, adhering to the thematic coding rules necessitates a careful reading and rereading of the transcribed data (Flick, 2014) and interpretations of the raw data to analyse; this process could be considered of an inductive approach nature (Thomas, 2006). I applied both approaches while analysing the data. Using these forms of analysis methods was to consider emerging themes that may provide new insights inductively into the phenomena of teachers' planning processes.

3.5.2 Data analysis of the teachers' classroom practice in scientific argumentation

The second dataset to answer RQ1 and sub-questions included audio and video recordings of scientific argumentation teachers' classroom practices and field notes. The main aim of the analysis was to build an exploratory picture of the science lessons with scientific argumentation. Each transcription of the selected lessons from each teacher was coded by using NVivo 12 to explore the phases of lesson structure and scaffolding argumentation pedagogy (SAP). The purpose of visualising the findings of lesson structure and SAP through Nvivo 12 scripts was not only to show the patterns of lesson structure and SAP, identify the commonalities and differences of the teachers' practices and their changes in their pedagogy of scientific argumentation but also to make comparisons of how argumentation lessons were organised and implemented. Three aspects of observable lesson structure were considered: (1) function, for example, the pedagogical functions of lesson components, (2) form, for instance, the patterns of social interaction, and (3) task structure, for example, the task structures that shape instructional practice (Savola, 2008). I argue that it is essential to consider the pedagogical purposes of the components of lesson structure. Therefore, particular emphasis was placed on the pedagogical functions assigned to the lesson's components. The pedagogical objectives of each component of lesson structure are closely linked to students' opportunities for engagement and the effective use of instructional time (Hiebert et al., 2003). It is also important to highlight that analysis of these data allowed me to consider the following questions: Does lesson structure vary between the teachers, over time, and across two years? How does the lesson structure of the argumentation lessons change across the teachers and the two years?

The phases of lesson structure were identified by looking at video recordings of each lesson and noting the main phases of these lessons in terms of form, e.g., small and whole-class discussions, pair discussion, teacher talk, reading, written frame. To identify each component of the lesson, I developed a simple coding scheme that worked across the lesson components. This coding scheme focused on key characteristics of pedagogical functions and processes, such as argumentation processes for group discussions as synthesised from the relevant literature (Erduran et al., 2004; Hiebert et al., 2003; McCallum et al., 2001). Each component was characterised by the instructional settings described in Table 3.3 below. The analysis focused on patterns of the various components of argumentation lessons. It explored variations within science lessons while the teachers were implementing scientific argumentation and analysed lesson structure to see how the teachers divided their lessons into different parts, the sequence of the instructional tasks for argumentation approaches, how much time they spent on different parts of the lessons, and how students were involved in each part. For instance, when the teachers were observed explaining the goals and objectives of the lesson, which was coded as teacher talk. A high quantity of time spent on a component indicates the learning that the instruction approach promotes. To establish the reliability and validity of the coding, I coded the argumentation lessons at different times and checked for consistency in the coding. Unpacking the form of coding stripes and analysis enabled me to compare the teachers and the patterns of their argumentation lessons across the years and to compare the patterns of the different teachers by using the same form of analysis.

Table 3.3 A framework to identify the different components of a lesson

Codes for different patterns in the lesson	**Features of the Patterns / Structures of the Lesson**
Teacher talk	Displaying verbal signs to draw attention to the fact that the lesson is about to start, Introducing the task/activity to students Introducing the goals and objectives of the lesson Explaining the goals of learning new content Commanding attention of the whole-class and giving input/ explanation/ knowledge/ reminder about the contexts / activity Concluding the lesson and giving homework
Small group discussion	Students (3 or more) work in groups throughout the lesson, discussing and completing the activity together, facilitating engagement in the classroom activity.
Whole-class discussion	Whole-class interactive work with teachers encourages students to share their ideas with the whole class.
Pair discussion	Students working in groups of two throughout the lesson discuss and complete the activity together.
Written frame	Allow students to construct their works in written form and complete the same activity either independently or in a group. Writing frames, essentially a set of prompts to structure student writing, are used to help students to structure and develop their arguments during small group discussions or oral presentations.
Video demonstration	Allow students to visualise a difficult situation or patterns.

While examining the components of the argumentation lessons, there was a variety of lesson structures observed. Figure 3.2 below is an example of the lesson structure from Mala's Dropping a box lesson showing:

- The distribution of class time across lesson components and what kind of strategies were used during the argumentation lesson as form dimension;
- What kind of instructional strategies were utilised across the lesson components as task structure; and
- What the pedagogical purpose of the lesson components is as function dimension.

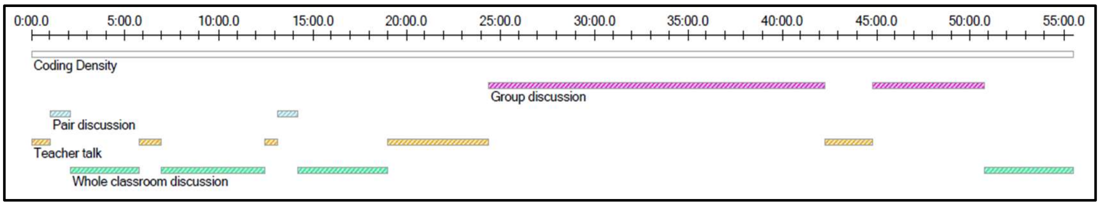

Figure 3.1 An example of lesson structure of the argumentation lesson (Mala's Dropping a box lesson)

As seen in Figure 3.1, when a teacher (Mala in this example) provided a brief description of the aim of the lesson as the pedagogical purpose of the lesson element or explained what argument and argumentation mean in science or explained what students were expected to do during an argumentation activity, this was coded as teacher talk. When she asked her students to discuss with their pairs as a form of social interaction, this was coded as pair discussion, and when students worked in small groups of three, four or five, this was coded as small-group discussion. When teachers brought the class together to obtain students' responses, this process was coded as a whole-class discussion.

Similarly, the visualising of the SAP, using Nvivo 12 for coding scripts, enabled me to examine and compare the teachers' scaffolding processes in the argumentation lessons and identify the changes in their pedagogy of scientific argumentation across two years. This coding scheme of the SAP focused on the key characteristics of this approach (Simon et al., 2006). As seen in Appendix 12, the framework developed by Simon et al. (2006) was used to identify the types of teaching strategies and instructions of scientific argumentation incorporated by teachers. This framework was extended to include strategies for science teachers to incorporate scientific argumentation into their pedagogical practice. Each of the categories is related to statements/affirmations/requests made by the teachers during their lessons to scaffold the pedagogy of scientific argumentation. These categories were then used to determine any changes in the development of the pedagogy of scientific argumentation and the teachers' oral instructions to carry out this scaffolding. The analysis of RQ1 and sub-RQ1-a, b, and c, followed the same processes, focusing on the patterns of scaffolding scientific argumentation processes and exploring variations in science teachers' practice. The coding target was a chunk of the transcript, which shows teachers' attempts to initiate, sustain, or develop the argumentation during the lesson.

The teachers' verbal instructions were coded using the analytical framework. An example of analysis can be seen in Figure 3.2 below. To assess the reliability of the coding through an interrater reliability assessment, my supervisor (Shirley Simon) analysed three scientific argumentation classroom practices (20% of data) over fifteen lessons. My supervisor and I discussed the reasons and validity of the codes until we came to an agreement for the codes.

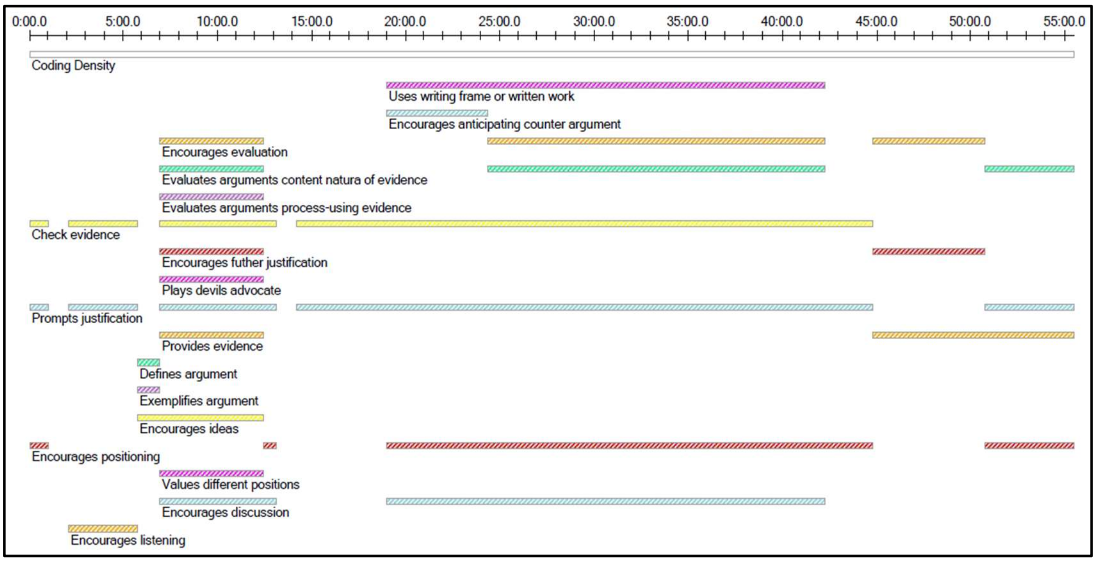

Figure 3.2 An example of SAP of Mala's Dropping a box lesson

Figure 3.2 is an example of the SAP from Mala's Dropping a box activity. A range of argumentation instructions was observed in use throughout the lesson, which varied along with the different components of the lesson. Mala's argumentation instructions included an implicit objective for students to engage with and participant in scientific argumentation. To get a better understanding of the strategies/instructions utilised by the participant teachers to incorporate scientific argumentation into their practice, the transcriptions of the lessons were analysed using the framework established by Simon et al. (2006). Table 3.4 provides exemplars of the teachers' instructions from the lesson transcripts that were demonstrated on at least one occasion. It also provides data transparency. The teachers' instructions in these argumentation lessons enabled me to identify a variety of instructions for facilitating and scaffolding the argumentation processes. These oral contributions also allowed me to identify the similarities and differences, and changes in the teachers' instructions across contexts, years, and lessons.

Table 3.4 Examples of argumentation processes exemplified by Mala, Padma or Ray

Categories of scientific argumentation Processes in teacher instructions	Codes for Teacher instructions for scientific argumentation	**Statements / affirmations / requests from teachers to scaffold argumentation processes**
Talking and listening	Encourages discussion	You need to discuss this with your group. Ensure that everybody is happy and agrees with the choices and contributes to the choices (Mala, Dropping a box lesson, October 2017).
	Encourages listening	Listening! I want to hear student 1's response again (Mala, Dropping a box lesson, October 2017)
Knowing the meaning of argument	Defines argument	What you have been doing something called argumentation; we have been discussing ideas, giving reasons and evidence that why you think those things (Mala, Dropping a box lesson, October 2017).
	Exemplifies argument	Someone could say that the Earth`s horizon is a curve. It must be spherical, but it is curving because the pictures of the earth show us (Mala, Dropping a box lesson, October 2017).
Positioning	Encourages ideas	Okay, I know you have got lots of good ideas, but another idea could be that pictures of the Earth show us that it is round, and student 1 mentioned that point of seeing pictures that show us the shape of the Earth (Mala, Dropping a box lesson, October 2017).
	Encourages positioning	There are three different statements in some of the boxes; what you need to do in your groups is decide which one is the correct statement (Mala, Dropping a box lesson, October 2017).
	Values different positions	We have got some good responses from a lot of people. There are lots of good arguments for opening a zoo and against opening a zoo (Mala, the Zoo lesson, September 2018).

Justifying with evidence	Checks evidence	There is a force of gravity that acts downwards. When we talk about these forces, do you think it gets a lot bigger as the box gets closer to the Earth? What is your evidence? (Mala, Dropping a box lesson, 2017)
	Provides evidence	Air resistance, so one piece of your evidence for this point is that forces come in pairs, it has to be a force acting to the other direction to the gravity does not it and you guys knew that that is your evidence (Mala, Dropping a box lesson, 2017)
	Prompts justification	Whatever the Earth shape is, you think, why do you think that? What is your reason for that (Mala, Dropping a box lesson, 2017)?
	Emphasises justification	When you present evidence, is it just what you think, feel, or need facts? (Mala, Dropping a box lesson, October 2017)
	Encourages further justification	Makes sure they are using evidence for a good argument. What is your evidence that you have chosen that? You are going to present your ideas scientifically. We need evidence. We need facts to support the ideas. You told me one fact is not enough, and we need lots of evidence (Mala, Dropping a box lesson, October 2017).
	Plays devil "s advocate	An idea could be someone could think the Earth was flat because the roads are flat, the roads do not start curving, do they? (Mala, Dropping a box lesson, October 2017)
Constructing arguments	Uses writing frame or written work/	Whilst you are discussing, somebody needs to be writing down the evidence and what is being said and why you have chosen these (Mala, Dropping a box lesson, October 2017).
	prepares presentations/gives roles	You guys need to get down your evidence. While you are discussing, one person can write it down (Mala, Dropping a box lesson, October 2017).
Evaluating arguments	Encourages evaluation	What do you think you need to make a good scientific argument? To make it strong. (Mala, Dropping a box lesson, October 2017)
	Evaluates arguments process – using evidence	Like we discuss what the good argument is in science. Makes sure they are using evidence for a good argument. What is your evidence that you have chosen that (Mala, Dropping a box lesson, October 2017)?
	content – nature of evidence	How do you know that? What's the evidence that the level of toxin increases up the food chain? What do we know that little animals do those big animals need? Do bigger animals need to eat more or less (Mala, the Food chain activity, March 2018).

Counter-arguing/debating	Encourages anticipating counterargument Encourages debate (through role-play)	Why you decided not to choose other statements and think about somebody else can disagree (Mala, Dropping a box lesson, October 2017). Remember you are not a student anymore, you are whatever your group is, you can pretend whatever role you are taking (Mala, the Zoo lesson, September 2018)
Reflecting on argument process	Encourages reflection Asks about mind-change	You need to think about why other people might think differently, if you try to change someone's opinion or change someone's mind you have to think about why they think differently from me and how can I persuade them to think how I think about them (Ray, the Zoo lesson, October 2018). Did anyone out of interest change their mind after listening to other people's arguments? What can you share? Why was that? (Ray, the Zoo lesson, October 2018)

3.5.3 Data analysis of students' written work

The data-set to answer RQ2 included students' written work obtained through the argumentation activity sheets. Students' engagement with scientific argumentation in discussions (Osborne et al., 2013; Sampson & Clark, 2008) and their quality of argumentation (Capkinoglu, Yilmaz, & Leblebicioglu, 2019; Erduran et al., 2004) were addressed through a range of analytic frameworks (Erduran et al., 2004; McNeill & Krajcik, 2011; Sampson & Clark, 2008). Each study concentrated on a particular aspect of argumentation. For example, some studies have identified quality and structural aspects using the Toulmin framework, including the components of claim, grounds, warrant, qualifier, rebuttal, and backing (Erduran et al., 2004), while others have focused on knowledge construction (McNeill & Krajcik, 2011). TAP examines how students organise the structural elements of an argument, including the claim, warrants, qualifiers, backings, and rebuttals. The primary criticism made about Toulmin's approach is that it makes it difficult to distinguish between claims, data, warrants, qualifiers, and rebuttals because the decision of what counts as such is dependent on what was exactly said in the dialogue and written in the task, and to what that refers (Erduran et al., 2004; Erduran, 2008; Sampson, & Clark, 2008). My aim was not to evaluate the quality of arguments students constructed (Erduran et al., 2004) or their knowledge construction, but rather to identify students' written work during argumentation lessons as an indicator of science teachers' scientific argumentation approaches. Therefore, I selected a simpler version of the Toulmin framework that can be easily applied to data to analyse students' written work.

Various studies (e.g., Jiménez-Aleixandre et al., 2000; McNeill et al., 2006) present cases wherein TAP was modified to include fewer elements. For instance, McNeill et al. (2006) developed a conceptual framework to analyse students' arguments as the Claims, Evidence, and Reasoning (CER) structure (McNeill, 2009; McNeill et al., 2006; McNeill & Krajcik 2008). A simplified modification of TAP, the CER combines warrant and backing components into single reasoning and removes the qualifiers. Studies applying McNeill et al.'s (2006) framework often ask for two pieces of evidence to create a convincing argument. Even though this rule is grounded in the disciplinary norm of using multiple pieces of evidence to construct the persuasiveness of an argument, following this rule does not necessarily help students learn how to choose appropriate evidence or make decisions about whether students have sufficient evidence to support their claims. Other critics point to instances in which TAP was modified to contain fewer aspects than the essential elements of TAP for a variety of reasons other than those mentioned above. Bulgren and Ellis (2012), for example, observed that teachers prefer to readapt the challenging vocabulary of TAP and replace the names of the components with concepts that seem to be more accessible to students. Therefore, the approach in which students are taught about the components of an argument in the argumentation lessons, or details about the example that was used to introduce an argument, are critical in identifying the components of an argument. Following these recommendations, my approach to the analysis of students' written work was to use them as an indicator of the teachers' approaches in scientific argumentation. Therefore, I only focused on how students produce their written work individually or collaboratively as an indicator of their teachers' approaches by descriptively analysing them. To accomplish that, one question was 'is there a claim?' that aims to elicit the presence or absence of a main claim in the argument. Likewise, the other question was 'does the argument have evidence/reason to support the claim?' that seeks to establish any data as part of the argument.

Additionally, my approach to the analysis was to identify whether the context is complex for students and whether they are able to choose the correct statements or explanations and provide correct reasons for their choices by making this the first step of the process of construction of written work. In some activities, such as Dropping a box, Phases of the Moon and Food chain activities, students were not asked to make their claims but instead were asked to choose one statement or explanation that they think is correct and then support their choices with reasons in the case of Dropping a box activity or provide reasons for all explanations in the case of the Phases of the Moon. The Food chain activity was designed to encourage students' discussion instead of obtaining their written work. In the case of the Zoo and the Leisure centre activities, students were asked to take a position (similar to making a claim) and then support their positions with reasons. Note that I am not specifying how students should defend their choices at this level, only providing some possibilities.

3.5.4. Data analysis of the teachers' reflective interviews

The final data-set to answer RQ3 included audio recordings of the reflective interviews on the teachers' scientific argumentation practice. I utilised the concept of teacher agency as a lens for investigating science teachers' pedagogical development of scientific argumentation as a new scientific practice. After implementing each argumentation lesson, reflective interviews with the teachers were conducted to get their reflections on their practices. I completely transcribed each interview and broke it down into 'instance of agency' using NVivo 12 inductively. This tracked emerging or deduced instances of the components of agency that related to each other and followed the teachers' changes in their development of agency.

I conducted a thematic analysis of teachers' interviews through a lens of teacher agency, following thematic analysis principles demand that repeated reading of the transcribed data (Flick, 2014). I drew on the work of Pantić (2015) and van der Heijden et al. (2015) to identify instances of agency. I did so by identifying 'instances of agency' in terms of a sense of purpose (intentionality), mastery (competence to achieve such purpose), autonomy to act and reflexivity. To determine the sense of purpose, I examined examples of teacher motivation toward utilising scientific argumentation in their practice for their own development and how it meets their belief about science teaching and their values. Furthermore, I identified teachers' demonstrations of competence and confidence in their use of scientific argumentation pedagogy, such as knowledge of scientific argumentation in different contexts and confidence to use and adapt this approach to best suit the needs of their students over a period of time. I looked for examples of decision-making and risk-taking to determine autonomy to act, such as the willingness to make decisions about which aspects of the approach they engage in and to take risks regardless of how this changes. Finally, I identified situations where the teachers participated in practice, reflected on practice, and implemented necessary changes. Excerpts from the reflective interviews showed instances of their development of agency in these components. Additionally, I identified the factors that either support or hinder agency, guided by my review of relevant literature, highlighting the critical role of social and environmental factors in influencing agency.

After coding the reflective interviews from each teacher for the Dropping a box lesson, my supervisor and I came together and discussed them. An open coding method was applied through repeated reading and searching the data. This captured emerging insights of the development of components of teacher agency as an indicator of developing agentic practice in the pedagogy of scientific argumentation. I intended to identify instances of development in agency related to the pedagogy of scientific argumentation. To accomplish that, I returned to the literature to make sense of the identified themes and construct and interpret them across time. Due to the dependent nature of agency and its iterative development through time, the illustrative examples were not unique from one another but rather overlapped across phases. Following that, all documents were coded and re-examined in order to account for themes. The teachers often addressed the key practice and feature of agency in response to questions, such as, how do you feel the argumentation lesson went? What are the strengths and challenges you experienced in implementing scientific argumentation in your classroom? (see interview questions in Appendix 1).

3.6 Trustworthiness of this study

I relied on subjective interpretations since I was particularly interested in the phenomena of classroom-based research. Being a subjective researcher may provide difficulties since it may undermine the results' trustworthiness. To address this possible issue, I utilised handwritten notes to enhance the data's trustworthiness (Seale, 2000). To address concerns about the data's trustworthiness, I made explicit the theory that guided this study, described the coding method, including an example of coding scripts from NVivo 12 to demonstrate the coding, openly wrote the codes, justified the codes, and finally, established a clear understanding of scientific argumentation (previously explained in section 3.5.2).

Additionally, some factors should be considered while interpreting the findings of this study. First, although the classes I observed were not the same in each year and each teacher, I still believe it is valuable to observe how the teachers implemented scientific argumentation in their classrooms while linking their understanding of scientific argumentation, their agency and agentic practice. However, when interpreting the results, it is important to keep in mind that I only analysed the practices of the teachers who differed in several aspects (e.g., scientific and SSI context, across two years, over a year). Second, students' contribution to the classroom dialogue was not considered in my analysis as I only focused on students' written work to identify teachers' scientific argumentation approaches.

Overall, this chapter discussed the research methodology used in this study, as well as the study design, which includes the purpose and research questions, the ethical considerations, the participant teachers, data generation methods, data transcription and analysis, and validity and reliability. Following this chapter, in chapter 4, the findings of this study will be presented in the form of three embedded cases of teachers' scientific argumentation practice and, in chapter 5, I will identify the instance of developing agency and agentic practice in this regard by drawing on Pantić's (2015) and van der Heijden et al.'s (2015) work.

Chapter 4: Findings of science teachers' pedagogical development of scientific argumentation

Throughout this study, I investigated how science teachers develop their pedagogy of scientific argumentation in science teaching. This chapter begins by presenting the findings of the initial interviews with the participant teachers that reveal their backgrounds, their existing objectives of science teaching and learning, and their beliefs about the value of teaching science through scientific argumentation (section 4.1). The findings relating to the three embedded cases are then presented. Each case starts with the general principles and procedures of lesson planning, followed by presenting data on how science teachers implemented the argumentation activities in their classrooms. The account of each activity includes visual profiles of the lesson structure (e.g., teacher talk, small and whole-class discussions) and the SAP (e.g., how the scaffolds the teachers utilised in their instructions were distributed throughout the lesson) taken from the NVivo 12. An overview of the teachers' practices is included extracts from the teachers' instructions, focusing on the aims of the argumentation activity, its organisation, and the facilitation of each phase of the lesson. This is followed by an overview of the student's written work. Each case concludes with a comparison of the teachers' practices of scientific argumentation and their pedagogical development. The first case compares three science teachers' implementation of scientific argumentation while they taught the same argumentation lessons within a scientific and SSI context (section 4.2) one year apart. The second case not only compares two science teachers' implementations of scientific argumentation while they taught the same two argumentation lessons within two scientific contexts but also identifies changes in their pedagogy of scientific argumentation across two years (section 4.3). The third and final case compares one of the science teacher's implementations of scientific argumentation while she taught two argumentation lessons within two similar SSI contexts to identify changes in her pedagogy of scientific argumentation and her students' written work over a year (section 4.4).

4.1 Accounts of teachers' backgrounds, initial understanding, and beliefs about values of teaching science through scientific argumentation

The initial interviews with the teachers aimed to identify their existing science teaching and learning objectives, initial values, and understanding of scientific argumentation as factors that might influence on their planning, instructional decisions, approaches and practices. Previous studies have emphasised a "strong relationship between teachers' educational beliefs/values and their planning, instructional decisions, and classroom practices" (Pajares, 1992, p. 326). Ray, Padma and Mala's accounts are presented in the following sections.

4.1.1 Ray's account

Ray was in his early thirties and in his third year of teaching science when the interview was held. He has a degree in engineering and physics, which is his main teaching subject. He also holds a postgraduate certification in education in secondary mathematics and had worked as a maths teacher for five years at another school before starting to teach science at the school, where he had also taken on the responsibilities of a science curriculum leader at the time of this study. In the initial interview with him, this is how he described his way of teaching science:

> I explain why something works, teach about the topics, give real-life examples of the topics to make students understand the principle, and help with understanding new concepts being taught (Ray, December 2017).

The excerpt above indicates that Ray saw himself as a source of scientific knowledge, which may have influenced his decision about scientific argumentation lessons. When asked about his initial understandings of scientific argumentation, he said that he considered this practice as the process of thinking about evidence and facts to support ideas:

> I think evidence for argumentation is essential; students have to think about evidence to back up the statement, the fact students are looking at (Ray, December 2017)

Additionally, the below quotation about his initial beliefs about the value of teaching science through scientific argumentation emphasises that Ray clearly believes that teaching science through scientific argumentation is an effective strategy for fostering students' conceptual understanding and assisting them in retaining their science learning. Moreover, he considered this practice as beneficial in determining students' misconceptions about the science content:

> I think argumentation would lead to a better understanding of the concepts because they spend more time thinking about examples and explaining them from their own understanding, which is quite powerful. Relating it to what they have experienced like that should help them retain that knowledge and get an understanding of it because they can figure it out and think and get it in there. It is also essential to find out students' misconceptions about the topic during discussions (Ray, December 2017).

To summarise, Ray considered teaching science through scientific argumentation to be a powerful way to support students' understanding of science content and reveal their misconceptions.

4.1.2 Padma's account

Padma was a science teacher in her mid-twenties and her first year of teaching science; therefore, she lacked much experience when she was interviewed. She had a bachelor’s and a master's degree in Physics. Before starting to work as a science teacher in the school, she had worked as a maths and science tutor full time and as a teaching assistant for two years. In the preliminary interview, this is how she described her way of teaching science:

> Breaking down concepts into smaller chunks, having some sort of narrative or story behind what you are telling them (students), whether this is its history or the simplest

> part, and then building up is essential to teach science. It is significant to have some sort of structure for your lessons. They could see how we come to understand the world a bit better (Padma, December 2017).

The excerpt above indicates that she believed that breaking down concepts and then expanding on them during a lesson is critical for students to have a deeper understanding of science. Padma mentioned that she was relatively inexperienced; however, she sees teaching science through scientific argumentation as an effective approach to learn science through discussions while listening and sharing ideas:

> I think it is a good way of teaching science, especially helping them (students) organise their ideas and listen to each other, learn with discussion and arguing, getting them thinking (Padma, December 2017).

She also values the importance of incorporating scientific argumentation into science teaching in relation to helping students think critically and discuss ideas in a structured way:

> Argumentation is important for them to be critical thinkers. It gives them time to think about things more deeply, talk to each other, and organise their thoughts. I think it is really useful because it brings the focus back on what they are thinking and how they are discussing the ideas in a structured way (Padma, December 2017).

In summary, Padma considered teaching science through scientific argumentation to be a useful way to learn science through listening and discussing ideas in a structured way.

4.1.3 Mala's account

Mala was in her early thirties and her second year of teaching science; therefore, she was relatively inexperienced when interviewed. She holds a dual degree in Music and Physics, with physics being her main teaching subject. In the first year of this study, she had just gained qualified teacher status in the same school. The number of classes she taught had progressively increased following her training. In our interview, Mala emphasised the need of resolving students' misunderstandings, modelling, evaluating, and discussing science as part of her teaching objectives.

She considers questioning, getting students thinking and explaining concepts to them by giving reasons rather than one-word answers as effective ways of teaching science. This demonstrates that she had previously included questioning and justification procedures into her instructional approach as part of her scientific argumentation pedagogy:

> When a student gives me an answer, I would say, "Why do you think that?" Or someone would disagree, and I would ask the rest of the class if they did too … or if I ask a question and someone gives me an answer and another student puts their hand up and says, 'No, I do not agree with that', I will ask the class "Okay how many people agree with this person?" and then I will ask the first student to explain why they (did not agree). So, in that sense, I do not think I have planned for it or specifically used it, but I think I have unknowingly used some of the ideas from it without realising (Mala, December 2017).

It is evident from her interview that she believed that teaching science through scientific argumentation is a meaningful way to develop students' understanding of how theories are backed up with evidence and how scientists work. She also considered it essential to identify students' misconceptions:

> I think it (scientific argumentation) is important in science because theories and evidence back up everything we do in science, and we investigate to prove these theories or evidence; that is how it works. No scientist is going to come and say something, and everyone just accepts it. We need to have the argumentation; we need to bring new ideas and ask what about this and what about that, so that we can come to that conclusion, have that understanding, and clear up any misconceptions that students might have (Mala, December 2017).

The quote above highlights the fact that Mala believes that this approach helps students understand science. She considers this practice beneficial to discover students' misconceptions about certain topics. In addition, she believes that the scientific argumentation approach is valuable as it gives the students a voice and some control in the lesson:

> You get to hear the voice of the students, and I think you get to hear some students that normally do not say anything. It gives the teacher a chance to step back and let the students take control, more of a lead in the lesson (Mala, December 2017).

Mala's views suggest that she had some understanding of scientific argumentation as an approach from the very beginning of her teaching career. Moreover, she emphasised using this approach in her lesson to develop students' discussion skills as she had recognised the necessity to develop these abilities. She aims to acquire strategies that will allow more open but organised discussions in lessons about scientific concepts or theories:

> Even if I ask a question, if it is true or false and the student says true, I always get them to explain why because sometimes other people think different things. Sometimes naturally, that leads other students to join the discussions and give their reasons for disagreeing or agreeing with their peers. It naturally evolves into a like scientific debate (Mala, December 2017).

To summarise, Mala considers teaching science through scientific argumentation as a valuable way to develop students' discussion skills, find out about students' misconceptions of science concepts and allow the students to have a voice in a structured way.

4.1.4 Summary of teachers' initial understandings and values of teaching science through scientific argumentation

The analysis of the initial interviews with the three teachers indicated that they were inexperienced in the pedagogy of scientific argumentation and were unlikely to incorporate scientific argumentation into their practice without a great deal of assistance and support. However, the teachers seemed to emphasise scientific argumentation as an effective way to improve the teaching and learning of science and to find out about students' misconceptions of science concepts. Moreover, as an instructional approach, they believed that scientific argumentation could help students think about and discuss their ideas in a more depth and structured way and saw it as a way to improve students' understanding of science's theories and concepts.

4.2 Case 1: Three science teachers' implementation of Dropping a box and Zoo lessons

This case aimed to provide a comparison of the teachers' instructional practices and approaches to the implementation of scientific argumentation within a scientific context (Dropping a box activity, section 4.2.2) and a SSI context (Zoo activity, section 4.2.3). This section first presents the overall principles and procedures of lesson planning for these activities (section 4.2.1). It then provides data on how the three science teachers implemented these two argumentation activities in their classrooms. The account of each activity covers visual profiles of the lesson structure and the SAP, as well as an overview of the teachers' practices which includes extracts from the teachers' instructions. This is followed by an overview of the student's written work and a comparison of the teachers' practices of scientific argumentation in the scientific context.

Similarly, I then present how the three science teachers implemented scientific argumentation within a SSI context a year later by providing an overview of the teachers' practices and their student's written work and a comparison of the teachers' practices of scientific argumentation in the SSI context. Lastly, this case concludes with a general comparison of the teachers' practices of scientific argumentation and their pedagogical development in both the science and SSI context lessons one year apart.

4.2.1 Lesson planning process for Dropping a box and Zoo lessons

The lesson planning meetings for the Dropping a box (November 2017) and Zoo lessons (September 2018) are presented in the following two sections to show how these activities were planned to be implemented in the classrooms.

4.2.1.1 Dropping a box activity

Before the meeting for Dropping a box lesson, I had a short chat with Ray, who gave me some information about NC for science and mentioned that science teachers follow a scheme of work for the placing and length of each topic in KS3, especially in Y7 classes (around eight topics to cover over an academic year-usually two topics per half-term and around seven-eight lessons for each topic). Ray stated that the teachers had enough time to finish the planned topics before the end of each half term.

When discussing the context in the teaching of scientific argumentation, it was important to consider how the topic was presented in the KS3 scheme of work. Ray suggested incorporating the Dropping a box activity into one of the lessons (seen in Appendix 4) using resources in the IDEAS pack (Osborne et al., 2004b). This activity was relevant to what was taught about force, which encompasses ideas related to forces[8] (DfE, 2014). Another point considered while choosing this topic was that teachers thought that students might have some misunderstandings about the topic (Driver, Squires, Rushworth & Wood-Robinson, 2014) that could be addressed during small-group and whole-class discussions. The objective of this activity was to develop students' understanding of forces by exploring different forces. Students were provided with a set of statements relating to an object falling under gravity and asked to select statements from a list arranged in a sequence and justify their choices. Thus, there were two distinct goals: learning about force and the process of scientific argumentation.

As this activity was the first scientific argumentation activity to be implemented, it was used by the teachers to introduce scientific argument and scientific argumentation to their students, including the exploration of the structure of argument, the language of argument and scientific argumentation. We first discussed how to introduce argument and scientific argumentation to the students. The teachers considered giving their students written and oral guidance on how to construct an argument; for instance, one idea suggested by Ray was:

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[8] The lesson goals for this topic are: "learn about forces as pushes or pulls, arising from the interaction between two objects"; "learn about non-contact forces: gravity forces acting at a distance on Earth and in space, forces between magnets".

> We can give the students a card saying this is a claim, this is evidence, so they can see what counts as claim and evidence. I think it will get them thinking about how they argue and construct their argument beforehand (Ray, November 2017).

The teachers anticipated that students would have difficulty coming up with evidence to support their ideas and explain the situations being discussed. Mala commented that:

> Choosing the correct answer is probably not that difficult, but backing it up is the hardest part and would be most challenging. I know the force of gravity, but I do not know how I would supply evidence for that other than stating it again, but that is just explaining it instead of providing evidence (Mala, November 2017).

In the quote above, Mala raised the concern that backing up the correct answer and supporting it with evidence is potentially challenging for the students on two counts, lack of sufficient knowledge about the topic and no experience using the argument structure. A similar concern was shared by Ray, who indicated that the activity was challenging for their students:

> With this activity, it is challenging because it is not just a case of getting the correct answers. That is just one of the aims; they need to have previous knowledge of the concept; therefore, they can choose correctly; however, the other purpose is about the argumentation that is more difficult - you could get them to do written answers to see why they got this right or wrong, a way of getting them to do it together, saying "This was wrong because of this" and you can go through this later on and assess if it is correct or not (Ray, November 2017).

Ray believes that teaching science through scientific argumentation is difficult for students because of their unfamiliarity with this approach and the possibility of having limited content knowledge. In addition, the statements given in the activity may be challenging for the students because they needed to have some previous knowledge about the topic to enable them to outline their reasoning behind their choice of one statement over another. Mala and Padma shared the same concerns. Therefore, the teachers decided to use this argumentation activity as a recap activity on the topic, as Padma explained:

> I have done forces with them; I might start the lesson by reminding them what we have done before. I would maybe show them a video of a box dropping from a plane

> to get them to visualise what is happening and maybe use cards to show the statements (Padma, November 2017).

As seen in the quote above, Padma drew attention to the importance of the student's previous knowledge about the topic, visualising the situation and using cards to present the statements. This would help students discuss the statements as a sequence of the phenomenon. All three teachers were concerned about how to deal with students' misconceptions about the topic. Both Padma and Ray stated that the student's understanding and possible misconceptions influenced the structure of the lesson and argumentation activity.

Another feature of the discussion was how to organise students for group discussions. The teachers had different opinions about how to group their students for small group work. For instance, Mala was willing to try a new group strategy for this first argumentation activity:

> I watched it (CPD Units website) in one activity; the teacher created groups of three, and she gave them a label of A, B, C and all of the students discussed in their own group, but just B students changed their groups (called envoy). We could use this kind of group strategy (Mala, November 2017).

In contrast, Ray and Padma did not consider using any different group strategies in this activity. Both teachers tended to group students in tables of four or five based on who was friends with whom. Ray and Padma did not consider trying any of the new grouping strategies offered by Mala and decided to organise their students as usual. In doing so, they did not pay attention to what group discussion might look like during the argumentation activity and how to sustain group discussion throughout the activity.

Another issue that came up in this meeting was that of timing; the teachers thought the lesson and the argumentation activity itself might need more than an hour to complete, as Mala stated:

> I imagine if I am going to do a little bit of introduction to the scientific argument, then doing the activity together would probably take a full hour; I would like them to have the time to get them stuck into the activity. But they might struggle with the activity and writing their reasons. It is also essential to have some time to check their responses (Mala, November 2017).

The teachers were aware of the challenge of time constraints and implementing scientific argumentation activities in their classrooms. Time constraints are crucial because, as Mala mentioned, they may limit the teachers' ability to deal with the argumentation strategy, introducing the argument and argumentation and their students' misconceptions and difficulties constructing their written work. The teachers were observed following the same ideas as suggested in the IDEAS pack (Osborne et al., 2004b) for this argumentation activity.

Teaching sequence agreed in the meeting:

- Remind students what has been learned about forces.
- Introduce the concepts of scientific argument and scientific argumentation.
- Organise students for group discussion (in tables of four or five).
- Distribute the activity sheet and provide instructions on the task (as suggested in the IDEAS pack).
- Allocate around 15 minutes for the group discussion.
- Finally, have a plenary session to discuss the students' responses during the whole-class discussion.

This teaching sequence reflects the conversations taking place during the lesson planning meeting. In this example, there was specific evidence of attention being given to the structure of the lesson.

4.2.1.2 Zoo activity

Notably, the teachers' previous experiences with scientific argumentation assisted their planning for further argumentation activities in the second year of this study. The teachers highlighted that that the first activity should be more accessible to students and serve as an introduction to scientific argument and scientific argumentation, for instance, as expressed by Mala:

> When we used the dropping a box activity, there was not a very good understanding of the concept, and I think they (students) also struggled just to be told what argument and argumentation are in the same lesson. We did one practice question

> and then, "Now you do it." There was not enough scaffolding and enough build-up. Students did not understand what they were doing (Mala, September 2018).

Mala concluded that the first task should not be complicated for the students while introducing scientific arguments and scientific argumentation. All three teachers suggested the task should be set in a SSI rather than a scientific context to make it easier. Therefore, the Zoo activity was considered the first activity to introduce scientific argument and scientific argumentation to the students.

I briefly outlined the initial purposes of the activity. The underlying purpose of the lesson was to facilitate students' meaning-making and reasoning in the context of a SSI context. The task would also be relevant to the students' everyday experience as well as the curriculum, covering concepts such as the extinction and preservation of species. In the suggested teaching sequence from IDEAS, the issue was described in a letter distributed to the students, who were then separated into small groups and asked to argue for and against funding a new zoo (seen in Appendix 5, taken from the IDEAS pack). The students were to provide justifications for their point of view; thus, the aim was to generate arguments for and against the funding of a new zoo.

The teachers and I had discussions on how the lesson might be structured, how the activity might be used, how the components of scientific argument and scientific argumentation might be introduced, and how students' groups might be organised in the lesson. The teachers already had experience teaching science through scientific argumentation in the previous year, and, therefore, they already had some ideas and suggestions on how the lesson might be structured. For instance, Ray put forward the following suggestion:

> We could first explain argument and argumentation, then they (students) need to discuss their responses about building a new zoo. And then they should write a letter explaining their opinions on building a new zoo. But in the beginning, I think we need to explain what argument, argumentation, reasoning, using persuasive language means to the students (Ray, September 2018).

On the other hand, Mala suggested starting the lesson by getting the students to write a letter about the issue being discussed to get students' initial thinking:

> Starting the lesson by writing a letter about the building of a new zoo could be better to get them thinking and gather their initial ideas, then explain to the students what argument and argumentation means, what they need to make a strong argument, what kind of language they could use and so on (Mala, September 2018).

Padma also supported the idea of starting the lesson by getting the students' opinions to write a letter, then introducing argument and scientific argumentation to them. The teachers hoped that students might be able to take a stand and construct their arguments by using their own experiences of zoos. Mala also highlighted that some students might change their perspective after discussing the issue with others, thus reconsidering their initial thoughts as an essential aspect of scientific argumentation, which shows how the teachers developed their knowledge and understanding of scientific argumentation. The teachers did not reach a consensus regarding how to start the lesson and their instructions. This indicates that the teachers had various understandings and approaches to scientific argumentation.

Another feature of the discussion was how students might be organised for the group discussion. The teachers' earlier experiences with their own students influenced their opinions about the organisation of their students. Padma mentioned that her students had some behavioural issues and she preferred pair discussion. Similarly, Ray considered that he did not yet know his students well and chose to organise them based on friendship around tables of four. Mala, however, considered a role-play strategy, as suggested in the teaching sequence, stating:

> I really like the idea of giving the students a role; they could generate their argument according to the role they are taking in fours (Mala, September 2018).

Mala was the only teacher who employed a different group strategy in her practice. The teachers considered more their students' characteristics when organising their students for group work. In addition, they focused on ways such as posing prompt questions to sustain the students' group discussion. As suggested in the teaching sequence in the IDEAS pack, the teachers considered using questions to keep the students engaged in the activity during the group discussion.

Summary of teaching sequence below:

- Ask students to write a letter about funding a zoo (Padma and Mala's plan; Ray decided to do this at the end of the lesson)
- Introduce scientific argument and scientific argumentation.
- Organise students for the group discussion (Mala decided to give her students different roles, Padma planned to organise students for pair discussion, and Ray planned to group his students around tables of four).
- Distribute the activity for group discussion and explain the task.
- Allow about 10 to 15 minutes for the group discussion.
- Finally, have a plenary session to discuss the students' responses during the whole-class discussion and ask them if they changed their minds.

Overall, in the second year, all three teachers took their classes and students' dynamics into consideration while planning the argumentation lessons. They spent more time discussing how to introduce argument and argumentation, organise the students in groups, and get students engaging with the activity and having group discussions. This demonstrates the teachers' development of a scientific argumentation pedagogy.

4.2.2 The three teachers' implementation of Dropping a box activity

This section presents an examination of each of the three teachers' (Ray, Padma, and Mala) implementation of scientific argumentation.

4.2.2.1 Ray's Dropping a box lesson

Figure 4.1 illustrates Ray's lesson structure of classroom practice.

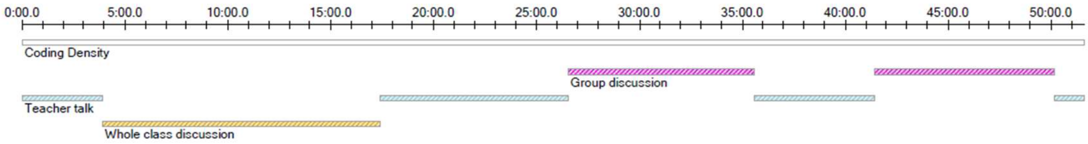

Figure 4.1 Phases of lesson structure of Ray's Dropping a box lesson in December 2017[9]

Figure 4.1 shows there is a period of teacher talk at the beginning of the lesson in which Ray provided a general explanation of what a scientific argument means and how to make a scientific argument supported by reasons and evidence. He then used an activity about how we see objects (obtained from IDEAS pack, Osborne et al. (2004b)). Then followed a long period of whole-class discussion led by Ray at the front of the class, during which his students evaluated statements given in the activity. In the second period of teacher talk, Ray introduced the argumentation activity and provided a general description of the activity. He then organised his students for the group discussion. In the first part of the group discussion, his students discussed the statements given in the activity sheet. Then, Ray brought the class together to ask his students to write their reasons on the activity sheet for the next part of the discussion. Thus, his students discussed the statements and wrote their reasons on the sheet. Ray then concluded the lesson by informing his students that they would carry on with the activity over one more lesson.

[9] When a PDF version of the document was generated, the colour of the Nvivo 12 coding was altered.

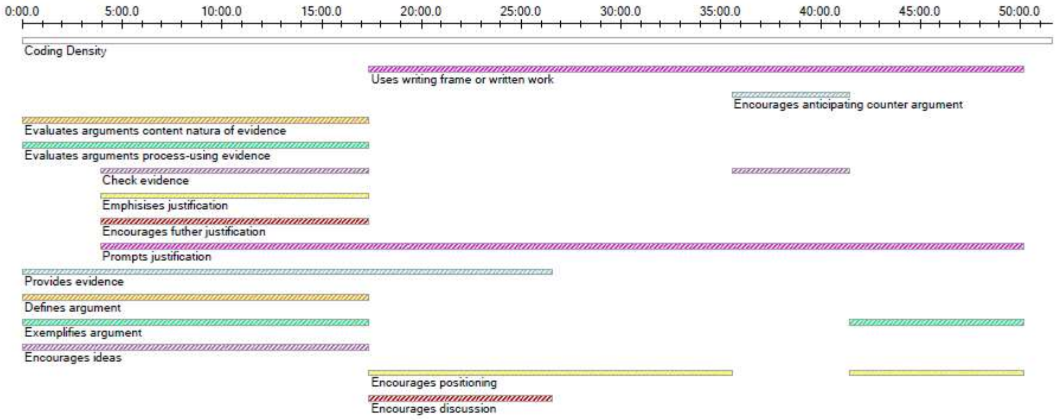

Figure 4.2 Phases of the SAP of Ray's Dropping a box lesson in December 2017

Figure 4.2 further examines the same lesson in terms of Ray's SAP throughout the lesson. The profile demonstrates that he attempted to utilise a range of argumentation processes to support his students' engagement in scientific argumentation throughout the first part of the lesson but used comparatively few argumentation processes during the rest of the lesson.

In the first phase of the lesson, Ray focused on defining and exemplifying scientific arguments. He highlighted the purpose of using evidence and reasons in constructing arguments by providing an example of how scientists prove their theories. Furthermore, as seen in Figure 4.2, most of Ray's instructions focused on enhancing the process of justification. He provided argument prompts (e.g., "Why do you think that?" and "What is the reason for that?") to encourage his students to add justification and reasons to their arguments throughout the lesson.

Ray provided the activity 'How we see objects' (Osborne et al., 2004b) to explain how evidence is used in a scientific argument and exemplify the construction of an argument. A representative episode from the whole-class discussion is shown below. Here Ray used arguing prompts such as "Why do you think that?" (line 3) to encourage his students to provide justification and reasoning for their claims.

1	Ray	Let's do the first one. Light travels in straight lines; does that help any of the hypotheses? Does it support any of these,

		the fact that light travels in straight lines, does that help at all? Student 1?
2	Student 1	Possibly
3	Ray	Why do you think that?
4	Student 1	Because if it (light) does not travel in different directions, it would not hit your eyes properly.
5	Ray	Okay, true. But the fact that it travels in straight lines could be applied to both of them. This one is saying the light bounces off stuff and goes into your eyes, and this one says the light travels out of your eyes and onto the stuff. So, the fact that light travels in straight lines does not help one over the other; they're both the same. So, the fact that number one, although it is true, does not really help either of these. Okay, what about number two: we can still see at night when there is no sun. Which hypothesis do we reckon that helps the most? Student 2?

During the exchange shown above, Ray provided a great deal of feedback and explanation for his students' responses. He followed a pedagogy of resolving the science content through talking most of the time (line 5). His approach was to "impose" the content knowledge on his students during the whole-class discussion. It is not surprising that his students' involvement appeared limited during this practice, with little chance to justify their ideas further.

For the introduction of the argumentation activity, Ray provided a detailed explanation of the activity, including what the activity would entail, explaining that students were required to justify their choices as a group, provide evidence in their responses and write their reasons:

> You are going to annotate your sheet to explain your choices as a group; you need to explain why you chose 3a, 3b or 3c. Why do you think it is the correct answer? What evidence shows that your statement is correct? What evidence do you know about that backs up your statement?

Ray then organised his students into groups of 4 or 5, depending on the number of students around a table, and provided them with some time to discuss the statements as a group. Throughout the group discussion, he walked around the room, joined in some of the group discussions, and prompted them with some questions (e.g., "Why do you think that? How did you reckon that? What is your reason for choosing this one and crossing out other statements?") to help them work out their reasoning. After some time, he brought the class together and encouraged his students one more time to justify their choices and write down their reasons for why they had chosen the statement:

> When you have made all your choices that you have agreed as a table, start writing down why you made the choices you did, why you chose it, what evidence supports it, why did you not choose the others?

During the second part of the small group discussion, Ray prompted his students to continue discussing the statements as a group and write their reasons on their activity sheets. However, the time given to the students was not sufficient to finalise the activity. Therefore, he judged that the students needed more time to complete the activity and write down more reasons and justifications for their choices. He decided to carry on with this activity over one more lesson. Figure 4.3 and Figure 4.4 show Ray's lesson structure and SAP of Dropping a box activity in the following lesson.

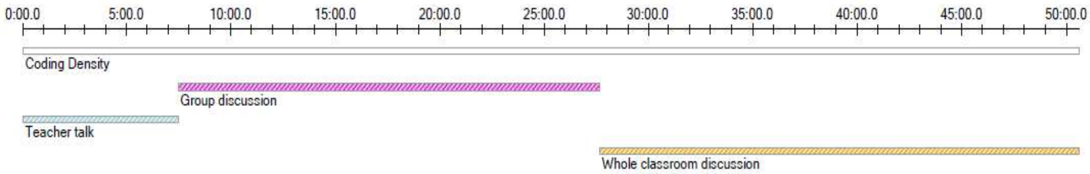

Figure 4.3 Phases of lesson structure of Ray's Dropping a box lesson (following lesson) in December 2017

Figure 4.3 shows there is a period of teacher talk where he provided a reminder of what the activity entailed. He asked his students to discuss the statements and write their reasons down on the activity sheet. Following this period, there was a long period of small group discussion during which his students discussed the statements one by one and wrote their reasons down. Most of the student's written work was produced at this stage of the lesson. At the end of the lesson, the teacher allocated a long period of participatory whole-class discussion during which he went through all statements given in the activity.

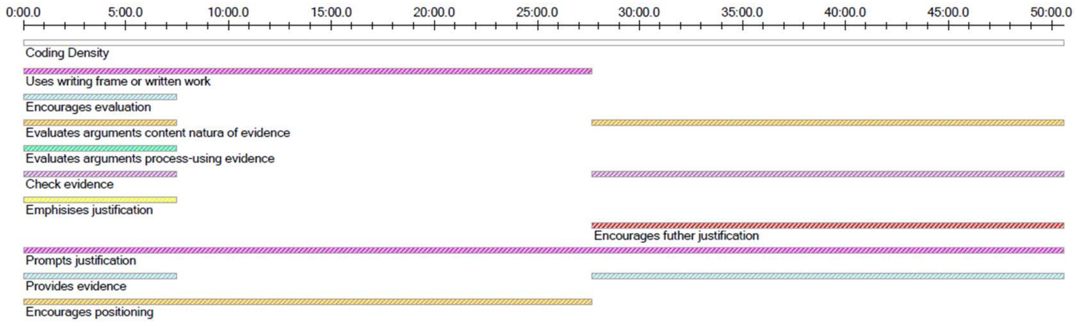

Figure 4.4 Phases of SAP of Ray's Dropping a box lesson (following lesson) in December 2017

As seen in Figure 4.4, most of the scaffolding processes Ray implemented in his instructions were geared to helping his students choose the correct statements and provide reasons for their choices. He highlighted the importance of evaluating an argument when providing evidence to support an argument and assessing the content of the evidence. Furthermore, he encouraged his students to write down their reasons on the activity sheet. The students then practiced discussing the given statements in the activity as he walked around the room and joined in with group discussions.

Lastly, for the majority of the whole-class discussions, Ray led the discussion by calling out a student's name and having that student respond to his question. He conducted a whole-class discussion to check his students' responses and to offer a comprehensive explanation for each statement to resolve the science content, as seen in the following excerpt from the whole-class discussion:

1	Ray	Look at 7. Is it A? The size of the air resistance force in the box is constant. Or is it B? The air resistance force gets bigger as the box gets faster. Student 1?
2	Student 1	B
3	Ray	B why? I agree. Why B.
4	Student 1	Because if you put your hand out at 20 mph, your hand will fall back (inaudible comment)
5	Ray	Very good example. So, if you're travelling in a car and putting your hand out the window, you're going at a low

> speed you feel small. You feel a force pushing your hand backwards. If you start travelling faster, then a force you feel is bigger. If you put your hand out the window, going at like 70, you'll be really fast. The faster you go, the bigger the air resistance is. If you think about moving faster, you are going to push more air out of the way to get through it, so the faster you go, the more air resistance there is.

In the second lesson, Ray provided more time for his students to discuss the statements and construct their written work. The time he spent on the activity is reflected in the students' written work. He approached this activity as a tool to get his students thinking and discussing the statements and also focused on resolving the science content, helping them choose the correct statements and providing reasons for their choices.

Table 3 (see Appendix 11) captures his students' responses and the reasons they provided for each statement given in this activity. In both lessons, Ray focused on helping his students find the correct answers and discussing them as a group. In the first lesson, his primary focus was to get his students to discuss rather than write down their reasons for their choices. In the second lesson, he gave them more time to discuss the given statements and write down their reasons. The result was that his students had more time to be able to produce comprehensive written work, check their ideas, and focus on the correct science. Therefore, they were better able to understand the statements and find the correct answers. The written work from them revealed that intensive discussion did take place during the group discussions. His students in all the groups apart from Groups 2 and 7 completed the activity. They attempted to choose the correct statements and provide reasons for their chosen answers. There is also a mixture of incorrect answers to some questions as the students were unsure about the correct statement for these questions.

As an example, the students in Group 1 attempted to pick the correct answer and then provide reasons for their choice. In addition, they anticipated alternative answers and made some possible counterarguments, giving comprehensive reasons in their written work. For question 7b, they wrote:

> The air resistance gets bigger when the box gets faster because it's trying to make it land safely; somebody else might disagree because number 3 is roughly the same size. Therefore they might believe that the size of the air resistance force is constant.

Some groups (e.g., Group 6) were unsure about their choices for question 4. They evaluated both statements and tried to give reasons for each one, which shows that the task was complex for them and difficult to think through.

In the first lesson, the students in Group 6 chose 4b and provided their reason. In the second lesson, these students had second thoughts about this question and chose 4a. This show that they reconsidered their choices after having a comprehensive discussion.

Some groups (such as Groups 5 and 6) provided similar justifications for their response to question 7, suggesting that the teacher influenced the students' responses and reasons to support their choices during the group discussion.

Overall, the student's written work reflected the approach taken by Ray during these lessons as he was focusing mainly on resolving the science content and helping his students choose the correct answer as well as providing reasons for their chosen answer. Giving the students more time to discuss the various options enabled them to produce more comprehensive written work.

4.2.2.2 Padma's Dropping a box lesson

Figure 4.5 shows the lesson structure of Padma's lesson.

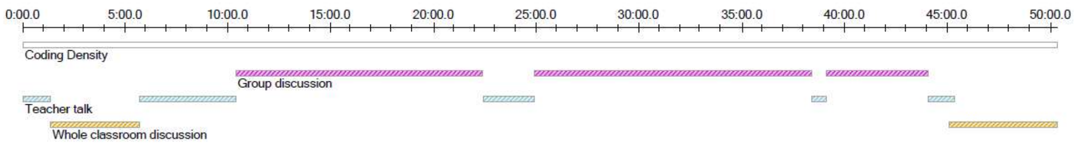

Figure 4.5 Phases of lesson structure of Padma's Dropping a box lesson in November 2017

Figure 4.5 shows there was a short period of teacher talk at the beginning of the lesson in which Padma explained the aim of the lesson and projected five statements about the Earth on the whiteboard. Then, she and her students evaluated each statement during the whole-class discussion.

The Dropping a box activity was then introduced. Next, there was a considerable period of small group discussion during which her students discussed the statements given in the activity sheet. She then brought the class together to remind the students what the activity would entail and carried on discussing the statements. Next, she once again brought the class together to ask the students to write down their reasons on the activity sheet during the last part of the group discussion. Finally, Padma brought the class together to ask their opinions about holding group discussions in science lesson.

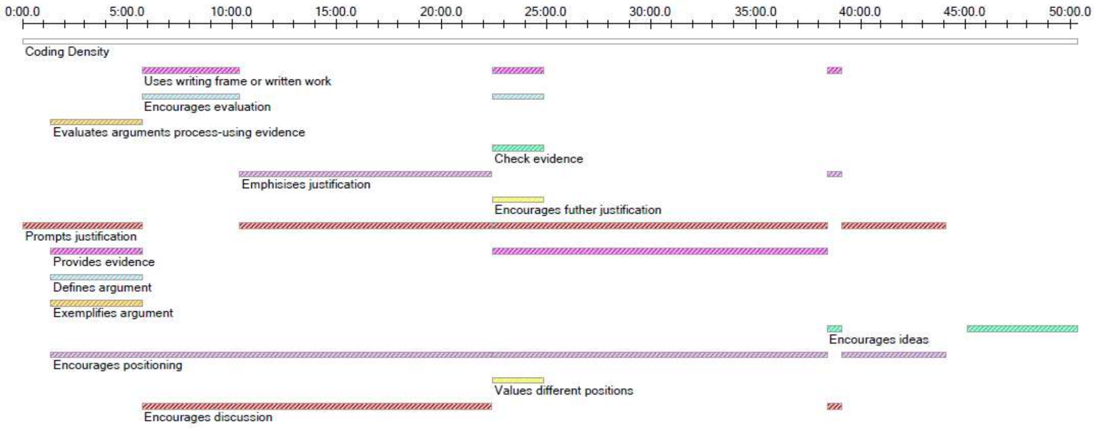

Figure 4.6 Phases of SAP of Padma's Dropping a box lesson in November 2017

Further analysis of the same lesson regarding the distribution of SAP shows that Padma utilised a range of argumentation processes throughout the lesson. As seen in Figure 4.6, she employed a variety of argumentation processes in the first part of the lesson, especially during the whole-class discussions but used relatively few argumentation processes in the rest of the lesson.

At the beginning of the lesson, Padma explained to her students what is needed to make a good argument. It encouraged them to construct arguments supported by evidence and reasons as follows:

> We are not talking about personal beliefs; that is not what scientists do. That is not an intelligent way of discussing. We are going to use ideas and evidence. We need to explain and give reasons why.

Padma then provided a general description of what the argumentation activity entailed and organised her students to work in groups of four or five students for the small group discussion as planned. She also encouraged them to discuss each statement, decide on the correct statements and write down their reasons as a group:

> You are going to use every single one of the boxes, but only one statement is correct from each box. I would like you to decide in your group which statement you are going with. Instead of crossing the line, I would like you to do a little star, do a star against the one you would like to get chosen. Once you have done that, put your hands up we can have a look. You have 10 minutes to discuss and decide the correct statements as a group. Remember that is not just your choice; you all have to agree.

Later on, she again reminded her students to choose the statement that they deemed to be correct, annotate their choice and write down their evidence and reasons. Padma's instructions focused on enhancing the process of justification. She provided argument prompts (e.g., Why did you choose the statement you chose?" and What evidence shows that your statement is correct? Why did you cross out the other statements) to encourage her students to add justification and reasons to their arguments.

Padma attempted to utilise this activity as a tool to encourage her students to think and discuss during small group work. Table 4 (see Appendix 11) captures her students' responses and the reasons they gave in support of each statement. In the first part of the group discussion, she focused on getting her students to discuss the statements rather than write down their reasons for their choice, demonstrating her priority at this point of the lesson. In the second part of the group discussion, Padma asked her students to provide reasons for their choices; however, she did not emphasise enough the process of writing their reasons on the activity sheet. Therefore, the written work gathered at the end of the lesson was limited. The written work revealed that discussion took place in the majority of groups and that, apart from Group 5, all the groups completed the task of choosing the statement they deemed correct. Most groups were observed choosing the correct statements during the group discussions. For instance, Group 1 chose the correct statement for each question. In addition, Groups 3 and 6 answered all questions (apart from question 10) accurately. There was also a mixture of incorrect answers to some questions, such as 7 and 10, as her students were unsure about the correct statement for these questions. As evidenced in Table 4, half of the groups (e.g., Group 1,2 and 3) did not give any reasons for their choices. The other groups (e.g., Groups 4,5 and 6) wrote their reasons briefly.

Some groups attempted to provide reasons for their incorrect choices (e.g., Groups 4 and 5). For instance, the students in Group 5 chose 7a, which was the wrong choice and provided the following reasoning:

> It (the box) will pull upwards if it (the size of the air resistance) gets stronger than gravity (Group 5).

Her students seemed to understand the notion of air resistance; however, they were confused about gravitational force. For instance, only Group 1 selected the correct statement in question 10; however, they did not justify their choice.

Overall, Padma focused mainly on encouraging her students to have extensive discussions as a group, and most of the groups did select the correct statements. However, she did not emphasise the process of writing down reasons; therefore, many students did not attempt to provide reasons for their choices.

4.2.2.3 Mala's Dropping a box lesson

Figure 4.7 demonstrates Mala's lesson structure.

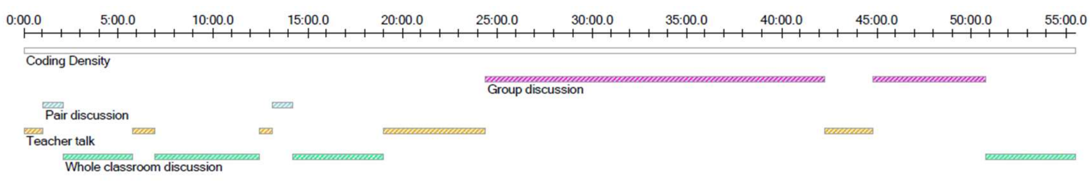

Figure 4.7 Phases of lesson structure of Mala's Dropping a box lesson in November 2017

Figure 4.7 shows that there was a short period of teacher talk at the beginning of the lesson in which Mala provided a brief description of the aim of the lesson and asked a question about the shape of the Earth. She then requested that her students discuss her question in pairs. She then brought the class together and obtained her students' responses through whole-class discussion. Next, she explained what argument and scientific argumentation means in science, showing five statements on the whiteboard and discussing them as a whole class. Mala then projected an image of a girl lifting a foot up on a scale. Three different statements about how the weight changed were shown, and her students were asked to identify the correct statement in pairs, after which she gathered her students' responses during whole-class discussion. Followed by a period of teacher talk, in which Mala introduced the argumentation activity, explained what the students were expected to do during the activity and asked them to work as a group. Her students then discussed the statements in small groups and wrote the reasons behind their answers down on the activity sheet. After that, she brought the class together and asked the students to swap their activity sheets with another group and evaluate the reasoning written down on the other group's sheet. Thus, during the second part of the group discussion, her students evaluated the other group's reasoning. At the end of the lesson, she again brought the class and used the whole-class discussion to obtain the students' responses.

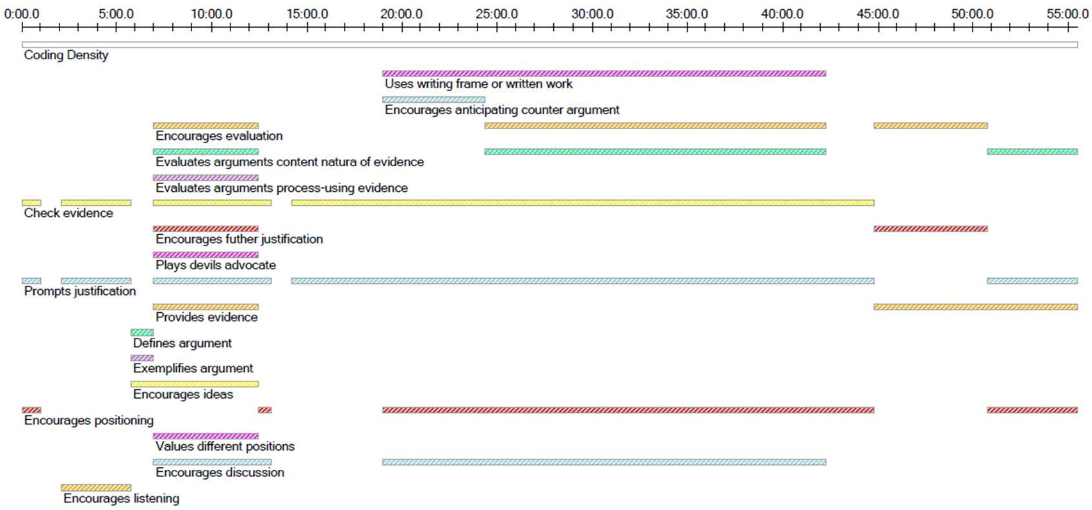

Figure 4.8 Phases of SAP of Mala's Dropping a box lesson in November 2017

The distribution of SAP in Figure 4.8 shows that Mala used a variety of argumentation processes throughout the lesson, especially during whole-class discussions and small group discussions.

In the first period of the lesson, Mala prompted her students to provide evidence and reasons while constructing their responses during pair discussion by prompting, ‘Why do you think that? What is your reason for that? What evidence do you have for that?’. She consistently applied these prompts during her practice to encourage her students to support their responses with evidence and reasons and justify them.

During the whole-class discussion, Mala placed herself at the front of the classroom and encouraged a high level of student participation. Several points are worth noting during this practice. Firstly, Mala encouraged students’ equal participation when it came to expressing their opinions. Her emphasis in this regard seemed to influence students’ participation as students took on one another’s ideas without critiquing them. Secondly, after Mala had received responses from a number of students, she encouraged her students to support their ideas with evidence and reasoning. In addition, she highlighted what counts as evidence and reason in an argument and exemplified these by using the students’ own responses.

Mala then provided a general description of what argument and scientific argumentation means by relating what her students were doing to what scientists do:

> What you have been doing is something called argumentation; we have been discussing ideas, giving reasons and evidence about why you think those things. This is what scientists do: they look at evidence, facts, discuss them, argue it, and then come up with a theory.

Furthermore, Mala exemplified some arguments about the shape of the Earth on the board and played devil’s advocate to get her students thinking and to stimulate further justification of arguments about the Earth’s shape by saying:

> An idea could be someone could think the Earth was flat because the roads are flat, the roads do not start curving, do they?

When posing the question of how the weight changes if a foot is raised up on the scale, Mala provided three different statements and asked her students to discuss these in pairs. She encouraged her students to take a position and support it by using evidence and reasons. During this process, she focused on checking students’ evidence and reasoning. She made visible to the class a structure that could be used to construct a strong argument. For instance, in the sequence below, Mala focuses on evaluating the process of using evidence to make a strong scientific argument. However, she does not consider evaluating the content of evidence while constructing an argument.

1	Mala	So, what do you think you need to make a good scientific argument to make it strong? Student 1?
2	Student 1	We need a point, a reason and a backup.
3	Mala	You need a point; you need to have a reason to that point. What do you mean by backup?
4	Student 1	Evidence
5	Mala	You need evidence, don't you? to back up what you are saying.
6	Student 2	We also need to give at least two bits of evidence to back up your argument.
7	Mala	Good, the more evidence you have the stronger your argument is going to be, isn't it? So, we have done that we have talked about backing up our ideas.

Mala then provided a general description of what the argumentation activity would entail, explaining that the students were required to work in groups of four or five, discuss each statement, provide evidence and reasons and write their responses down on the activity sheet. It is important to note here that Mala thought it was necessary for the students to explicitly understand the strategy:

> I want you to annotate why you have made these choices. I want you think about why you chose the statement, what your evidence shows to suggest that the statement that your group have chosen is correct, why you decided not to choose other statements, and think about how somebody else can disagree. You are going to follow the story, choose the correct one, cross out incorrect ones. On that side, we need to write down why you choose that one and what your evidence is.

Mala provided an extended period of time for group discussion and encouraged her students to use evidence in their responses (e.g., asking them about their evidence) and explain their reasoning (e.g., "think about what you know about forces that would be acting on the box . Can there only be one force that acts on the box at one object? Or does it have to be in pairs?"). She highlighted once again what is needed to construct an argument and asked her students to construct their response in a structured way:

> We discuss what the good argument is in science. Make sure you are using evidence for a good argument. What is your evidence to explain why you have chosen that? You are going to argue. You are going to present your ideas scientifically. We need evidence; we need facts to support the ideas. You told me one fact is not enough, and we need lots of evidence to make a good, strong argument.

When Mala brought the class together, she asked her students to swap their sheets and use different coloured pens while evaluating the other group's responses, evidence and reasons provided. In addition to this, she asked them to provide reasons backing or opposing each statement that they had discussed. During this practice, her students had the opportunity to evaluate each other's arguments, critique the quality of a piece of reasoning, and reconsider their previous responses. This practice shows that Mala thought this process was essential for her students to gain a better understanding of argumentation. During the last part of the lesson, Mala received some responses from her students about each statement being discussed, asked them whether they agreed with the other group's choices and gave the correct answers. There was not sufficient time to complete the activity, and her students were only able to check their responses up to the 6th question.

The observation of Mala's approach to SAP was reflected in the students' written work. She attempted to use this activity as a tool not only to encourage her students to discuss, provide reasons for their choices and but also to evaluate each other's responses rather than simply identify the correct answers.

Table 5 (see Appendix 11) provides an overview of students' responses and their reasoning for each statement in this task. In the first part of the small group discussion, Mala focused on getting the students thinking and discussing, as well as writing down reasons for their choices, which shows what Mala thought was important. Students' written responses reflect this emphasis. Only the students in Group 4 did not complete the activity within the given time. The students in Group 5 could not provide any reasons for the last two statements. There is also a mixture of incorrect answers to some questions, such as 3, 9 and 10, as her students were unsure about the correct statement relating to these questions. The students seemed to understand the notion of air resistance. For instance, all students selected the correct statement and provided accurate reasoning for question 6; however, they were unsure about gravity and gravitational force. As evidenced in Table 5, her students got confused in question 3, and two out of the five groups of students selected the correct statement and provided their reasoning. For instance, the students in Group 4 selected 3a and wrote:

> Gravitational forces will not change regardless of whether the box gets bigger or smaller (Group 4).

The students in Group 3 selected the correct statement 3a; however, their reasoning was not accurate. Additionally, the students in Group 2 selected 3c and the reason they provided did not seem to make any sense.

When Mala asked her students to swap their activity sheets and evaluate another group's arguments and reasons, her students attempted to evaluate the other group's written work. At this stage, she encouraged her students to discern and discuss the various options; this indicates that she thought evaluating each other's arguments was important in argumentation strategy. This allowed her students to produce counter-arguments. As illustrated in Table 5, the students' written work underlined responses were collected in the second part of the activity. Only one group completed the task and provided their opinions on the chosen answer within the time given.

The students provided their opinions both when they agreed and disagreed with the other group's choices. For instance, the students evaluated Group 5's responses and agreed with the chosen answer to question 6b, adding their own reasoning:

> Because the air resistance stops the box from going down, stops it. We agree, but our reason was that the gravity always goes the opposite of air resistance (Group 5)

Another example was that the group evaluated Group 4's responses to question 6b and attempted to add further justification for their choices.

> Air resistance will always be reacting upwards. Agree; this is because air resistance always makes objects slower, not faster. If it is acting downwards, it would be faster (Group 4).

On the other hand, the students who evaluated Group 3’s responses to question 8 disagreed with Group 3’s choice and provided their reasoning for this question, writing:

> This can happen because gravity needs to bring the box to make it towards the Earth. Disagree because the air resistance will not stop the box but will make it slower (Group 3).

Overall, the student's written work reflected Mala's approach during the lesson as she focused mainly on encouraging her students to discuss the statements, provide reasoning for their chosen answers, and evaluate their responses by considering their initial responses and others’ responses. Allowing her students to evaluate another group’s answers helped them develop alternative explanations and provide reasons for their choices.

4.2.2.4 Comparison of the teachers’ practices for Dropping a box lesson

The analysis of Dropping a box lessons enabled me to compare the teachers’ scientific argumentation practices within a scientific context. Despite the fact that they planned the lesson collaboratively, the way they implemented the plan in the classroom varied according to their understanding and values of teaching science through scientific argumentation, approaches to using this activity, time and the organisation of students’ discussion.

All the teachers anticipated students would struggle to formulate their responses due to a lack of sufficient knowledge and misconceptions about the topic, as well as no prior experience with the argument structure. Therefore, they applied the activity as a recap of the scientific context; thus, their students were able to provide reasons based on their previous knowledge of forces. All three teachers thought that the idea of teaching science through scientific argumentation would be challenging because the students were unfamiliar with the approach. Therefore, to introduce scientific argumentation within a scientific context, the teachers took a variety of approaches according to their understanding and value of teaching science.

Ray attempted to provide his students with a great deal of explanation about the topic, spending more time on that activity to help them produce written work. Padma encouraged her students to understand the idea through group discussion by listening to one another. On the other hand, Mala attempted to help her students understand the ideas being presented when discussing them in groups, listening to one another, producing written work, and evaluating each other's work. The findings show that the teachers had different purposes for approaching the argumentation strategy in their lessons, as Mala and Padma considered scientific argumentation valuable for encouraging students' thinking, reasoning, communications and interactions with each other (McNeill et al., 2013; McNeill & Krajcik, 2008).

All three teachers used different methods while providing a general explanation of scientific argument and scientific argumentation processes. Ray, for instance, used an activity to introduce the construction of an argument and scientific argumentation processes. Padma provided examples of scientific arguments to demonstrate how to construct an argument and briefly explain the scientific argumentation processes. Before giving a general explanation about how to construct a scientific argument, Mala used prompts to help her students understand the idea of argument construction. She then, like Padma, provided examples of scientific arguments to demonstrate how to construct an argument. Afterwards, similar to Ray, she used an activity to explain the scientific argument and scientific argumentation processes to her students. The teachers were observed using prompt questions constantly to support students' argumentation (McNeill & Pimentel, 2010).

When organising group work, all three teachers utilised the same group strategy, students working with the students who happened to be sitting at the same table. She was the only teacher willing to experiment with a new strategy in her practice for this lesson but appeared to be following Ray and Padma's approach.

Another difference between the teachers was the time permitted for the small group discussion. Ray allocated additional time to his students to work in groups and produce written work collaboratively than Padma and Mala. This was possible because he had decided to dedicate two lessons to the activity. The student's written work was directly related to the teachers' instructional practices, as highlighted by Erduran et al.'s (2004) study. The amount of time the teachers spent on the activity and the ways in which they attempted to implement the activity influenced the students' written work. However, written work was only one indication of how the scientific argumentation approach is incorporated into practice in terms of enhancing students' argumentation skills. For instance, Mala encouraged her students to discuss and produce written work as groups and to evaluate the other groups' reasoning. Padma spent an extended period of time on group discussion and placed less emphasis on written work during small group discussions. Ray and Mala encouraged their students to share their responses and reasons with the class and checked their students' understanding during the whole-class discussion. In contrast, Padma utilised whole-class discussion at the end of the lesson to gather her students' opinions about the argumentation practice, rather than providing time for her students to share their responses and reasoning with the class.

In terms of SAP, the findings revealed that all three teachers attempted to utilise a variety of argumentation processes during the lessons. Their instructions indicated what they considered significant when incorporating scientific argumentation into science teaching and how much they emphasised science teaching using this approach. The different approaches taken by the teachers are likely to have had an influence on students' written work and engagement in this practice. All the teachers strongly encouraged their students to understand the meaning of scientific argumentation, construct their responses through providing evidence and reasons to support their responses, and justify them. In addition, they modelled the argumentation process utilising examples of arguments and constantly supported their students by focusing on the justification process. The teachers provided some time for students to explore the use of evidence and reasons to support a claim by asking, "What is your evidence?" (McNeill et al., 2017). These features of their practice show that they shared a good understanding of how to incorporate this practice at the outset.

A further key difference emerged between the teachers' use of the argumentation approach; Ray incorporated a range of scientific argumentation pedagogy in his instructions. However, his role was mainly to ensure that his students understood the science content and gave appropriate reasons. He asserted the importance of choosing a ‘correct statement’ and producing written work was demonstrated as his main focus and required his students to choose the right answer and provide reasons to support their choices about the topic.

Padma included some argumentation processes throughout her lesson. She spent the majority of her time making sure her students contributed to the group discussions. The importance of discussing a ‘correct statement’ and contributing to the discussion was demonstrated as her main learning goal, as she required students to discuss as a group, listen to each other and provide reasons to support their choices. However, she did not emphasise producing written work.

Mala’s argumentation approach differed from that of the other two teachers in several ways. She encouraged group discussions by prompting them to examine the structure of an argument and justify their evidence and reasons. In addition, she played devil’s advocate to stimulate further justifications and highlighted anticipating counter-arguments in her lesson. Due to the limited time frame, her students were unable to complete the activity. Nevertheless, she helped her students develop the argumentation skills thought processes with regard to discussion and the evaluation of each other’s arguments. Mala’s learning goals comprised both less focus on science content and a stronger focus on scaffolding scientific argumentation.

4.2.3 The three teachers’ implementation of Zoo activity

In this section, the examination of the teachers’ implementation of the Zoo activity is presented for each teacher, Ray, Padma and Mala, respectively.

4.2.3.1 Ray's Zoo lesson

Figure 4.9 below shows Ray's lesson structure of classroom practice.

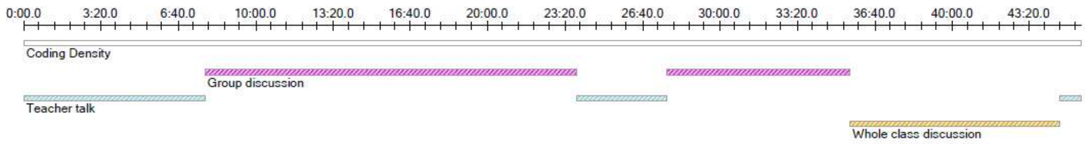

Figure 4.9 Phases of lesson structure of Ray's Zoo lesson in October 2018

Figure 4.9 shows that there is a period of teacher talk in which Ray introduced the argumentation activity. He then explained what a scientific argument means and how to make a good scientific argument supported by evidence and reasons. Then followed a long period of group discussion in which he handed over a series of question cards to his students (provided in the activity, see Appendix 5). His students discussed each of the questions as they received them. Ray then brought the class together to remind his students of how to make a good scientific argument and asked them to come up with a final decision as a group. He then provided some time for group discussion, after which he asked each group to present their final decision supported by their reasons within a whole-class discussion. In addition, he also asked if anyone had changed their mind after listening to other groups' ideas at the end of the whole-class discussion. Finally, he set them the task of writing a letter as homework.

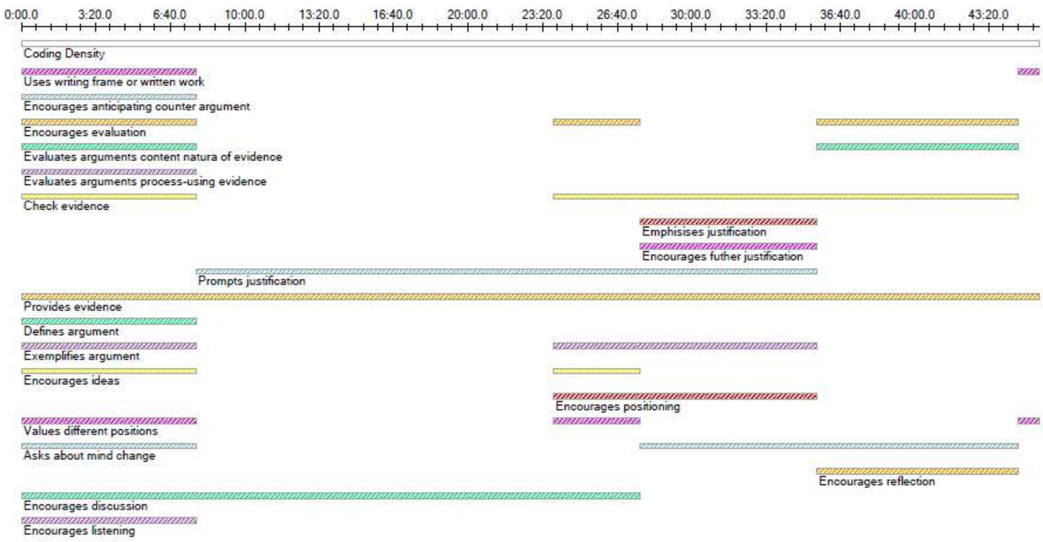

Figure 4.10 Phases of SAP of Ray's Zoo lesson in October 2018

To further examine the same lesson in terms of SAP, Figure 4.10 presents a profile of Ray's instructions during the lesson. The profile indicates that he attempted to utilise a variety of argumentation processes during the first phase of teacher talk but applied relatively few argumentation processes during the rest of the lesson.

In the first phase of teacher talk, several things are worth noting about his instructions. The first is that Ray exemplified how to construct a good scientific argument and highlighted the purpose of using evidence and reasons to support a claim. He also connected this scientific argumentation process to the practices followed by scientists:

> Scientists make claims about certain things, and they have to have reasons and evidence to support that. So, for example, things about climate change and global warming, so scientists make a claim the climate is changing, and the average temperature on the planet is increasing. They cannot just say this and expect people to believe them; they have to have evidence to show and support what they have seen, they have to explain it with science and back it up with evidence, so they know it is true. We are looking at that in a science lesson because this is what science is about.

Secondly, he also highlighted the aim of using persuasive language to include the idea that scientific argumentation is a process in which you are trying to convince others of a claim, which is why it is crucial to apply this process in a science lesson. He also encouraged his students to anticipate counter-argument:

> We want to create good strong scientific arguments; we need good reasons for our arguments and evidence, facts for your argument. You can use persuasive language; the language you use is important. Also, you need to think about what other people think; if you try to change someone's opinion or change someone's mind, you have to think about why they think differently from me and how can I persuade them to think how I think about it.

Thirdly, Ray prompted his students to discuss the task as a group and listen to each other in the group discussion by considering their own experiences and perspectives of the advantages and the disadvantages of having a new zoo. In addition, he emphasised the importance of feeling free to change their initial opinion during the small group discussion. He projected some examples of sentence starters to help the students construct their arguments (see Appendix 10). Ray explicitly states that he believes these three points are necessary for developing students' argumentation skills.

For the group discussion, Ray organised his students into groups of 4 or 5, depending on the number of students sitting around each table. He then gave his students a series of question cards provided in the activity, such as 'Is it cruel to keep animals in cages? (Ethics)' and 'Do zoos allow you to see a large number of different animals? (Education)' (see Appendix 5), which required generating arguments from different perspectives to encourage his students to discuss different opinions. While his students were discussing the questions, he prompted them to provide reasons for their thinking and discuss them as a group.

In the second phase of teacher talk, Ray prompted his students to make the final decision for or against funding a new zoo as a group:

> You are allowed just only one opinion for or against, yet? You have some opinions on both sides. You have a lot of different opinions, so what I want you to do is try to come up with a final decision, okay, not ignoring all of the stuff you think of against or for it. In your group, come up with a decision where you can look at all of the evidence and make a decision.

He also encouraged his students to consider their initial experiences and perspectives and evaluate their own decisions. Additionally, he reminded his students to use a sentence starter to build their arguments.

Ray then encouraged his students to provide their reasons and justify their opinion while making a final decision during the second phase of the small group discussion. Furthermore, he prompted his students to take a position as a group (lines 5 and 8 below) and reflect their opinions if there was a conflict between group members, as shown in the extract below:

1	Student 1	My arguments for are that people can learn more and animals are safe in the zoo from poachers. Endangered animals can be protected more, like rhinos. And arguments against it; they could break out and kill, they might not have enough space, if predators are not released back, they may not be able to hunt.

2	Ray	So, what do you think, it is your choice as a group, are you for or against it? Yes or no for the zoo.
3	Student 1	Yes
4	Student 2	Yes
5	Ray	So, you think yes, if you have a vote between the three of you. What is your conclusion here, yes or no, for the zoo?
6	Student 2	I think yes. what do you think?
7	Student 3	I think no.
8	Ray	Oh, so what do you have? 2 for and 1 against. It is not my decision; it is yours, so you have to try and decide in your group for or against the reasons for and against. Obviously, it is not one way or the other; you have to make a decision.

At the end of the lesson, he encouraged the groups to share their final decisions with the rest of the class. Each group presented their decision and provided their reasons. During this process, Ray encouraged his students to reach a consensus and value the differences in their opinions. At the end of the exercise, only one group was unable to make a final decision as they were unable to reach a consensus, with two students voting for and two students against the idea of opening a new zoo.

Lastly, after listening to each group’s decisions, Ray touched again on the importance of taking a position, considering different opinions, and anticipating counter-arguments. He also encouraged his students to reflect on their opinions by asking them if they had changed their minds in any way after listening to others’ opinions.

Ray then asked his students to write a letter as homework about their decision on whether a new zoo should be opened, stating their opinions and reasons. However, not all students did the homework, as only seven students’ written work (roughly a third of the class) was eventually collected. However, some insights could be elicited from the seven responses. First, all these students processed the written work in the same way. Firstly, they all started their individual letter by stating whether they were for or against building a new zoo and then providing their reasons for their decisions. While looking at the students’ written work, there is some balance in terms of the students’ decision, with four students for and three students against building a new zoo. The students gave a variety of reasons in their letters to justify their decision. It was evident that the students' reasons reflected the rich discussion held during the lesson as the letters focused on different aspects of the discussion.

Students’ reasons for building a new zoo included protecting endangered animals, taking care of the injured animals, education, and economics (e.g., promoting tourism and economic resources). For instance, Student 1 wrote:

> I have decided that we should have a zoo! I have come up with some reasons why I think having a zoo will help us. Firstly, we should have a zoo because it promotes tourism-more tourists around the world will come to the UK. Secondly, it gives people an opportunity to learn more about animals and nature. It engages children in science. Thirdly, a zoo provides a protected environment for endangered animals because they have lots of protection in the zoo. And finally, zoos are an economic resource because they provide jobs for others. I hope you’ll consider having a zoo.

In contrast, students’ reasons against building a zoo included issues with the very concept of zoos, the lack of facilities for animals (e.g., not able to get enough food, treatment), having animals live out of their natural habitat (e.g., natural instinct), the cost, the environment (e.g., lack of land, congestion), and animals’ feelings (e.g., being tormented, being caged). For example, Student 2, whose reasoning against the building of a zoo included opposition to the concept of zoos, cited the environment, cost and congestion issues:

> After thinking over the proposal, I feel that building a zoo in a residential area would not be suitable. Firstly, the environment is not suitable for animals in a natural-looking habitat because of the lack of land. It would not be able to accommodate different types of animals. Secondly, building another zoo when we have zoos in the country would be very costly. Also, where would we get the animals to fill the zoo? Furthermore, it would cause a huge amount of congestion to the surrounding areas. In conclusion, I believe my valid reasons could persuade you to reconsider building a zoo.

In conclusion, as seen in the students’ responses above, the wide range of reasons to support or justify their decisions reflects the wide-ranging discussion of the issue in the lesson. I have no information on how long his students spent writing their letters. However, it is evident that giving this task as homework helped them produce comprehensive written work.

4.2.3.2 Padma's Zoo lesson

Figure 4.11 shows Padma's lesson structure of classroom practice during the lesson.

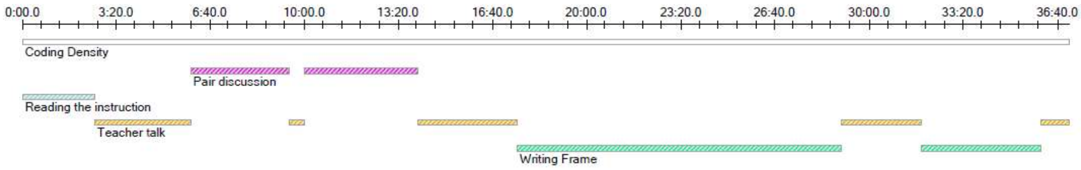

Figure 4.11 Phases of lesson structure of Padma's Zoo lesson in September 2018

Figure 4.11 reveals that Padma provided some time for her students to read the activity sheet. Then, there is a period of teacher talk in which she obtained her students' initial opinions about opening a new zoo by asking them 'hands up for or against'. Next, she asked her students to discuss their opinions for and against opening a new zoo during the two pair discussions. Following this, Padma brought the class together and asked her students to fill out a sheet and write down their reasons for and against. Figure 4.11 includes a writing phase in which her students wrote down their ideas on the activity sheet. After this activity, she brought the class together one more time and asked her students to write down their conclusion. At the end of the lesson, she collected her students' activity sheets and explained how the activity relates to science.

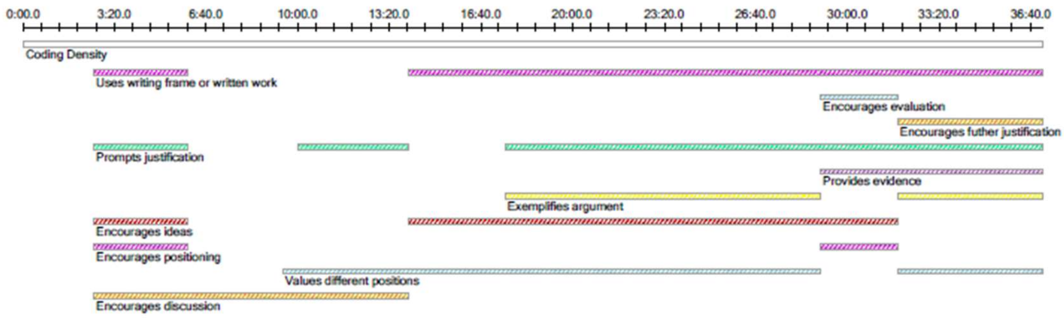

Figure 4.12 Phases of SAP of Padma's Zoo lesson in September 2018

Further examination of the same lesson from the perspective of SAP is presented in Figure 4.12, which provides a profile of Padma's instructions during the lesson. The profile shows that she utilised relatively few different argumentation processes in her instructions during the lesson.

As seen in Figure 4.11, Padma encouraged her students to first discuss their opinions first for and then opinions against the issue during the pair discussions. While discussing opinions for and against the opening of a zoo, she prompted her students to consider two different perspectives and construct their reasons to back up two opposing opinions. This practice helped her students consider counter-arguments.

During pair discussions, Padma encouraged her students to produce a wide range of reasons and justify their opinions by asking them, ‘What is your reason for that?’. Following this, Padma asked them to independently write down the main issue being discussed and their reasons for and against using a template she provided (see Appendix 9). She then spent an extended period of time on this writing phase. The main aim of this practice was to help her students come up with reasons both for and against. However, she did not explain the aims of the lesson and the activity as planned. They completed the task without having explicit instructions. Moreover, she did not explain to them how to construct an argument and provide reasons to support their argument. One of her students asked the question, “How is this related to science?” throughout the lesson. This should have prompted her to provide a brief description of argument construction and argumentation in science. However, instead, she responded to the question with “I will answer that when you finish this task”. She did not provide her students with the rationale behind introducing this activity in the lesson.

In the last phase of teacher talk, Padma asked her students to write down their own conclusion. She emphasised the importance of taking a position and explaining the reasons behind their choices:

> The last part is your conclusion. As part of your conclusion, you have to take a stance. You have to decide personally whether you are for or against building a new zoo? And then you have to explain why. Now it should be fairly straightforward explaining why because you have stated some of the reasons. But we need to make sure the argument makes sense and all the points follow each other. So, think about how you would explain your stance and opinion to someone else and then write your summary down.

During the second writing phase, Padma projected some sentence starters (see Appendix 10) on the board to help her students construct their arguments; however, she did not explain how to use these sentence start while constructing an argument. At the end of the lesson, she collected her students' written work. The student who had questioned the task's relation to science asked the question again. She responded by providing a very brief description of the scientific argumentation process addressing only the student who had asked the question, as seen in the extract below:

> The lesson we did today is about learning science with argument and argumentation. Argumentation is a big part of science; it comes with discussion and debate in science. As Y7, you do not have the skills yet. You need to argue, discuss and debate in science.

As mentioned earlier, her students discussed opening a new zoo from both the 'for' and 'against' perspectives during the pair discussions. This practice helped her students consider a range of different reasons from both sides. Twenty-four students' writing work was collected from the class (two examples of students' written work is provided below). Firstly, they all started their individual letter by stating that the issue being discussed is whether a new zoo should be funded. Then, all the students provided reasons for and against building the zoo. Lastly, most of the students presented their own conclusion about the issue. It is evident that the writing frame helped them structure their written work.

In terms of students' responses, there were twelve students against, seven students for, and five students who did not present their own conclusion about building a new zoo. Some of the students made a list of the arguments that they were bringing forward to support their claims. These were varied and reflected the discussions held during the pair work. Their reasons for building a new zoo included protecting endangered animals (e.g., taking care of animals, providing food), education, entertainment, and economics (e.g., promoting economic resources). On the other hand, similar to Ray's students, Padma's students' reasons against the building of a new zoo included an objection to the existence of zoos per se, a lack of facilities (e.g., not being able to get enough food, not being able to provide enough space), animals being out of their natural habitat (e.g., natural instinct), economic reasons (e.g., cost), animals being kept in captivity (e.g., not free, being caged), and losing their abilities (e.g., to hunt).

Some of the students simply made a list of reasons for and against the issue being discussed. For example, one of these students wrote:

The issue we are discussing is whether we should fund a zoo or not.	
Arguments for	Arguments against
Zoos are very educational for younger children (Educational). There are open for any age. It is fun for humans to look at the animals with interest (Entertainment). It is better to look at it in person than see it online. (Educational) You will have a great experience at the zoo, and it is exciting (Entertainment).	Zoos are keeping animals (Under captivity). The animals are not free They get new habits.
In my opinion, we should have more zoos as you get to see live animals (Entertainment) and they are real animals. It is educational for any age to see animals (Educational).	

A few students constructed their arguments differently. An example of one of these students' written work is below:

The issue we are discussing is whether we should fund a zoo or not.
For: I think we should fund a zoo because it keeps endangered species safe (Protecting endangered animals), it gives them shelter and food, so they live. It provides these innocent animals who find hunting laborious have a chance to relax.
Against: I think we should not fund a zoo because it can render the animals shocked to find their zoo home smaller than their actual home. It takes animals' freedom away and could make them feel indignant and perturbed to be kept in a zoo against their will.
Conclusion: My conclusion towards this debate is against it because no one should be taken against their will (Under captivity) and put in a place that could make a huge difference to their actual homes (Lack of facility)). No one should relinquish their homes for a place ten times smaller. It also makes them lonely because they are caged up and have no one with them (Under captivity).

In short, her students were encouraged to provide reasons both for and against the issue of opening of the zoo. Therefore, their reasons varied, given that they were considering the issue from different perspectives. However, Padma did not introduce to them what a scientific argument means in science or how to make a scientific argument. Thus, they were left to reason only based on their own experiences and knowledge about zoos.

4.2.3.3 Mala's Zoo lesson

Figure 4.13 shows Mala's lesson structure of classroom practice.

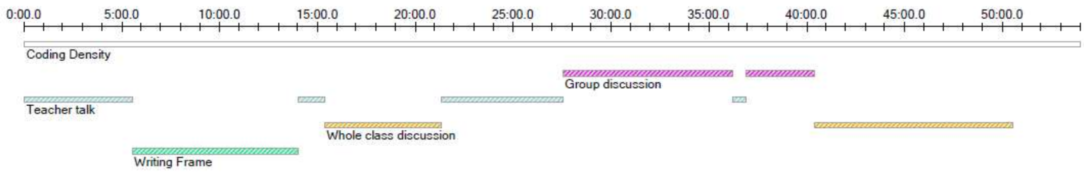

Figure 4.13 Phases of lesson structure of Mala's Zoo lesson in September 2018

There is a phase of teacher talk at the beginning of the lesson in which Mala introduced the aim of the lesson and asked one of her students to read the activity sheet. She then asked her students to write a letter including their opinions and reasons and allocated a period of time for writing. Next, Mala briefly explained what a scientific argument means. Following this, she asked her students a question about what shape the Earth is, then projected some examples of scientific arguments on the board to help the students evaluate each argument during the whole-class discussion. She then explained how to make a good argument. Next, as seen in Figure 4.13, there is a second phase of teacher talk in which Mala provided a general description of what the argumentation activity would entail and organised her students for the group discussions using role-play. Next, her students discussed the task during the small group discussions. She then brought the class together and asked her students to write their arguments down. The students then carried on with the discussion and the writing down their responses in the second phase of the group discussion. At the end of the lesson, there was a period of whole-class discussion in which Mala requested each group to present their decision and asked as to whether anyone had changed their minds after listening the other groups' reasons.

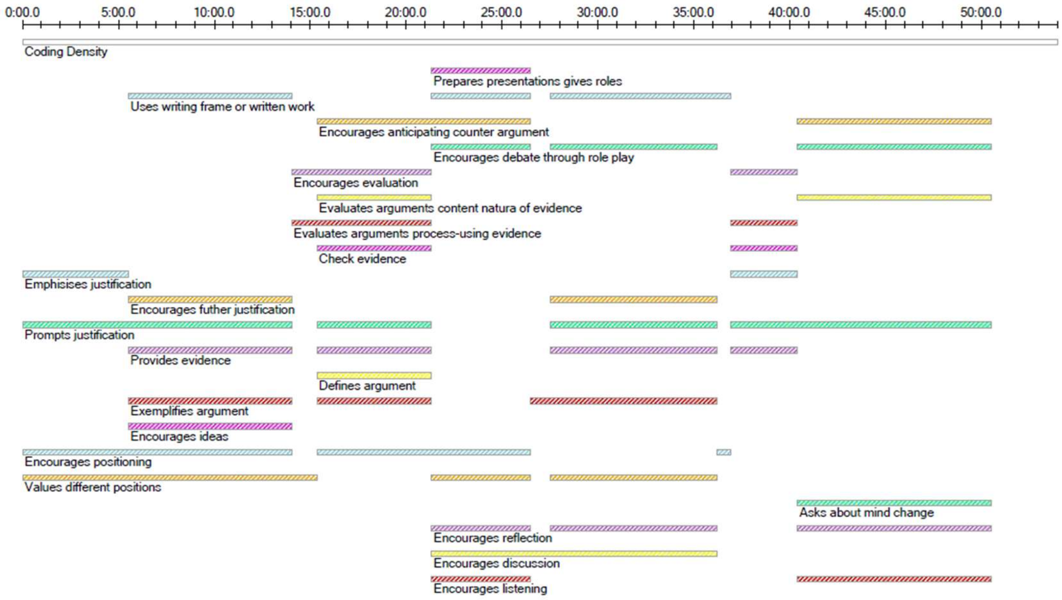

Figure 4.14 Phases of SAP of Mala's Zoo lesson in September 2018

Figure 4.14 shows that Mala attempted to use a number of argumentation processes and distributed these processes throughout the lesson. In the first phase of teacher talk, Mala encouraged her students to decide whether they agreed or disagreed with the opening of a new zoo and justify their reasons for their choices. Then, during the process of writing, she encouraged her students to write down reasons to support their opinions. She also walked around and gathered ideas from her students. She constantly highlighted the importance of providing reasons and the value of having a different position.

Letters were collected from all the 20 students who were present in the lesson. The majority of students were able to develop a position on building a new zoo and provide a few reasons to back up their position. Only one student was not able to back up his decision with a reason; the other thirteen students were for, and seven students were against building a new zoo, and they all gave a variety of reasons to back up their opinion. The reasons they gave were brief and reflected the fact that they had not had the chance to discuss the topic beforehand.

The students' reasons for or against building a new zoo were recorded in their written work and were drawn from their personal experience of zoos. The main point being made here is that the students could come up with valid reasons without discussion. The students’ reasons for building a new zoo included protecting endangered animals, taking care of animals (e.g., endangered animals, providing food, being extinct), education, and entertainment. For instance, Student 1 wrote:

> I agree that this zoo should open. There are my reasons; firstly it will attract children's attention to learn things about them and their habitat where, how and what they eat. Secondly, if the zoo opens, we can save some endangered animals. Animals will be taken care of and fed.

On the other hand, the students’ reasons against building the zoo included the lack of facilities (e.g., not able to get enough food), animals being out of their natural habitat (e.g., natural instinct), cost, and animals’ feelings (e.g., under captivity, being caged). Student 2 stated:

> I believe that zoos should be banned because you keep animals, and I do not want animals to be kept under captivity. They should be free because they have a life. How would you like it if you were taken from your natural habitat and taken to a cage with a small amount of space for people to look at? How would you feel?

Only 2 of her students gave reasons both for and against opening a new zoo:

> I have disagreements as to why not open a new zoo. First of all, animals will need to be cared for and feed, which needs a lot of money to spend on staff, food and building. On the other hand, students will enjoy coming to the zoo and feeding or looking at the animals.

In conclusion, the student's written work shows that they wrote their letters briefly and supported their ideas with reasons based on their own experience of zoos.

Following this activity, Mala defined and exemplified scientific argument and introduced the aim of argumentation in science:

> Now, you have been writing a scientific argument, so whether you choose for or against opening a zoo, you are backing up your reasons with facts and evidence. So, you have not just said yes, we should open a zoo and left it at that; you are giving me good reasons why. In science, this is a technique that we use to discuss things; something is called argumentation.

Mala then employed the same activity she used in the Dropping a box lesson a year ago about the shape of the Earth. Her main aim was to highlight the importance of including evidence and reasons to support an argument and the aim of evaluating evidence and reasons. In addition, she provided some examples of the arguments used again in the Dropping a box lesson and evaluated each statement with her students. She then explained what makes a good scientific argument by introducing the process of using evidence, reasons to support an argument (see line 1), considering different opinions, and reflecting on them (see line 3). This shows a shift in how she was foregrounding the process of anticipating counter-argument and reflecting on the argument.

1	Mala	Some pictures show that the earth looks like a sphere. I think this is a better argument than the other one (showing the arguments on the board) because it says pictures of the earth show us that it is round. That is evidence, isn't it? Pictures of the Earth that have been taken by astronauts that have gone into space. That is a better argument. So, when we look at argumentation in science, we need to consider arguments, including reasons for our argument, evidence for our argument, any facts that back up what you are saying and using persuasive language. What does that mean? What is persuasive language?
2	Student 1	It means the language you use with a person when talking to; you are trying to persuade them to agree with you.
3	Mala	Yes, so it is using language so that someone else agrees with your argument. So, the language you use to get them to agree with what you are saying. It is good to think about because other people might think differently. So, people who say that we should open the zoo should also consider what arguments people who vote against it might have.

After this activity, Mala organised her students into groups and set up a role-play where her students played the role of different community members, including local residents, science teachers, students, councillors, zoologists, and conservationists. She distributed a template (see Appendix 9) and asked her students to fill it out during the discussion. She tried to encourage them to discuss from the perspective of the role that they were given and to anticipate counterarguments. The use of the role-play approach led to the students using a variety of argumentation skills.

During the small group discussion, Mala attempted to join each group discussion and prompted her students to provide reasons to support their opinions. She exemplified how to construct an argument for one group of students according to their role. In addition, she encouraged them to write down their opinions and reasons and asked them to leave the conclusion part empty. Furthermore, she highlighted the fact that some students may wish to change their stance after listening to other opinions from different perspectives:

> To decide whether we should open a zoo or not, in your group you are taking the role of these people, you are going to decide one, yes, we agree, or no we disagree based on the people that we are. For example, local residence, perhaps, you will be against it because you do not want all of the noise with the animals when you are trying to sleep. You are only going to pick one side, and you are going to discuss them as a group—the box at the bottom I want you to leave empty because we will come back. After listening to each other's arguments, you are either going to stick to what you thought at the start or if another group persuade you to think differently, then you can change your answer.

At the end of the lesson, Mala employed whole-class discussion where her students shared their opinions according to their roles and listened to one another's perspectives and reasons. This process helped them think about the issue from different perspectives and consider counter-arguments. She also encouraged them to reflect on whether the arguments put forward could change their initial opinion. Mala included the idea that argumentation is a process in which you are trying to convince someone of a claim you are making. This indicates that she believes this process is essential for gaining argumentation abilities:

> So what we are going to do is go to each group in turn, and every other group needs to listen carefully because at the end we are going to decide your conclusion whether you still agree with your argument or whether someone in another group has convinced you to support the opposite argument, so if you think yes and another group say no and you think actually they have some good arguments there. So, this

time we all need to be listening, and only the group who is giving feedback need to be talking.

The students provided a wide range of reasons to support their stance. For instance, one of the groups whose role was students' discussed the issue from a student's perspective and provided the following arguments in favour of opening a zoo:

The issue we are discussing is opening a new zoo.	
Arguments for	Arguments against
If studying wildlife for GSCE's instead of reading books, we could investigate ourselves by seeing animals in a zoo. If bored students can visit the zoo and animals during the lunch break (Instead of sitting down and doing nothing, they could go and see animals) Students could feed animals at any time and study about animals.	
My conclusion is	

Another group discussed the topic from the perspective of zoologists and provided the following arguments against the opening of the new zoo:

The issue we are discussing is opening a new zoo.	
Arguments for	Arguments against
	It would be hard to capture the wild animals because you would not know what the animals would do. The transport would cost a lot. The animals (predators) have to hunt- when let out in the wild, they would not know how to hunt. Waste of money if they send the animals back. Hard to find rare animals.
My conclusion is	

Only one group of students provided their reasons from two perspectives, as Mala asked them to pick one side to support before starting the discussion. This attempt influenced students' written work. As seen in the example responses, Mala's students provided different reasons to support their ideas according to their assumed role. The students expressed their conclusions orally during the whole-class discussion; there is no written work to refer to for this part of the activity.

4.2.3.4 Comparison of the teachers' practice of the Zoo lessons

In year two, the Zoo activity enabled me to compare teachers' scientific argumentation practice associated with a SSI context. The teachers' practice illustrated the main differences in what they emphasised and approached in the scientific argumentation pedagogy. The teachers took their students' needs and their own previous experiences with scientific argumentation into consideration when planning and implementing their lessons and organising students' groups for discussions. Therefore, unsurprisingly the level of the students' engagement and the written work they produced varied.

In terms of practice allocated for small group and whole-class discussion, Ray's students had more time to engage in group discussion than Padma and Mala's students. Mala encouraged her students to discuss the topic from different perspectives using role-play. Padma asked her students to discuss the topic from two opposite perspectives, encouraging them to anticipate counter-arguments. Both Ray and Mala ended their lesson with a whole-class discussion in which their students shared their opinions and reasons about their opinions, but Padma did not provide an opportunity for students to share their final decisions with the class. The written work provided differed, reflecting how the teachers used the activity in their lessons.

All three teachers utilised different group strategies when organising group work, considering their students' abilities and classroom dynamics. Mala was the only teacher willing to experiment with a new strategy in her practice for this lesson and used role-play, which shows her willingness to take risks to enhance her pedagogy of scientific reasoning. (Loucks-Horsley et al., 2010). On the other hand, Padma used pair discussion, and Ray organised his students' group of four.

All three teachers strongly encouraged their students to justify their arguments and support them with evidence and reasons, particularly when expressing and writing their responses by constantly emphasising justification. The features of their practice indicate they shared a better understanding of teaching scientific argumentation in the second year. Pedagogically, the learning goal for his lesson was to strongly encourage his students to produce a wide range of reasons and justify their opinions. His arguing prompts facilitated discussion from different perspectives and helped his students form their ideas and scientific argumentation.

Padma’s argumentation pedagogy shows little evidence of defining argument and scientific argumentation, and explaining the rationale of the activity. Although her students did not have formal preparation in scientific argumentation, they were capable of making claims, supported with evidence and reasoning (Berland & Hammer, 2012b). However, she encouraged her students to construct arguments supported by reasoning and to express two different perspectives. By doing this, she highlighted anticipating counter-arguments.

Mala’s SAP profile reveals that her instructions included a variety of scientific argumentation processes during the lesson than Padma and Ray. She was better able to incorporate scientific argumentation into her teaching practice in year two. Mala not only focused on obtaining ideas for and against zoos but also encouraged her students to discuss different positions during the lesson. By doing this, she encouraged her students to construct arguments supported by reasoning and express their perspectives by taking on different roles. Overall, the learning goals for her lesson included gathering her students’ initial ideas and encouraging them to discuss the topic from different aspects, position themselves and provide reasons according to their roles.

4.2.4 Comparison of the teachers' practices one year apart

Findings from Osborne et al. (2004a) and others (e.g. Sadler & Donnelly, 2006; Zohar & Nemet, 2002) informed the design of this case. This case aimed to compare the pedagogy of scientific argumentation of the three science teachers as implemented within a scientific and SSI context one year apart. Even with collaborative planning and similar resources, the practice of scientific argumentation by the three teachers differed by the context in terms of lesson content and structure, timing and student organisation. In addition, the different emphasis placed on scientific argumentation processes as well as time spent on different practices, such as written work, reflects the contrasting goals and values of the three teachers. Although all three teachers discussed argumentation as an essential learning goal for their students, their starting points differed, as did their classroom instructions and their students' engagement and written work. Students were observed to be more engaged in the SSI context than in the scientific context due to the ability to relate their personal experiences to the SSI context lesson.

The results suggest the teachers' approaches to using these activities, their use of argumentation processes and the approaches they emphasised with the students are possible indicators of how they emphasise teaching science through scientific argumentation. Teaching experience and underlying emphasis have an impact on students' engagement with and participation in argumentation. Teachers like Mala, who place more emphasis on scientific argumentation processes and goals, as evidenced in her SAP profiles and lesson activity, may be more likely to support students' argumentation skills.

For Ray resolving the scientific topic seemed more important than engaging in scientific argumentation processes (McNeill et al., 2013). Meanwhile, Padma's instruction suggests a limited understanding of argumentation in her own teaching approach. A characteristic of her teaching was to address students' conceptual understanding and get students thinking and discussing. When she implemented the scientific topic, she devoted an extended period of time for comprehensive discussions with the risk of having students go off task. On the other hand, Mala's instructions included a clear focus on scientific argumentation, with a wide range of argumentation processes in both lessons. She demonstrated an active interest in utilising scientific argumentation in her lessons and was willing to take risks related to trying a different group strategy (e.g., role-play in the zoo lesson) in her classroom.

4.3 Case 2: Two science teachers' implementation of Phases of the Moon and Food chain lessons across two years

Differing from case 1, this case aims not only to compare two science teachers' pedagogical practices and approaches to teaching science through scientific argumentation in the same scientific contexts but also to identify changes in their pedagogical practices across the two years after gaining some experience teaching a particular topic. In the subsequent sections, the overall principles and procedures of lesson planning (section 4.3.1) and the results of the teachers' practice are presented according to lesson structure and SAP; however, here, the focus is on how each teacher's pedagogical practices and approaches evolved when teaching the same activity again a year later. Comparing the two teachers' approaches to scientific argumentation shows considerable differences in emphasis and changes in practice in response to different scientific contexts. The first activity is the Phases of the Moon (presented in section 4.3.2), and the second is the Food chain (presented in section 4.3.3). It is important to acknowledge here that the Y7 classes observed were different. However, they all comprised mixed-ability groups of Y7 students, which means the two teachers were teaching comparable students on both occasions across two years.

4.3.1 Lesson planning process for the Phases of the Moon and Food Chain lessons

The lesson planning process for the Phases of the Moon (March 2018 / April 2019) and the Food Chain (May 2018 / May 2019) activities that I held with Padma and Mala is presented in the following two sections. Ray did not cover these topics with his students and, therefore, did not join these planning meetings. The following sections describe how the teachers and I planned the argumentation activities for these same topics across two years and how the teachers took their own reflections and experiences of teaching the same lesson in the first year into consideration when planning it in the second year.

4.3.1.1 Phases of the Moon activity

The Phases of the Moon activity (as seen in Appendix 6) was obtained from the IDEAS pack (Osborne et al., 2004b). The objective of this activity was to evaluate different explanations for what causes the phases of the moon[10]. In the first part of the activity, the students would be required to choose an explanation and argue why they thought it was the best explanation. In the second part of the activity, the students would be required to justify their choice of explanation and why they do not agree with the other explanations.

The planning meeting for this activity took place in March 2018. The teachers first shared their experiences implementing the previous argumentation activity (Dropping a box) at the meeting, which influenced their planning of this activity. The teachers shared their experiences with each other to highlight the strengths and weaknesses of their practice with this approach. Mala reflected on her experience of organising group work and structuring the lesson after implementing the Dropping a box activity:

> I think we needed to spend more time on the organisation of group work and how to transition between different parts of the lesson (Mala, March 2018).

Padma shared similar concerns at the meeting. She was concerned about how students did group work:

> My group understood what they were supposed to do during the activity, but they could not manage themselves in their group. Maybe we needed to assign roles in their group to help them moderate themselves and ensure everyone has enough chance to speak (Padma, March 2018).

The teachers were aware of students' lack of experience working in groups. Mala commented that:

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[10] The lesson goals for this topic are: Identify the phases of the moon and their names using a model. Determine the moon's phase at different points during its orbit around the Earth. Justify one’s observation that only one side of the moon is visible from Earth.

> I prefer my students to get more training on group work on how to do it well. We can do similar tasks throughout the half term to improve students' group work skills, not necessarily for argumentation lessons (Mala, March 2018).

It is noticeable that the teachers took account of their previous experiences and reflection while organising their students for group discussion. That reveals they developed their knowledge and understanding of organising group work. They had concerns about students' lack of engagement with the argumentation activity and participation in group discussions. Therefore, I suggested applying envoys for group discussion, where students would take on a role in the group work. We watched a video on the CPD website explaining how to organise students for envoys group activity. The teachers decided to employ this group strategy in their lessons. The teachers also decided to consider the students' group choices before sending the envoy to other groups that had made different choices about statements regarding the activity.

We then had a conversation about how to introduce the topic, the argument, scientific argumentation, and the activity to the students. Padma touched on the fact that the students were confused about how the sun, the earth and the moon rotate, commenting:

> First, I am going to get them to draw how they think the earth, sun and the Moon are related and rotated. I think some of them will get it wrong. I have not taught this topic before, so I am going to do a simple demonstration with a lamp and a ball. Then, we could introduce the activity (Padma, March 2018).

The teachers drew attention to the importance of the student's knowledge about the topic. They also considered reminding the students how to construct an argument and what is needed to make a strong argument. For instance, Mala pointed out that:

> I will remind them what argument and argumentation are in science in as much detail as they need. I don't assume that they would remember (Mala, March 2018).

We discussed argumentation skills that students need to develop, and one of them was the evaluation of an argument. This point was highlighted in this lesson planning meeting; therefore, the teachers decided to start the lesson by explaining the component of an argument and how to construct a strong argument.

The teachers highlighted introducing the task with more guiding instructions to help their students understand what is required of them in the activity. That shows that the teachers saw the importance of providing explicit instructions for argumentation. For instance, Mala commented:

> We need to give more explicit instructions about what students need to do in the activity. In the Dropping a box activity, that explanation was not clear enough to help them understand the argumentation and the structure of the argument (Mala, March 2018)

These excerpts show how the teachers' experiences and reflections led to the introduction of changes in their instructional practices and the organisation of students' group work.

In summary, the teaching sequence in year one was:

- Remind students what makes a strong scientific argument, what argumentation means in science.
- Demonstrate the different phases of the Moon, either a hands-on activity or video demonstration.
- Organise students' groups, give them roles as envoys, scribes, facilitators.
- Distribute the activity sheet and provide instructions on the task (as suggested in the IDEAS pack).
- Allocate around 15 minutes for the group discussion; then, envoys need to change groups (Note: Envoys need to be sent to a group that has made a different choice of statement).
- Finally, have a plenary session to discuss the final responses from all the groups. Ask each group which explanation they choose and their reasons and ask what other groups think about it.

A year later (April 2019), I held a meeting with Mala and Padma to plan the same argumentation activity. The teachers drew on previous experiences of using the activity in their classrooms. First, they emphasised the importance of students' pre-existing knowledge about the topic, highlighting that prior knowledge should be considered as a pre-condition in the process of scientific argumentation. Therefore, both teachers decided to use the activity as a recap after teaching the topic to their students to check their understanding and misconceptions. Mala commented:

> Last year, we did not teach the topic before using the activity. So, some of the groups had picked a or b. Now, in previous lessons in this scheme of work, we will be looking at the topic and talking about the phases of the moon. So, they could have that knowledge. It is also a good way for me to check their understanding of the topic as a whole (Mala, April 2019).

Another point to consider was how to organise the students for the group discussion. The teachers once more considered their students' behaviour and stances when deciding which group work strategy to implement for this activity. The teachers had previously used envoys, but they had found that the student's understanding of the strategy was limited. Therefore, they decided to reconsider the organisation of the groups in the second year and opted for pair discussion instead. The two teachers shared their experiences. Mala said:

> I think I made it (lesson) too complicated as it (envoys) was not a technique that I used in my lessons frequently enough so that students could be used to that routine. I used Pair discussion a lot. This is how we are going to do it they would know what they need to do (Mala, April 2019).

Padma said:

> There is a lot going on in terms of behaviour, and I just don’t think it (envoys) works as well with them (students). They have been through a lot of changes as a class, so I guess I try to keep it (group discussion) really simple. Pair discussion works better with them (Padma, April 2019).

A further point discussed during the meeting was the need to remind students about the process of argument construction. Padma was concerned about the lack of students' understanding of how to construct an argument and how to make a strong argument. Therefore, she considered starting the lesson by reminding students what makes a strong argument and how to evaluate an argument. In contrast, Mala considered starting the lesson by using an activity to remind students of these processes.

Mala also suggested finishing off the argumentation activity through whole-class discussion. She planned to go through each statement and then show a video that demonstrated how the Phases of the Moon occurred. She asked the students whether they had changed their minds about their chosen statements and corrected their misunderstandings. Padma considered starting the lesson with a video presentation to remind her students how the Moon phases occur. The teachers did not reach a consensus on any of the points discussed; each established their own plan for implementing argumentation in their own lessons based on their individual approaches to this activity.

In summary, the teaching sequence in year two consisted of the following steps:

- Remind students what makes a strong argument and how to evaluate an argument (Padma's plan); use an activity to remind students of the process of construction of argument (Mala's plan)
- Explain how the phases of the moon are formed or demonstrate the different phases of the moon with either a hands-on activity or a video.
- Organise students' groups for group discussion pair discussion.
- Distribute the activity sheet and provide instructions on the task
- Allow about 10 to 15 minutes for this group task.
- Conduct a whole-class discussion and go through each statement (Mala's plan)
- Finally, show the students a video that demonstrates the different phases of the moon (Mala's plan)

The data analysis revealed that all of the points raised during the meeting demonstrate that the teachers developed their knowledge and understanding of scientific argumentation through collaborative work and reflection on prior experiences over time. They gradually began to reconstruct how they would implement scientific argumentation in their classroom. Moreover, the teachers considered more their class dynamics when planning the argumentation lessons and spent more time planning this activity, including organising the students' groups and how to get the students engaged in the activity.

4.3.1.2 Food chain activity

The meeting to design and plan the Food chain activity was held between Mala, Padma and me in May 2018. First, the two teachers shared their experiences and reflections on the Phases of the Moon activity, which influenced the design and planning of this argumentation activity. The design process for this argumentation activity began with identifying the framework and the specification of the learning aims for this activity. This was followed by creating the resources that would help students discuss the different statements within this context. The objective of this activity was to evaluate arguments for what might happen if there were to be a disruption or a change to the food chain. The students would be required to choose the best statement presented in the activity and explain why they thought that they had chosen the best statement (see the activity in Appendix 7). In both years, the teachers did not include a writing frame in the activity sheets as they designed the activity to encourage students' discussions but asked students to write their opinions in their books.

We then chose a framework that we could adapt for use in this scientific context. We were aware that designing and planning a lesson in a new science context using a generic framework would be a complex task. When the teachers and I designed the activity, we only considered these three frameworks for the activity: classification, competing theories and Predict-Observe-Explain. These frameworks have been widely cited in the literature (Simon & Richardson, 2009). The teachers became familiar with competing theories from the phases of the Moon activity. Therefore, the teachers preferred to apply the same framework to this activity. Padma commented:

> They (students) have to say which one they agree with and why they disagree with others. I really like how the other boxes here (the phases of the moon activity) force them (students) to identify and explain their choices (Padma, May 2018).

Next, we started with the articulation of goals and the procedures that we would use to implement the activity. This involved imagining the lesson and how the activity might proceed with the classes. We considered how the lesson would begin, how the students would be organised to facilitate small group discussion, how the science would be addressed through the resources used, and how the activity would be brought to an end. The teachers were aware of the complexity of the statements and students' ability to understand the statements based on their own experience, knowledge or access to resources, so this needed to be considered. They realised that students needed to have access to sufficient resources to engage in the activity successfully. Padma explained how the statements would be created and how students would use the food chain as resources:

> Statements would be based on the food webs for example; we would have a few just looking at a simple food chain. Statements might say what would happen; there is a change in the food chain. We would be trying to give a few different perspectives and predictions of what would happen in the food chain, and then they would say which one they most agree with and why. There would be something for them to discuss. They would be using evidence, data from the food web (Padma, May 2018).

After lengthy discussions, the teachers decided to start the lesson with a single statement and ask students whether they agreed or disagreed with it and give reasons. They decided to remind their students to make a strong argument at the beginning of the lesson. They would then devise three activity sheets with statements regarding a change in the food chain. The students would be asked to critique and evaluate the ideas written on each sheet, with the statements getting progressively more complex. Both of the teachers intended to use the activity to recap the topic as they considered their students' previous knowledge a precondition for argumentation.

We also decided to use a pair of cards, including sentence starters and argument evaluation, to help students deepen their discussions, construct and evaluate the given statements. That indicates the teachers started considering their students' abilities and skills of argumentation.

Another point discussed in the meeting was how to organise students for the group discussion. For this activity, students were expected to critique and evaluate each other's arguments. Verbal tennis (also called pair discussion) was deemed to be a convenient strategy in this lesson. Mala stated:

> I like verbal tennis; they can talk to each other. So, we try to put them (students) in pairs. Like the way I think for my class is to put them in pairs with matching ability. Some of them have matching abilities, some of them are friends with each other. I think the mixed ability is better. So, we make sure they are able to talk (Mala, May 2018).

As evident in the quote above, the teachers took their classroom dynamics, the student's ability and friendships into account while organising their students into groups to support and encourage their discussions.

For this activity, the teachers were willing to observe each other's classroom practice to see how they each taught the same lesson, even though they had planned it together.

In summary, the teaching sequence included:

- Give students a simple statement to discuss as a starter and show them how to make a strong argument.
- Organise student groups for pair discussion.
- Distribute the activity sheet and explain the activity to students
- Allow about 15 minutes for the group discussion.
- After the first sheet is complete, conduct a whole-class discussion to obtain students' responses, then move on to the other sheets.

A year later (May 2019), I organised a planning meeting for the same argumentation activity with Padma and Mala. The teachers shared that they did not have any issues with the activity and the organisation of the students for group discussion in year one. Therefore, they did not make any changes to the activity sheets. A few points did, however, come up during the meeting. They thought that students did not have sufficient time to discuss each sheet separately, and the statement on the last sheet was too complicated for the students; therefore, the teachers decided not to use this last sheet in the lesson.

The main point of difference between the teachers was their reason for using the activity in their lesson. Padma wanted to use the activity as a recap after teaching the topic to check the students' understanding of the topic. Mala planned the activity as part of a sequence within the scheme of work. Although the teachers planned the lesson together, they had different purposes for using the activity and ended up taking individual decisions.

In summary, the teaching sequence in year two included:

- Give students simple statements to discuss as a starter.
- Organise students' groups for pair discussion.
- Distribute the activity sheet and explain the task
- Allow about 10 to 15 minutes for the group task.
- On completing the first sheet, conduct a whole-class discussion to listen to students' responses, then move on to the other sheet (Mala's plan); or, after completing all activity sheets, conduct a whole-class discussion to get students' responses (Padma's plan).

Even though the teachers planned the lesson together, they used scientific argumentation activities in their classrooms differently and for varied purposes. Also, the teachers gave more consideration to their class and student dynamics when planning the argumentation lessons. They spent some time planning the activity, organising the student groups, and engaging the students in the activity more than they had done previously. Additionally, they were observed utilising their previous experiences as resources.

4.3.2 The two teachers' implementations of Phases of the Moon lessons across the two years

In this section, the results of the Phases of the Moon activities for each of the teachers, Padma and Mala, are presented for the two years.

4.3.2.1 Padma's Phases of the Moon lessons

Figures 4.15 and 4.16 illustrate the lesson structure for Padma's lessons across the two years.

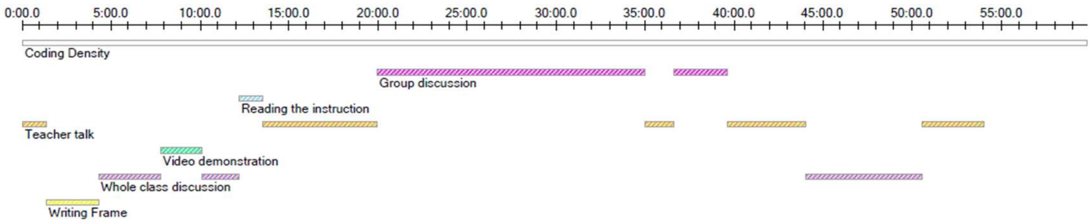

Figure 4.15 Phases of lesson structure of Padma's Phases of the Moon lesson in April 2018

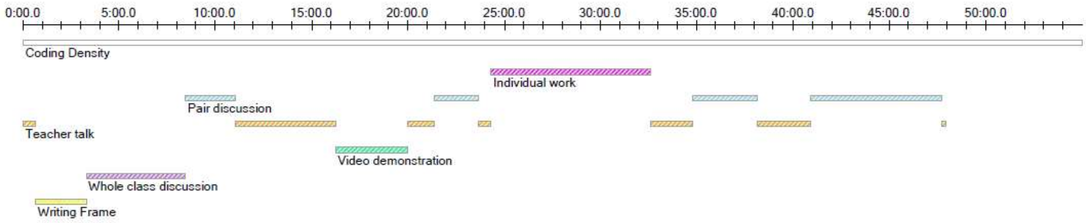

Figure 4.16 Phases of lesson structure of Padma's Phases of the Moon lesson in April 2019

As Figure 4.15 shows, the lesson begins with teacher talk and a writing task. Padma explained the lesson's goals and requested that her students draw a labelled diagram visualising the Earth's movement and the relative movements of the Sun the Moon. She then posed several questions about the Moon's phases in the context of a whole-class discussion to assess the students' understanding of the content. Following that, she presented a video setting out how the Moon's phases occur. She and her students then quickly discussed the Moon's phases. She then distributed the activity sheet and allowed her students to read the explanations provided on the sheet. Padma explained the activity and then organised her students for the group discussion during the second period of teacher talk. She then allowed students to discuss the explanations during the group discussion and then write their reasons on the sheet. Following that, she gathered the class together and requested that students designated as envoys change groups for the following group discussions. After the envoys had changed groups, her students continued to discuss the statements in groups. There was a period of whole-class discussion during which Padma requested that her students justify each explanation. Finally, she provided general explanations of the topic to resolve science content.

In year two, as seen in Figure 4.16, it was apparent that this lesson was structured differently in terms of the patterns of small and whole-class discussions. During the whole-class discussion, she engaged her students in a discussion about how to construct a strong argument. She then presented several arguments about the Earth and asked them to evaluate these in pairs. Similarly, before implementing the argumentation activity, she offered a general explanation and projected a video showing how the Moon's phases occur. Padma employed a variety of strategies, including individual work and pair discussions. During these practices, she gave her students an opportunity to evaluate the given explanations, and then asked them to write their reasons on the sheet. She skipped the whole-class discussion at the end of the lesson.

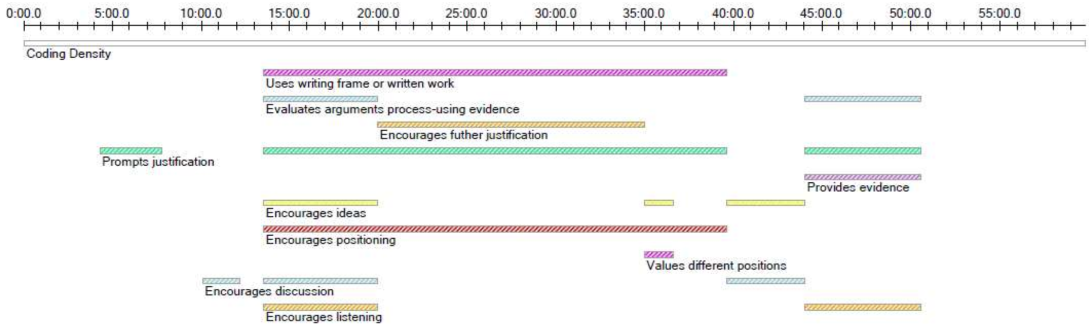

Figure 4.17 Phases of SAP for Padma's Phases of the Moon lesson in April 2018

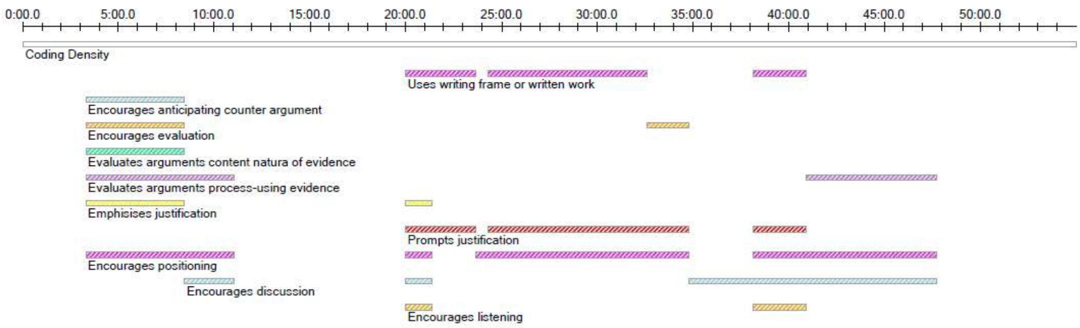

Figure 4.18 Phases of SAP for Padma's Phases of the Moon lesson in April 2019

As seen in Figures 4.17 and 4.18, further analysis of the same lessons in terms of SAP reveal that the characteristics of Padma's instructions with regard to scientific argumentation across the two years. Padma offered comparable argumentation processes and demonstrated a variety of argumentation processes, all of which facilitated her students' engagement in scientific argumentation. In year one, she employed a variety of argumentation strategies during her teacher talk; however, she utilised a few during group and whole-class discussions. In year two, in contrast, she used a range of argumentation strategies during the whole-class discussion but a relatively few argumentation processes during the rest of the lesson.

In year one, Padma first asked several questions to her students, such as ‘What are the phases of the Moon? What does the Moon look like in its different phases? Why do we see the phases of the Moon?’ discuss possible answers during the whole-class discussion. She repeatedly prompted a question of ‘Why do you think that?’ to encourage them to justify their answer. In year two, She began the lesson by discussing with her students how to construct a strong argument and used a slightly different approach. Several things are worth noting about this exchange between Padma and her students. One is that she highlighted that argumentation is a process of trying to convince someone of an opinion (see lines 1 and 5). This practice helped her student to anticipate counter-arguments. Secondly, she focused on the process of constructing a good argument and the evaluation of arguments (see lines 3, 5, 7 and 9 below, from year two) as crucial for her students. When she instructed her students on how to construct a good argument, they appeared to understand her points. By sharing some examples of scientific arguments, she aimed to help her students understand how to construct a strong argument and use evidence and reasons to support it. This means that providing students with both weak and strong arguments and discussing their features helped them understand what makes one better than another, illustrating that she had developed a greater understanding of this aspect of argumentation.

1	Padma	There are some statements on the board. We are going to be discussing what makes a good argument? Can you make a good argument that might still be wrong? Can you make a bad argument and still be correct? We are not discussing whether they are true or false. What is going to alter someone else’s opinion? What does a good argument include?
2	Student 1	Evidence.

3	Padma	What do you mean by evidence? Can you explain this to others?
4	Student 1	We need to prove our point.
5	Padma	Something proves the point. It is not just what you are saying; I think this, or this is obviously true; you need to convince the other person, you need to use facts, anything else?
6	Student 2	We need to give a good explanation to support our arguments.
7	Padma	Not only this evidence shows my point is true, but this is also how the evidence links to the point, right? This is how my evidence shows this is true.
8	Student 3	We need to have a point.
9	Padma	You need to have a point in the first place to decide for or against the argument. What is the point you are trying to make?

Padma then displayed several arguments and encouraged her students to evaluate them in pairs. She prompted them to discuss and assess the value of evidence when constructing an argument. In both years, she projected a video demonstration, which was productive for her students, as it helped to illustrate the process by which the phases of the Moon occur. She addressed the science content by resolving her students' misconceptions around the topic by doing so.

During implementing the argumentation activity, the principal difference between years one and two concerned how groups were organised. In year one, Padma applied envoys, assigning different roles to her students during the discussion. The assignment of distinct roles to students in the group discussion was intended to encourage them to participate more actively in the discussion. She also urged them to evaluate the different explanations and provide their reasoning for each explanation on the activity sheet, as well as encouraging them to engage in further discussion after the envoys changed their group. In contrast, in year two, she was aware of some behavioural issues with her students. Therefore she asked them to work independently on the activity and encouraged them to choose the best explanations and provide reasons for their choices.

Following that, she organised them into pairs to evaluate one another's choices and the reasons for their choices.

As seen in Figure 4.17, in year one, Padma encouraged her students to listen to one another and discuss the explanations given by the group, also reminding them of argumentation procedures, stating:

> It is really important that you listen to each other's ideas, and we will practice argumentation. Hear each other's thoughts out. See what information you already know, what information they have and how you can use that to answer the question or to solve your problem. So, you need to be working together as a group.

When writing their responses on the activity sheet, she also prompted her students to justify why they believe their choice is the best explanation and why the others are not as good. During the second phase of the group discussion, her students embarked on a further discussion.

As evidenced in Figure 4.18, in year two, she asked her students to choose the best explanation and justify their choices during the individual phase. Following that, she asked her students to evaluate each other's choices and explain their rationales in pairs. In both years, Padma encouraged all group members to contribute to the discussion and motivated them to participate in the activity.

There is a further difference between the two years with regard to the feedback from the students. In year one, Padma encouraged her students to share their thoughts regarding each explanation and build on each other's ideas, stating:

> What did you write about C? What have you discussed about C?

> If somebody else from the group wants to add an explanation to explain what you all discussed, include that. What else did you think about that statement?

She then evaluated the students' responses and briefly explained their answers to resolve the science content. She also encouraged her students to further justify their choices; clarifying:

> Clouds get in the way of the Moon, which is why it appears to have different shapes. It is not the clouds, is it? There is light from the Sun, which causes the shadow. This

> does not occur because of clouds. What causes the different shapes? What does that denote? Why are their different phases?

Following this task, she provided a general explanation of the Moon's phases to address her students' lack of understanding of the science content and any remaining uncertainty regarding the topic. This practice helped her assess her students' understandings. In year two, she did not include a whole-class discussion so that her students could share their ideas with the class as planned in the planning meeting.

Her student's written work arising from these lessons reflects her approach in the two years. As seen in Figure 4.15, in year one, the students were given time to discuss the explanations given and provide their reasons for each explanation during the group discussion, in which written work was generated. Padma approached the activity as a tool for not only getting students thinking and discussing explanations, but also to get them to choose the correct explanation and provide their reasoning in groups. Appendix 11 (see Tables 6 and 7) provides an overview of the student's written work. As seen in Table 6, in year one, her students engaged in a comprehensive discussion and worked to provide reasons for each explanation. She emphasised the process of writing in the first part of the group discussion. The results reveal that half of the student groups identified the correct explanation. However, notably, only one group of students, group 2 (see Table 7), provided a valid reason for their correct answer as D. That shows that the context is challenging for her students:

> This is correct because the Moon orbits the Earth so that a part of the Moon is not lit up, and we cannot see it.

Group 5 also selected D; however, it did not provide an accurate reason for their choice:

> It makes more sense than the rest of them; D is a fact.

Group 1 chose D as well and attempted to describe the rationale for their choice. However, they had limited knowledge of the process, stating:

> The Sun reflects light onto the Moon since the Moon orbits the Earth. Some parts are being blocked, and the parts that have light reflecting on them could be facing us on the other side of the world.

In contrast, in year two, the student's written work was generated during the individual tasks. Padma encouraged her students to choose the best explanation from their viewpoint and detail their reason. Therefore, the written work was not obtained as a result of a discussion process. She approached the same activity in year two as a tool for not only getting her students thinking about and selecting the correct explanation but also developing their reasons for their choice so as to assess their knowledge of the topic. Table 7 provides an overview of the students' individual responses and the reasons for their choices. In total, eighteen student's written responses were collected.

The results reveal that only six students selected the correct explanation as D, and of those, only one accurately supported his/her choice in writing:

> We cannot always see all the parts of the Moon, which is lit up by the Sun. (Student 5)

Student 10 provided an incoherent reason for his/her choice:

> Because we know it does not rotate on its own axis. My evidence is that since the Moon is smaller than the Earth, we should see it move faster than a day since we cannot see it. It shows that my point is right. I think this is a strong argument. (Student 10)

The other four students did not provide accurate information to support their choice.

Overall, the student's written work suggests the use of this particular argumentation activity provided an opportunity for students to effectively show their understanding of the topic and provide reasons for each explanation, as well as helping Padma to understand her students' thinking and level of understanding. In year one, to some extent, most of the student groups could also justify alternate explanations. However, in year two, the students were only required to provide their reasoning for their chosen explanation. This practice helped her determine each student's understandings of the topic. However, the process did not support students' argumentation skills. In both years, as evidenced in the student's written work, only a very small number of the students' responses and their reasons for their choices were accurate. Thus, Padma had an agenda to work from when following up on this activity.

4.3.2.2 Mala's Phases of the Moon lessons

Figures 4.19 and 4.20 demonstrate the lesson structure of Mala's lessons across the two years.

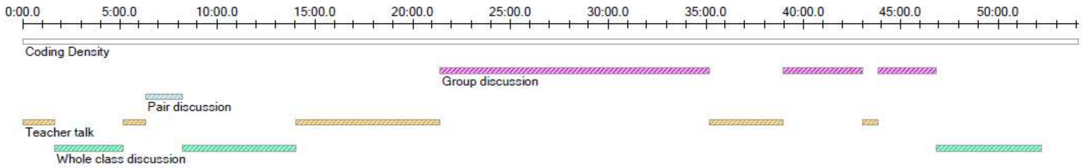

Figure 4.19 Phases of lesson structure for Mala's Phases of the Moon lesson in April 2018.

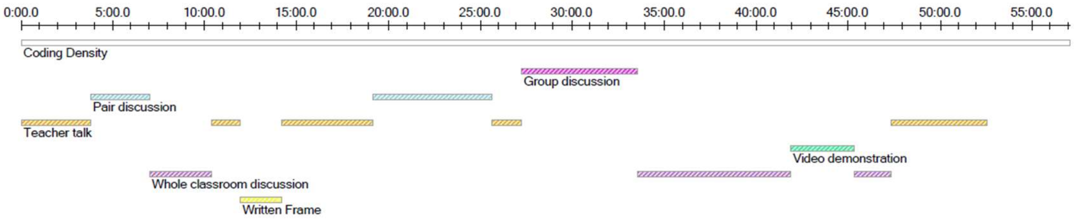

Figure 4.20 Phases of lesson structure for Mala's Phases of the Moon lesson in April 2019

The lesson structure for Mala's first-year lesson (see Figure 4.19) includes a period of teacher talk at the start of the lesson. Mala outlined the lesson's objectives and elicited the components of a strong argument. During the whole class discussion, she then received responses from her students. She then formulated four different arguments about the Moon's light onto the whiteboard and instructed her students to discuss them in pairs. She then gathered the class together to hear the students' responses and justifications for them in the context of a whole-class discussion. Mala then provided explanation of the Moon's phases, followed by a broad description of the argumentation activity, and then organised her students for the group discussion process. During the group discussion, her students discussed the explanations provided on the activity sheet and provided their justifications for both their preferred and alternative explanations. She then brought the class back together and requested that the envoys change groups for the following round of discussions. Her students then continued debating the explanations and examining their justifications. She then gathered the class together once more and instructed that the envoys re-join their original groups and share their discussions for a final group discussion session. At the conclusion of the lesson, she devoted an extended period of time to a plenary discussion. She encouraged her students to detail their choices, express their justifications for them, and present alternate explanations.

In year two, she set the activity up slightly differently in terms of the patterns of small group discussion. Mala provided a brief information session regarding the phases of the Moon before applying an argumentation activity to reinforce the students' content knowledge regarding the topic. Another distinction between the approaches in the two years concerned how she arranged the student groups. Mala requested that her students work in pairs first and then asked the pairs to join up with another pair for further discussion, followed by a whole-class discussion. A further difference included the use of a video demonstration, explaining the occurrence of the phases of the Moon to resolve her students' content knowledge.

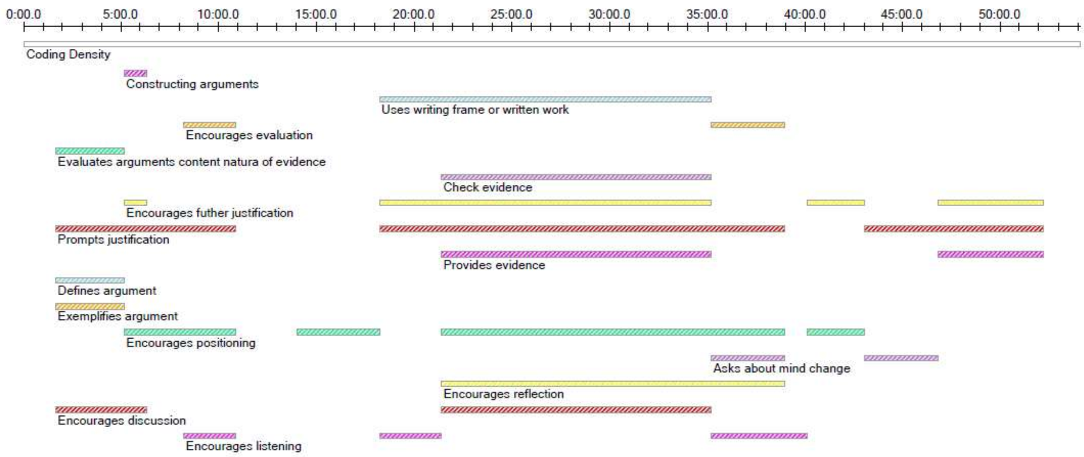

Figure 4.21 Phases of SAP for Mala's Phases of the Moon lesson in April 2018

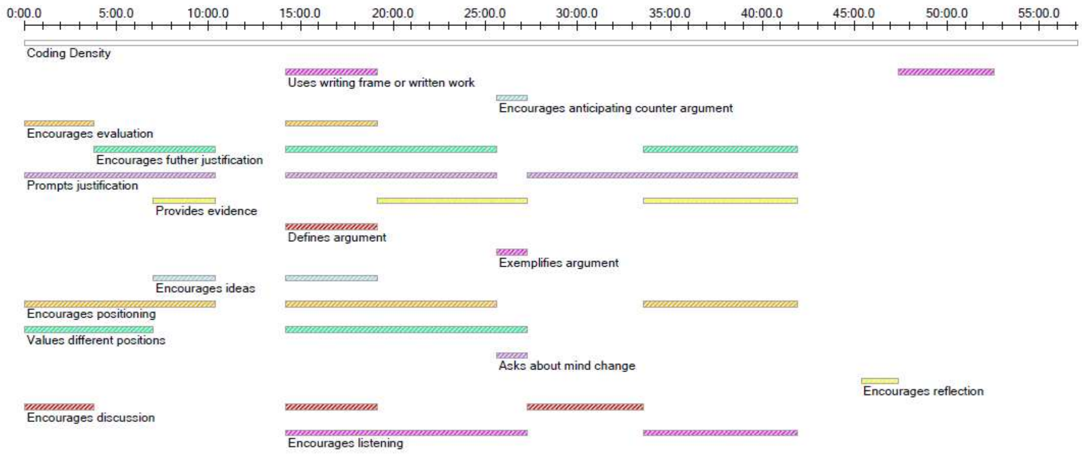

Figure 4.22 Phases of SAP for Mala's Phases of the Moon lesson in April 2019

Further analysis of the same lessons in terms of the distribution of SAP showed that Mala scaffolded a variety of argumentation processes during these lessons across two years to support her students' engagement with scientific argumentation. Similarly, she employed a range of argumentation processes during the small-group discussions and the whole-class discussion in both years (as indicated in Figures 4.21 and 4.22).

In year one, Mala commenced the lesson by emphasising how to construct a good scientific argument. The finding supports her belief that focusing on highlighting the process of producing a scientific argument is crucial for her students. When she asked her students what they needed to produce a scientific argument, they appeared to understand what she was looking for. She further attempted to develop her classes' understanding of how to construct a good argument and elaborated on the process of using evidence and evaluating arguments, expressing:

> You would make a point and present evidence. You back up your evidence with good examples. So, should the evidence that you use be just what you think of something factual? So if we are looking at the Moon, can I just say 'I think the Moon is soft', and if I just stopped, is that okay? If I say, 'I think the Moon is soft like cheese because there was an advert that said that on TV'? Is that a good argument? If I said, 'I think that the Moon's surface is rocky, because…', then what else could I say to make a good scientific argument? What do we know?

More importantly, she illustrated the processes involved in constructing an argument by setting out what scientists do:

> People have gone to the Moon; they have looked at samples from the Moon. They have brought back data and evidence from the Moon- that's how we know. This is what scientists do, scientists come up with a theory and look at the evidence, and they argue and debate about whether it is true or false. The theory is the most sensible and has the most evidence to back it up.

In both years, before implementing the argumentation activity, she introduced a short activity (included four different opinions, labelled them A, B, C, and D). Her approach was similar in both instances as she encouraged her students to choose an opinion that they thought was correct and then justify it by offering their reasoning. They are required to offer reasons for why they agree or disagree with their pairs while during the pair discussion activity. The main difference between the years was that Mala emphasised more justifying alternative opinions in year two further, illustrating that she had developed a greater understanding of this aspect of argumentation.

Similarly, in both years, during the pair discussion task, Mala joined some pairs and prompted her students to take a position and justify it. After the pair discussion, she focused on gathering the students' opinions together and debating the reasons for their choices in the context of a whole-class discussion. She mainly encouraged her students to justify their choices further and provide reasons for them (see line 1 below, which is an extract from year two). The main difference in this practice across the two years is that in year two she encouraged her students to provide justifications for why alternative arguments may be implausible (see lines 3 and 7), clarifying that she supported wanted her students to know that it is important not only to argue that one particular scientific idea is accurate, but also that alternative ideas are not. This dual approach can ultimately enhance students' conceptual understanding.

1	Mala	Who agrees with A? Can you give me another reason that Student 1 has not given? Why do you agree with A? Student 2?
2	Student 2	Because the Sun is a star (Inaudible comment)
3	Mala	Wait…Are you saying you agree with B? That is fine. You agree with A, but you also agree with a bit of bit with B. Why do you agree with a bit of bit with B?

4	Student 2	The Sun is a star, and some other stars also have light, so they shine on the Moon.
5	Mala	The Sun is also a star, so if the Sun's light is shining on the Moon, why not the other stars as well? Student 3?
6	Student 3	I disagree with B because it said distant stars, and since Sun is far away like many light-years away, it cannot (Inaudible comment) it is not that distance as B said.
7	Mala	Okay. So, the Sun is actually not as distant as distant stars because we said the light is from the Sun; we have not said there is light from the Earth and distant stars. Why do you all, most of you disagree with C? Why do you think C is wrong?
8	Student 4	Because the Earth is not a strong source of light.
9	Mala	Good. Any other reason why we disagree, Student 5?
10	Student 5	The Sun provides light even when we do not have any electricity.

Following this practice, in both years, Mala introduced the argumentation activity to the class and organised her students for the group discussion. Similarly, in both years, she approached the activity as a tool to motivate her students to think and discuss the explanations given to them. She mainly focused on getting her students to choose the best explanation, providing them with reasons for the explanations, and resolving the science content. The critical differences between the two years were that she focused more on resolving the science content and providing correct explanations in year two.

A further difference between the two years was the group strategy Mala utilised in the group discussion. In year one, she used envoys and assigned her student's different roles. The idea of giving students different roles in a group discussion was intended to encourage them to participate more in the activity. However, this approach was challenging for her students, and they sought further clarification of their roles in the group discussion. Therefore, she spent time providing more explanations for their roles. She then asked the envoys to change groups and share their responses with other groups. She prompted further discussion by sending the envoys to a new group that had made a different choice from the envoys' initial group.

In contrast, she preferred not to use envoys in year two, as this idea was challenging for her students to understand and apply. Therefore, she first organised her students into pairs for discussion and then asked them to join with another pair with a different view for further discussion. This practice went beyond simply encouraging them to evaluate one another's explanations (as she did in the Dropping a box lesson) by prompting them to reach a consensus. Consequently, the activity prompted them to resolve their differences. As a result, her students engaged more in the group discussions as a way to reach a consensus and develop their understanding of the broader science content.

Throughout the small group discussions in both years, Mala encouraged her students to listen to one another, discuss the given explanations, justify their choices, and provide reasons for the explanations. In particular, in year two, she encouraged her students to provide reasons to explain why they disagreed with the other options. As seen in the extracts below from both years, she encouraged her students to reflect on their opinions and then change their minds if they wished to do so:

> The envoys go back to their group and present those arguments and see if the other group can change your mind or not, so the envoys have a lot of responsibility. (Mala, April 2018)

> Do you think you agree with that, or do you think that is not right? If you believe it is not right, can you provide a reason as to why it is not correct. Perhaps, you might decide to change your answer. If you believe the correct one is E, perhaps after hearing somebody's reasoning and giving their reasons for arguments C, you might think that their suggestion makes more sense. (Mala, April 2019)

During the whole-class discussion in both years, Mala elicited her students' choices, their reasons for making those choices, and their explanations by following a similar approach. In year two, she allocated more time for her students to share their ideas with the class. Moreover, she encouraged more of the class to share their opinions and explanations. In both years, she prompted her students to share their justifications by asking them why they agree or disagree after receiving their responses (see lines 1 and 5 - extract from year two). A difference noted across the two years was that she did not spend as much time evaluating each explanation in year one. In contrast, in year two, she mainly focused on clarifying why the students think alternative arguments are not plausible, thereby ensuring students' understanding of the content (see line 3):

1	Mala	Who disagrees with D? Student 1, why do you disagree with D?
2	Student 1	Because we were thinking of D and E, but we got that E makes more sense because the Earth spins, and that is why we have nights, right?
3	Mala	Yeah, the Earth does spin for night and day. We looked at that in the last lesson.
4	Student 2	I believe this is the best argument because the part of the Moon we cannot see is because of the Earth's shadow. So, the light of the Sun does not hit it, and E says that.
5	Mala	Alright, okay. Who disagrees with E, then? Student 3, why do you disagree with E?

Another difference across the two years is that after the plenary discussion in year two, she showed a video demonstration of how the phases of the Moon occur. She then asked her students to think about their choices and reasons with regard to the statements:

> Based on what we saw there (in the video), do you still agree with your initial thoughts? So, people who said they agreed with E, do you still agree with E? (Mala. April 2019)

This instruction above mainly encouraged her students to reconsider their scientific understanding and reasoning in reference to the explanations provided, which is vital for developing argumentation skills. This shows Mala had developed her understanding of scientific argumentation in this regard. The video demonstration was productive for her students, as it helped to illustrate the process by which the phases of the Moon occur. By doing so, she not only addressed the scientific content by resolving her students' misconceptions around the topic but also promoted argumentation pedagogy.

The observation of her approach to scaffolding the argumentation process and the time Mala spent on the activity is reflected in the students' writing. In addition, her students' prior knowledge of the content served as a resource for engaging in argumentation.

In year one, as seen in Figure 4.19, Mala allowed her students time to discuss the explanations given and provide reasons for the explanations in the group discussion, after which their written work was collected. In addition to this, time was assigned to complete the discussion task. Mala approached the activity as a tool, not only for getting her students thinking and discussing all the explanations but also for encouraging them to provide the reasoning for all the explanations. Tables 8 and 9 (see Appendix 11) capture an overview of the student groups' responses and their reasons for each explanation. She also encouraged them to choose the best explanation, provide reasons for all the explanations, and discuss the statements as a group. Moreover, she emphasised the process of writing during the first part of the group discussion. The written data from the students revealed that intensive discussion took place amongst the majority of the student groups during the group discussion phase. Therefore, most of the student groups completed the activity, selecting the best explanation as they saw it and providing reasons for both their chosen explanation and counter the alternative explanations. The results reveal that half of the student groups chose the best explanation to be D. However, it should be noted that only group 5 provided a reason and that the reason offered was not correct:

> The light of the Sun bounces on the Moon on different sides, which makes the Moon have different faces.

Most of the student groups engaged with explanations A, D and E (see Table 8, Appendix 11) which shows that her students did not fully understand the topic.

In contrast, in year two, Mala initially asked her students to discuss the statements with their pair. She then asked each pair to join with another pair to continue discussing and sharing their ideas and reasoning. As shown in Figure 4.20, the student's written work was collected after the two pair discussions. In some cases, groups revised their responses following the small group discussion. During both the pair and small group discussions (joint pairs), she encouraged her students to to discuss all the explanations, choose the best explanation and explain why they believe their choice is the best explanation by providing a reason, as well as reasons for the other explanations. Therefore, written data was obtained during the discussion process. She approached the same activity in year two as a tool for not only getting her students thinking and discussing all the explanations but also to clarify the science content.

Table 9 offers an overview of the student groups' responses and rationales. She emphasised the process of writing during the pair discussions. The written data from the students revealed intensive discussion amongst most of the groups during the group discussion task, with most of the student groups completing the activity. The results indicate that only 3 of the groups chose the best explanation as D. This shows the topic is challenging for her students. However, it should be noted that only Group 4 and 10 provided a reason, but the reason was incorrect, writing:

> The Moon could be behind the Earth, and the Sunrise goes on it, and the shadow of the Earth falls on the Moon. (Group 4)
>
> Yes, we cannot always see the sides of the Moon (Group 10).

The student's written work reveals that during a further discussion about the explanation with the joint pairs, one group of students changed their responses from E to D, indicating an intensive discussion and an ability to reflect on their responses.

The results also reveal that most of the student groups engaged with explanations D and E (see Table 9, Appendix 11), which shows confusion and a limited understanding of the topic. In most cases, the students referred to aspects from the lesson. At the end of the lesson, to resolve the science content, Mala provided a video demonstration explaining the phases of the Moon and asked her students whether or not they still considered E the best explanation. In the written task, her students were not asked to revise their responses.

Overall, the findings, based on students' written work from the lessons, suggest that this argumentation activity was essential in building an understanding of the topic. The fact that they had to provide reasons for their choices as well helped Mala understand her students' thinking and understandings, as well as their misconceptions about the topic. In both years, as evidenced in the students' written work, only a very small number of the responses were correct, and none of the groups accurately justified their correct explanation. This demonstrates that this topic was a challenging one.

4.3.2.3 Comparison of the two teachers' practices of Phases of the Moon lessons and changes in their practices across two years

Reviewing the teachers' implementation of scientific argumentation across the two years allowed me to compare the teachers' practices, approaches and changes in practice. Despite collaborative planning, the teachers implemented scientific argumentation into their practice differently in terms of structure, the organisation of students for discussions, timing and approach, and pedagogical development.

After examining the lesson structure of both teachers, Padma initiated her lesson in year one using a video demonstration, and Mala began by emphasising the process of constructing and evaluating arguments. However, in year two Padma integrated approaches to scientific argumentation at the beginning of the lesson. Mala also briefly explained the science content and introduced a short activity to remind students about how to argue critically. Thus, the results show that the lesson's objectives and resultant emphases varied across two years.

In year one, both teachers established the Phases of the Moon activity following a similar pattern of small group and whole-class discussions and tried a new group strategy, envoys, in year one. However, their organisation of group discussions differed in year two. Whereas Padma used individual tasks and pair discussion, Mala utilised pair and joint-pair discussions followed by whole-class discussion. Thus, Mala introduced something new – pair to joint pairs – to her practice and developed her understanding of facilitating group discussions over two years.

Both teachers used the activity to recap the science content and identify students' understandings and misconceptions about the topic. The task's structure encouraged students to use their prior knowledge in their reasoning as they were familiar with the tasks presented (Dawson & Venville, 2010; Lewis & Leach, 2006; von Aufschnaiter et al., 2008). In both years, Padma provided a brief explanation and a video demonstration to clarify the science content. Despite being restricted by her students' behavioural challenges, Padma gave additional opportunities for her students to understand argumentation in year two. Mala did the same but also encouraged her students to reflect on the changes to their understanding at the end of the lesson in year two. She also used the activity in the scheme of work instead of a stand-alone lesson, which shows her development and understanding of this approach.

Further analysis of the same lessons in terms of SAP reveals both teachers utilised a range of argumentation strategies throughout the lessons. This indicates what teachers prioritise when incorporating scientific argumentation into science teaching and their approaches in this practice. The student's involvement in the activity and their written work reflects the teachers' differing argumentation approaches. I observed the teachers outlining and discussing how to construct a good argument in support of an opinion, and then using prompts such as, "How do you know that?", What do you need to make a good argument?" to encourage their students to engage more in both years (McNeill & Pimentel, 2010). In particular, Mala's instructions demonstrated more shifts in emphasis when evaluating both accurate and alternative explanations.

In year one, both teachers' approaches were similar, emphasising group discussion and listening to one another's explanations. In year two, the teachers used a variety of methods to implement the activity. Padma specifically asked her students to choose the correct explanation and explain their choices, allowing her to assess their scientific understanding and the students to evaluate each other's work. Mala, in contrast, required that her students choose the best explanations and write their reasons for both their chosen explanation and alternatives. During the small group discussion, her students actively interacted with each other. She also provided a video demonstration and explicitly taught the science content in year two to resolve any misunderstandings. Based on the students' written work, they found the

Phases of the Moon activity complex, as they had a limited understanding of the science content. The activity effectively allowed both teachers to assess their students' levels of comprehension.

A further difference was that Padma used a few variety of scaffolding techniques in her interactions with students but altered her pedagogy over two years. Her lesson aims emphasised both scientific knowledge and argumentation structure. Similarly, Mala's interactions with her students revealed a broad understanding of how argumentation can be promoted in group discussions. She altered her pedagogy from one year to the next while stressing a variety of argumentation processes effectively, including the process of changing one's mind after listening to others' ideas, highlighting her belief that this is an important aspect of scientific argumentation. Overall, her class objectives emphasised science content but prioritised developing students' reasoning skills and argumentation processes.

4.3.3 The two teachers' implementation of the Food chain lessons across the two years

This section presents the details of Padma's and Mala's practices during the Food Chain activity across the two years.

4.3.3.1 Padma's Food chain lessons

Figures 4.23 and 4.24 show the lesson structure for Padma's lessons across the two years.

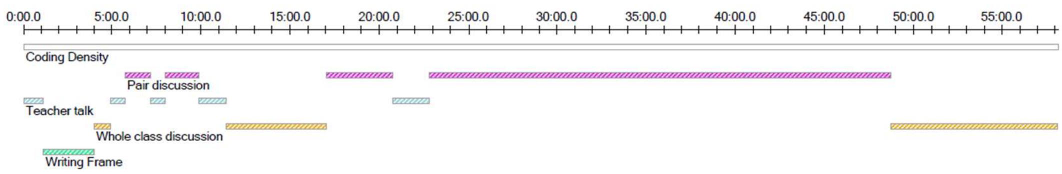

Figure 4.23 Phases of lesson structure for Padma's Food chain lesson in June 2018

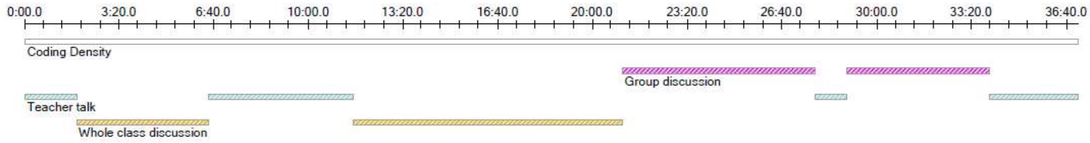

Figure 4.24 Phases of lesson structure for Padma's Food chain lesson in June 2019

As seen in Figure 4.23, there is a short period of teacher talk during which Padma briefly explained the lesson aims, then posed the question of what happens if the food chain is disrupted, allowing time for her students to write their responses in their notebooks. During the plenary discussion, she elicited and received several responses from her students. She then provided a brief description of the small group approach, known as verbal tennis, demonstrated how it works and provided a short outline of the value of the practice. Next, she encouraged her students to practice in pairs. She projected some explanations of how to construct a strong argument during the second period of whole-class discussion. After this, she instructed her students to evaluate one another's written responses. Padma then continued by presenting an overview of what the argumentation activity would entail. As seen in Figure 4.23, a prolonged period of pair discussion then occurred, during which her students discussed the statements given on activity sheets. Finally, she concluded the lesson with a whole-class discussion, in which the students shared their responses and justified them.

In year two, the Food chain activity was established differently, utilising an approach combining small group and whole-class discussion. After introducing the lesson's goals, Padma outlined what is required to construct a strong argument during the whole-class discussion. She then introduced the argumentation activity, which was followed by a whole-class discussion in which she demonstrated how to discuss the statements and engaged her students in doing so. During the small group discussion, Padma encouraged them to discuss the other activity sheet. She then gathered them together.

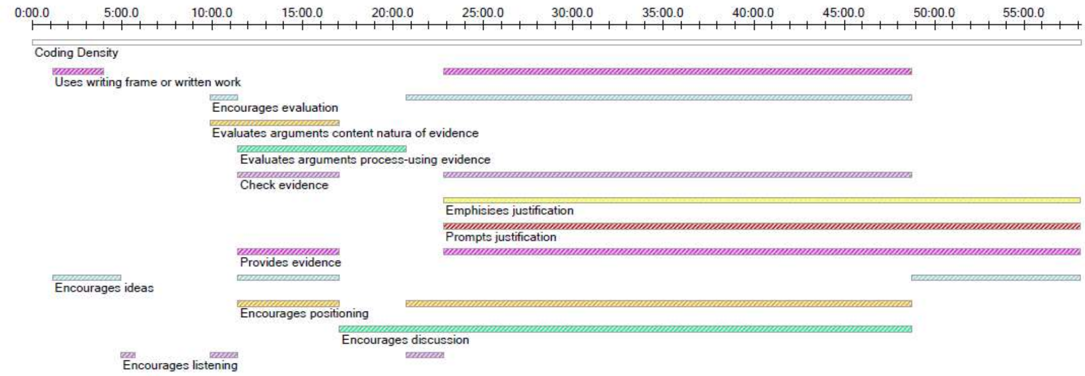

Figure 4.25 Phases of SAP for Padma's Food chain lesson in June 2018

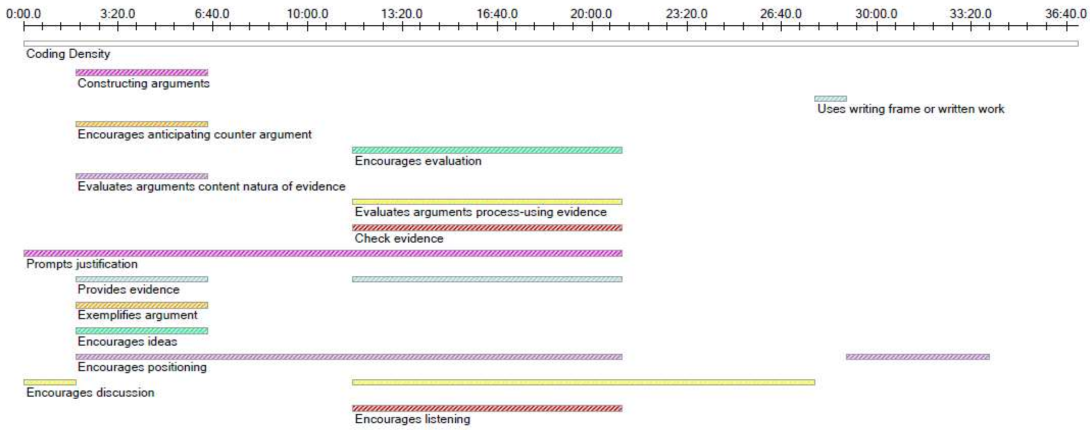

Figure 4.26 Phases of SAP for Padma's Food chain lesson in June 2019

Figures 4.25 and 4.26 provide the profiles of Padma' instructions throughout the lessons. Further examination of the same lessons in terms of SAP across the two years revealed that Padma had developed a range of argumentation processes to encourage her students to engage in scientific argumentation. In year one, she used a variety of argumentation processes during whole-class and small group discussions. In contrast, she used a range of argumentation processes in year two during teacher talk and the whole-class discussion.

In year one, Padma began the lesson by asking her students to prepare scientific arguments, answering the question 'What happens if a disease affects a food chain?'. Some of her students wrote their ideas in their notebooks (see below some examples of the student's written work). She then asked some of them to share their ideas with the class. Next, she introduced a small group strategy called verbal tennis and spent some time helping her students share their opinions while listening to each other. Padma's main focus was on assisting her students with understanding the process of constructing a good argument and evaluating that argument, indicating that she thought assisting her students in understanding how to construct a strong argument and utilising evidence is important to help them engage more with the process. She stated:

> You state your opinion. You use evidence and offer an explanation to back up your point. It covers many possibilities. If someone's statement is only based on one person's opinion, then it's only their own opinion. Is it a strong or weak argument? So why is it a weak argument?

She also highlighted that considering others' opinions is significant to encourage her students to engage in the argumentation practice:

> Considering other points of view or other possibilities and perspectives is important. The argument should be clearly explained. You are not just writing something down or just writing down what you think. Your argument has to make sense to another person.

She then asked her students to evaluate one another's arguments. In total, 13 students produced written work—there are four examples given below to illustrate how her students evaluated each other's arguments. There was only one student who attempted to rewrite his/her argument to strengthen it. This practice shows her students had some understanding of the structural language of argument and were able to use it at times during the lesson.

Examples of students' written arguments	**Students' evaluations of each other's arguments**	**Students' written argument after the process of evaluation**
If the marsh grass died out, the grasshopper population would decrease as there would not be any food to eat.	The good argument put evidence, e.g., the food web	I know this because this is what the food web shows, and it does not give any other options for it to eat.

The population of grasshoppers may slowly die out because they need the marsh grass to live on.	Good argument; however, it needs evidence from the food web to back up your point that the population will decrease
If the marsh grass died out, the grasshoppers would slowly die out as they would have no food. Also, some shrews would slowly die because they eat grasshoppers; however, they would still have crickets to eat not to die out. These will keep the hawks and snakes alive as they do not only eat shrews. The hawk eats snakes, and the snake also eats frogs.	Strong argument

Similarly, in year two, Padma's instructions focused on evaluating an argument and how to make a strong argument. She reminded her students about when they had previously engaged in scientific argumentation and indicated the importance of forming an argument.

> What shape is the Earth was the point we were discussing. When we are looking at argumentation, we are more interested in your reasoning. The point of these activities is not to have the right answer, but if you are having the right sort of conversations. What do we say makes a good argument? So, whichever shape you decide or whichever shape you feel is the correct shape of the Earth, how could you make a good argument for it? We are talking about forming a good argument. Why is it so important that scientists form a good argument about something?

The main difference between her approach in years one and two was that she emphasised the importance of using relevant evidence in year two. This included evaluating both the process of using evidence and the content of that evidence, as well as creating a connection between the point made and the evidence to support the point. This demonstrates that she had expanded her understanding of argumentation. She stated:

> The shape of the Earth was a controversial topic because many religious texts said that the Sun goes around the Earth, the Moon goes around the Earth. And the scientists at the time had to present the relevant evidence to prove their points. 'This is the evidence we have. This is what we think scientifically'. So if a scientist discovers something controversial or something that goes against the current way of thinking, they need to explain their ideas clearly; they need to make strong arguments in favour of what they are trying to present. That is why it is so important. Relevant evidence is not just something you pick up to back up your point. You might need to add more information about how your evidence explains the point. You should be able to make that link.

She also encouraged her students to consider counter-arguments and construct arguments scientifically exemplifying scientists' work when discussing evidence by highlighting what counts as relevant and strong scientific evidence.

When applying the argumentation activity, how she organised her students for the group discussion differed between the two years. She organised her students into pairs for discussion in year one, but a year later, she organised them into groups of 4. Another difference is that she provided prompt cards to help her students understand the argument structure in year one. The fact that she did not do this in year two suggests that she believed her students could use the argument structure without support.

Padma spent much time in year one engaging in pair discussions. In addition, throughout this period, she provided her students with an evaluation card to help them evaluate each other's arguments and an opinion card to help them construct their arguments. However, she did not explain how to use them. She also encouraged her students to discuss and justify their responses in pairs. Encouragement of evaluation and reasoning was the main goal of her instructions. In comparison, a year later, she demonstrated to her students how to evaluate arguments to ensure they understood what was required during whole-class discussion. Additionally, she emphasised the necessity of reaching a consensus, stating:

> Some statements you are going to decide whether they are good arguments. If they make a good argument, have they used the evidence correctly? Does that make a good argument? We're not talking about whether it's right or wrong. We're talking about whether the person has made a good argument or not. There will be one side

> you agree with more. You imagine if you and I disagreed on something you would say what you think and I would say what I think. We would not get anywhere if we are not using any sort of evidence to back up our point. We wouldn't reach any sort of consensus.

At the end of the activity, in year one, Padma encouraged her students to share their responses with the class. In addition, she asked them to further justify their choices and encouraged them to provide their reasoning:

> You've used the food web as evidence. Why didn't you choose any of the others? What was wrong with the other statements?

In contrast, in year two, she asked her students discuss the statement as a group. However, she encountered some behavioural issues with the class. Therefore, she was not able to utilise the method of whole-class discussion at the end of the lesson as planned. Instead, she collected her students' activity sheets and moved on to the next topic.

Padma used the Food chain activity as a way to recap the topic each year. Therefore, her students' prior knowledge of the content was utilised as a resource for engaging them in scientific argumentation. Furthermore, she highlighted the process of evaluating arguments at the outset of the lesson on both occasions, as her students were already familiar with the scientific concept and understood what was being presented to them. Moreover, in both years, she approached the activity as a tool for encouraging her students to discuss and evaluate each statement according to whether they were strong and in reference to their knowledge of the structural language. Her students were also asked to use their content knowledge to evaluate the explanations. Thus, it should be noted that the task had not been designed to gather the students' written work. Therefore, minimal written data was obtained from the students during the group discussions each year.

While looking at her students' responses on the first activity sheet, the majority of the groups engaged with explanations B and D. On the second activity sheet, most of the student groups engaged with explanations A and C. Most of the groups discussed the first two activity sheets in the time frame allotted. Therefore, only a few groups discussed the third activity sheet and engaged with explanations B and D. When reviewing her students' written work, it appears that they had information about the structural language of a strong argument when evaluating each explanation. For instance, one group of students wrote:

> <u>First activity sheet:</u> I think that Person D is correct because it is a strong argument because it has a clear point that is explained well. It is also backed up with evidence that shows more proof. The other statements state that blue tits will have other things to eat, which remains another option, but there is no evidence from the food web to support this. Person A has made a statement offering no explanation or evidence, which shows they have a weak argument. Person D has the strongest explanation, as it is supported by evidence from the food web.
>
> <u>Second activity sheet:</u> I think Person C is correct. My reason for thinking this is because it has a strong argument and explains that the hawk can still eat the blue tit, rabbit, and chaffinch. This is true. Person D, which I disagree with, says the rabbits will also die out. This is incorrect because they can still eat grass, so they will not die out.
>
> <u>Third activity:</u> I think with Person B because evidence from the food web shows that the rabbits do not directly eat barley as Person D says.

As seen in the example above, it is apparent that her students were looking to the main points to provide a strong argument, as Padma highlighted during the lesson.

In year two, Padma used the first two activity sheets. These activity sheets were obtained from 7 groups of students. When looking at her students' responses, most of the student groups engaged with explanation D on the first activity sheet. On the second activity sheet, the majority of the student groups engaged with explanations A and B. By examining the students' written work, it can be observed that her students had information about what structural language comprises a strong argument that they drew on when evaluating each explanation. For instance, one group of students wrote:

> <u>First activity sheet:</u>
>
> D: It has everything. Good important information, evidence is relevant. It makes a good point, evidence, and a good explanation.
>
> A: Lack of evidence and explanation.
>
> B: False evidence and irrelevant explanation.
>
> C: Only explanation.

Second activity sheet:

B: It has relevant evidence linked to the point and have a good explanation.

A: No evidence linked to the point; it is their opinion.

C: No proper evidence, incorrect point.

D: Irrelevant fact.

Overall, the student's written work in these lessons suggests that the use of the argumentation activity provided an opportunity for them to show their understanding of the topic, particularly in year one, and their understanding of how to evaluate an argument in terms of its structural aspects. In addition, this activity helped her understand her students' thinking and learning of the science context.

4.3.3.2 Mala's Food chain lessons

Figures 4.27 and 4.28 demonstrate the lesson structure for Mala's lessons across the two years.

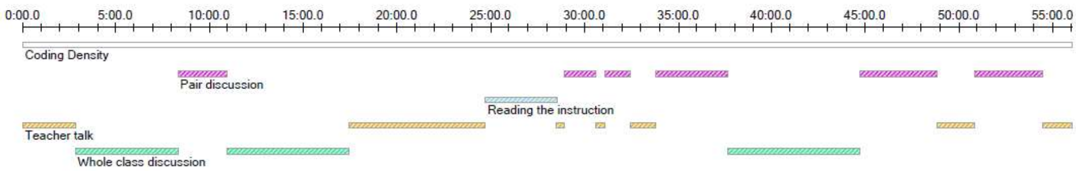

Figure 4.27 Phases of lesson structure for Mala's Food chain lesson in May 2018

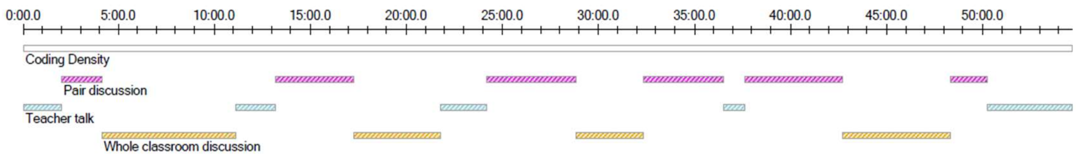

Figure 4.28 Phases of lesson structure for Mala's Food chain lesson in May 2019

Figure 4.27 presents a period of teacher talk, during which Mala explained the objectives of the lesson. She then asked her students what the aim of referring to the food chain is from the perspective of scientists and allowed them to respond as a whole-class discussion. She then offered three possible opinions about what might happen if there is a disruption to the food chain and asked her students to discuss them in pairs. Next, she recorded her students' responses and the reasons for their choices briefly on the whiteboard during a whole-class discussion and also discussed what features construct a strong argument. In the second period of teacher talk, she provided a general description of what the argumentation activity would require and provided time for her students to read the statements provided in the activity sheet. She then asked her students to discuss the statements and evaluate one another’s opinions in pairs. There was also intermittent teacher talk, during which she reminded her students of the requirements of the activity, followed by a whole-class discussion in which her students shared their responses and gave reasons for their choices. She then distributed two more activity sheets one by one, asking her students to discuss the statements on the sheets and write their reasoning during pair discussions. Finally, she collected the activity sheets and ended the lesson.

In year two, as seen in Figure 4.28, the lesson structure followed a similar pattern, except that Mala used whole-class discussion throughout the lesson to obtain her students' responses and the justifications for their choices and used teacher talk to resolve her students' misconceptions about the topic.

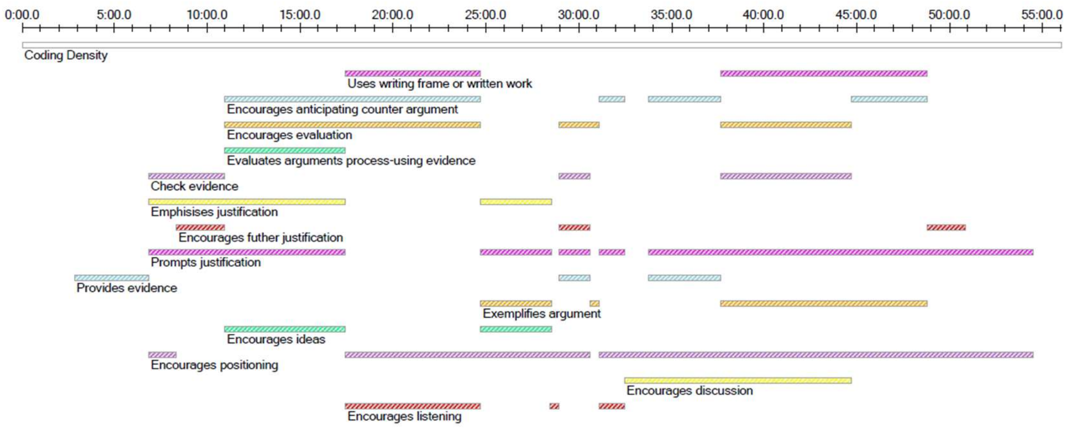

Figure 4.29 Phases of SAP for Mala’s Food chain lesson in May 2018

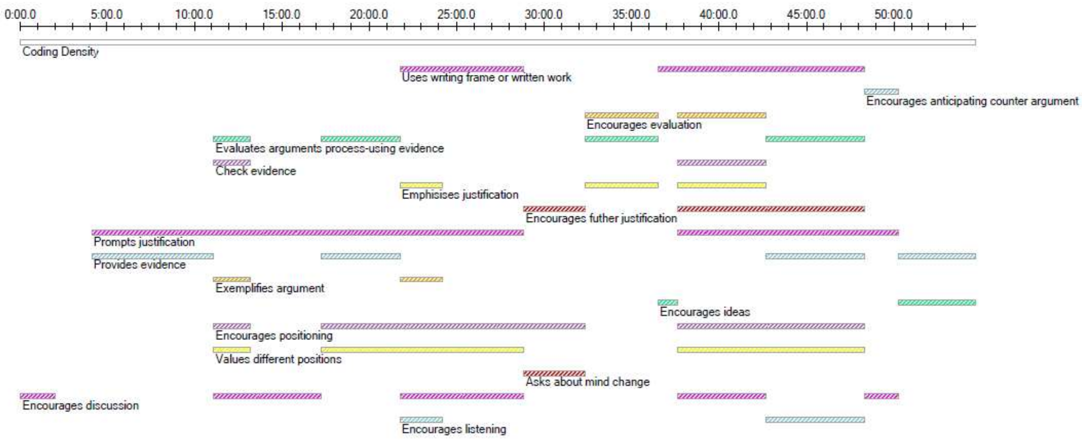

Figure 4.30 Phases of SAP for Mala's Food chain lesson in May 2019

Further examination of the same lessons across the two years in terms of SAP, as shown in Figures 4.29 and 4.30, reveals that Mala utilised various argumentation processes throughout the lessons in both years, predominantly during the whole-class discussion and pair discussions. Furthermore, in part, her practices in terms of SAP demonstrated more similarities and limited changes across two years. This suggests that she did evolve her pedagogy from one year to the next.

In both years, at the start of the lesson, Mala checked her students' prior knowledge of food chains and their opinions about the purpose of referring to food chains. During that practice, she used the strategy of providing evidence in both years. In addition, she encouraged discussion and justification in year two during pair discussion. She then implemented a short activity. Designing the activity in a similar way to the Phases of the Moon lesson, she provided different opinions, then asked her students to take a position, discuss it in their pairs and then justify their choices. A whole-class discussion then followed this to enable her students to share their responses with the class. In the sequence below, a representative episode from the whole-class discussion in year one shows how she encouraged her students to check their evidence (see line 11), justify their opinions (see lines 5, 9 and 11) and anticipate counter-arguments (see lines 3 and 20). In addition, she included the belief that argumentation is a process in which you seek to convince someone of an opinion (see line 3). The main difference across the two years is that in year one when receiving her students' responses, she wrote them on the whiteboard and asked them to evaluate their arguments (see line 14). The findings show that she focused more on the processes of constructing and evaluating arguments (e.g., the process of using evidence) to help her students comprehend the argumentation processes in year one. The main aim of this practice was to show her students what they needed to construct a strong argument. Additionally, students' responses show that they were listening to each other responses (see lines 10, 12 and 13).

1	Mala	Let's hear some ideas; I have actually heard some good ideas. Student 1, what do you think?
2	Student 1	I think both B and C.
3	Mala	Okay, so you think it's both? Is that enough to convince me? What do you need to do to convince me? Let's stick with B now? What arguments could you put forward?
4	Student 1	The Hawk has multiple sources of energy.
5	Mala	How do you know?
6	Student 1	Because the food web shows, it can eat voles and moles as well.
7	Mala	That's what the food web shows, yeah? Okay, Student 2.
8	Student 2	I think it's A and C.
9	Mala	Okay, tell us why you think it's A?
10	Student 2	Because then it will have to feed on a vole or a mole. Foxes already eat moles, so there will be fewer moles, which means that there will be no food for Hawks so then they will die of starvation.
11	Mala	Ok, what shows you that? How do you know that, and how did you come to that reasoning?
12	Student 2	Because that's what it says on the diagram.
13	Student 3	I think it is B. It would not be person A because the Hawk can eat moles. It might be person C, but I don't think it is because if it's the thrushes, they will not die out, but some of them will die out, and nothing will eat them because it's the top of the food chain, but most of them stay alive, but some of them died. I think it is like person B.
14	Mala	On the board, I have written down some of what you've said. Can you notice the difference between this side and this side? (showing students' weak and strong arguments) Which arguments are better, these ones or these?

15	Student 4	The left one.
16	Mala	Why is this site better?
17	Student 5	Because they have an explanation of why the statement is true.
18	Mala	Because I have got an explanation, this one is because the food web shows this. What are we looking at? What are we linking back to? We are linking it back to the evidence that we have. The food web is the data and the evidence that we have. Why are these statements not so good?
19	Student 6	Because it doesn't show any evidence and you need evidence to prove it.
20	Mala	Yes, you need evidence to prove it but what else might you need to prove it? So, you need to use the evidence and you need to justify your argument. You need to give me a reason why and you need to convince me that is the reason why. Does that make sense?

After the whole-class discussion in both years, Mala explained the argumentation activity to the class. The difference between the two years is that in year one, she provided her students with both an evaluation card to help her students evaluate one another's arguments and an opinion card to help them construct them scientifically. She also exemplified how to use the evaluation card by evaluating a statement, which showed she considered modelling a significant way to help her students understand this practice. Moreover, she encouraged her students to consider counter-arguments as part of the pair discussion activity:

> Okay, an argument is against your point of view; I am using the evaluation card using evaluation language. Is that the evidence we have in front of us? So, you said that you agree with person B. An argument against that is that you said they could eat something else like worms; however, the evidence in front of us does not show that the blue tits eat worms it only indicates that the blue tit eats greenflies. (Mala, May 2018)

Whereas, a year later, she just reminded her students about what they had previously done in terms of scientific argumentation, i.e. Phases of the Moon lesson, which showed that her students knew how to complete the activity and what was required from them. She provided her students only with an opinion card and some sentence starters on the whiteboard to help them formulate their arguments scientifically.

In both years, during the pair discussion task, Mala encouraged her students to listen to one another, discuss the statements with their pairs, and justify them. She joined most of the pair's discussions to encourage them to discuss comprehensively. Moreover, she strongly emphasised evaluation and arguing prompts. In year two, one of her students used an opinion card to formulate his responses (see line 4), which suggests they were somewhat comfortable with the structural language and were able to use it at times during the discussion. The sequence also demonstrates that her students listened to one another's opinions carefully, which led them to reconsider their initial opinion (see line 5). This finding shows that her students' engagement in argumentation improved, as they did a similar practice in their lessons. However, the teacher did not ask them to justify further why they had changed their minds.

1	Mala	OK. You have four statements. What are you thinking? Which person, A, B, C or D, do you agree with? Student 1.
2	Student 1	I agree with A; our group agree with A. My reason for this is that if the rose dies out, the green flies die out, which means that the blue tits die out on the food web, although the decrease in blue tits will affect the greenfly populations.
3	Mala	Student 2, which person do you agree with?
4	Student 2	I agree with person D. Because the food web shows us blue tits only eat (Inaudible comment)
5	Student 1	I agree with you.
6	Mala	So now you agree with D. You have changed your mind. Okay, so you need to decide which one you agree with here in your point of view why that one in the bottom write down why you disagree with the other ones.

She realised that some of her students found the activity quite challenging and could not reach a consensus about their choices through pair work discussion:

> Some of you found this hard because you agree with one person, but then you read another statement that makes sense. So, it is difficult to come up with reasons why

you thought those ones didn't make as much sense as the one you picked. (Mala, May 2019)

A further difference is that in year two, Mala encouraged her students to justify their ideas further and questioned why they disagreed with the other statements. This practice helped them provide further justifications for both their choices and alternative ideas. At the end of the lesson, she provided an overview to resolve the science context.

She utilised the Food chain activity as an activity in the scheme of the lesson each year. Therefore, she used the activity to assess her students' understandings of the science content. This approach helped her students engage actively with the argumentation task. Furthermore, she highlighted the process of evaluating arguments in both years, and consequently, her students were already familiar with the scientific concepts and understood what had been presented to them. In both years, she approached the activity as a tool to get her students to discuss and evaluate both explanations. It should be noted here that the task was not designed to acquire students' written work. Therefore, limited written work was obtained from the students during the pair discussions each year.

Her students discussed the statements in pairs in year one. Written work was obtained from 10 students' groups, and several students did not complete the written work in each activity sheet. In the first activity, most of the student groups engaged with explanations B, C, and D, which shows the statements were complex because they were confused about the argument structure when evaluating each statement. Only two groups engaged with the second activity sheet on which explanations A and D were written; this was most likely because most of her students had an intensive discussion about the first activity, so they could not move on to the second one. Therefore, the majority of the groups discussed the first two activity sheets in the allotted timeframe. Only one group discussed the last activity sheet. For instance, the sample of a students' written work included below shows that the student was unsure about which explanation was the best and so agreed with B, C and D, writing:

Personally, I agree with B, C and D. This is because if lettuce plants die, the hawks will have less food; therefore, they will have to compete with each other for the rest of the food. Some hawks will adapt to this life, but the hawks might attack each other, which will reduce the number of hawks. Hawks could eat other animals, but that will create problems for other animals, and the hawks could still die. Basically, the hawks will suffer, but there is a chance that it won't be a big decrease.

Another student completed two activity sheets and wrote:

First activity: I agree with Person D because they are right when they state their opinions. There is evidence to support this. The food web shows that the only thing that blue tits eat is the greenfly, which feeds on the rose, which has been infected. Second activity: I agree with Person D because lettuce is eaten by the second consumer, ending with the top consumer, the hawks. They do have other choices, but soon enough, other consumers will eat the other sources of energy.

The results show that her students were unsure which explanation was the best. However, it is noteworthy that they drew on their prior knowledge concerning the science content.

Similarly, in year two, the written work was obtained from ten pairs of students. Most of the groups engaged with explanations A and D gathered from ten groups on the first activity sheet. Most of the student groups engaged with explanations A and C, obtained from the six groups on the second activity sheet. For instance, one group of students wrote:

First activity sheet:

D: I think D is correct. It has explained it correctly because if roses die out, greenflies die out, and blue tits die too. The food web shows this.

A: It is not so good because it is not detailed, and if the roses die out, it won't affect the blue tits.

B: It is wrong because it is not its predator; the energy does not affect the reduction in the number of blue tits.

C: It is not wrong, but it is just not detailed.

Second activity sheet:

C: The fox will eat the dormouse so they would die out, and then there will be more barley.

A: It is wrong because hawks can eat chaffinches; rabbits do not affect it.

B: The fox will get affected because there will only be dormice, which they would finish, but then there will be more.

D: That is not true there would be less barley.

Overall, the student's written work suggests that the use of this argumentation activity provides an opportunity for her students to show their understanding of the topic and their ability to evaluate an argument in terms of its structure. In addition, it helped Mala follow her students' thinking and assess their learning better.

4.3.3.3 Comparison of the teachers' practices of the Food Chain lessons, and changes in their practice across two years

The practices from these lessons enabled me to compare teachers' practices and observe how they had changed a year later. The analysis of the lessons shows that the teachers incorporated scientific argumentation into their practices in a varied way in terms of managing the structure, the classroom, timing, approach, and pedagogy according to their own classes and experience.

Considering both teachers' lesson structure, Padma utilised small group discussions and argument evaluation, followed by whole-class discussions expressing students' choices and reasoning. In year two, she employed plenary discussion to model evaluating arguments and small group discussions. On the other hand, in both years, Mala used small group discussion followed by a whole-class discussion with the purpose of discussing and evaluating arguments as Padma did. In year two, she spent some time resolving the science content at the end of the.

Focusing on these same lessons by reviewing the profile of SAP reveals that both teachers employed a range of argumentation processes. In year one, both teachers encouraged their students to listen to each other and discuss matters that arose as a group. They encouraged strategies such as justifying with evidence, mainly with emphasis on providing evidence and arguing prompts. The findings show the teachers strongly encouraged their students to discuss the activity as a group and justify their arguments using evidence and evaluations in both years. They both used evaluation and opinion cards to help students develop their skills, although Mala was the only one to model how to use the cards in practice.

In year two, both teachers' argumentation pedagogy evolved in a varied manner regarding their emphasis on argumentation. Whereas Padma spent time modelling how to evaluate an argument through whole-class discussion. Mala used a plenary discussion after each small-group discussion to check her students' conceptual understanding and evaluated their arguments. A significant difference between the teachers' scientific argumentation instructions was that Mala stressed a variety of essential components of scientific argumentation, suggesting she had developed her pedagogy with regard to this approach. Overall, their class objectives briefly emphasised science content and developed students' reasoning skills and argumentation processes.

4.3.4 Comparison of the teachers' practices across two years

Differing from case 1, this case aims not only to compare the two science teachers' pedagogical practices and approaches to teaching science through scientific argumentation in two scientific contexts but also to identify pedagogical changes in their practices after gaining experiences.

This revealed that the teachers implemented scientific argumentation in a variety of ways across the two years, as there were considerably fewer differences between the teachers, including instructional focus and structure, timing, and student organisation and pedagogical development. A variety of argumentation processes informed the teachers' instructions, as shown in the SAP profiles. There are also indications that the teachers developed their scientific argumentation pedagogy and the organisation of students' groups from one year to the next. Additionally, the degree of change shown by each teacher demonstrates learning and signs of development. The case shows that their initial approach to implementing scientific argumentation did not fundamentally change; however, it was refined and evolved across the two years. Moreover, in both years, the teachers used instructional strategies (e.g., modelling, exemplification, prompt and evaluation cards, or sentence starters) to promote the goals of scientific argumentation. Teachers use of instructional supports (i.e. modelling around the use of evidence to justify claims) helped students engage with scientific argumentation (González-

Howard et al., 2017). In many ways, Mala's instruction included a clear focus on scientific argumentation, with a broad range of argumentation strategies, such as counter-argument and reflection.

Both teachers benefited from trying out various strategies for incorporating scientific argumentation into classroom practice as a way to determine what works and what does not for their students. I observed teachers considering their prior experiences and students as resources to plan their argumentation activities in year two. For instance, in year one, both teachers used envoys as a group strategy. However, a year later, they used a different group strategy reflecting their students' needs and ability to use argumentation.

With regard to the teachers' argumentation practice, their pre-existing teaching practice, values and understanding of science teaching through scientific argumentation greatly impacted their implementation of the lessons (Simon et al., 2006). In the case of Padma, she mainly focused on the importance of discussing and listening to others, justifying opinions, supporting with evidence and reasons, constructing and evaluating arguments through modelling and exemplification, and indicating implicit goals that suggested she valued, even more so in year two. Meanwhile, Mala mainly focused on the importance of discussing and listening to others, explaining the meaning of arguments through modelling and exemplification, positioning oneself within an argument and justifying one's position with supporting evidence and reasons, constructing, and evaluating arguments, anticipating counter-arguments, and reflecting on the argument process. These show the implicit goals she emphasised in terms of various aspects of scientific argumentation. Furthermore, the teachers felt that they had benefited from teaching the same lesson in different classrooms across the two years. As seen in the lesson planning meeting, both the teachers utilised their previous experience as resources to develop their pedagogy of scientific argumentation.

4.4 Case 3: One science teacher's implementation of the Zoo and the Leisure centre over a year

Unlike cases 1 and 2, the aim of this case was not only to compare Mala's instructional practices and approaches to implementing scientific argumentation within two SSI contexts, one at the beginning of the year and one at the end of the year (the Zoo activity, previously discussed in section 4.2.3.3; the Leisure centre, section 4.4.2) with the same students, but also to identify any changes in her facilitation and incorporation of scientific argumentation into her pedagogical practice, and indicate whether the pattern of change was the same over an academic year. In subsequent sections, the overall principles and procedures of lesson planning (section 4.4.1) and the results of the teacher's practice were again presented in terms of lesson structure and SAP. The second aim of this case, and most important, relates to how her students construct their written work in these lessons and the detectable changes in their written work over a year. Following the presentation of the results, a comparison of the two lessons and the student's written work reveals significant variations in emphasis and alterations to practice for her students.

4.4.1 Lesson planning process for Leisure Centre lesson

When looking for the overall changes in Mala's practice over an academic year, I focused on evidence of change in her pedagogy, practice, and her students' written work. The Leisure Centre activity was chosen as a basis for comparing the scientific argumentation implemented by Mala at the end of the academic year (see Appendix 8). I met with Mala to plan the activity in July 2019. The activity allowed students to engage in a SSI context about building a leisure centre in a nature reserve area. At the beginning of the meeting, I briefly outlined the initial purposes of the activity, which had similar objectives to the Zoo activity. In the suggested teaching sequence, the issue was described in a letter distributed to the students. The students were asked to argue for and against building a leisure centre in a nature reserve area in small groups and provide justifications for their point of view.

Firstly, Mala and I had a conversation about how to start the lesson. She considered her students' prior experiences with a leisure centre and nature reserve area. She suggested starting the lesson by talking about a leisure centre and a nature reserve area separately. This would allow her students who did not have any prior experiences with leisure centres and nature reserve areas to gain information about them to discuss the issue in small groups. Then, we had a conversation about how to utilise the argumentation activity and group the students for discussion. Mala referred to her experiences during the Zoo activity:

> I think when we did the zoo one, that worked quite well. At the start, I said write what you think about the issue. Then, I got them into groups as those role-playing groups, and then they can fill in this (the activity sheet) as a group (Mala, July 2019).

As seen in the extract above, her previous experiences and reflections on her practices had an influence on her lesson plan for this activity. The teacher decided to have a whole-class discussion not only to encourage students to share their ideas according to the roles they had taken but also to ask them about any change of mind they may have had after listening to others.

In summary, the teaching sequence was:

- Give some information about leisure centres and reserve areas.
- Ask students to write a letter about whether a leisure centre should be built in a nature reserve area.
- Organise students for the group discussion (role-play).
- Distribute the activity for group discussion and explain the task.
- Allow about 10 to 15 minutes for the group discussion.
- Finally, conduct a whole-class discussion, gather students' ideas according to their roles and ask students about any change of mind.

4.4.2 Mala's Leisure centre lesson

Figure 4.31 below details the lesson structure of Mala's practice throughout the lesson.

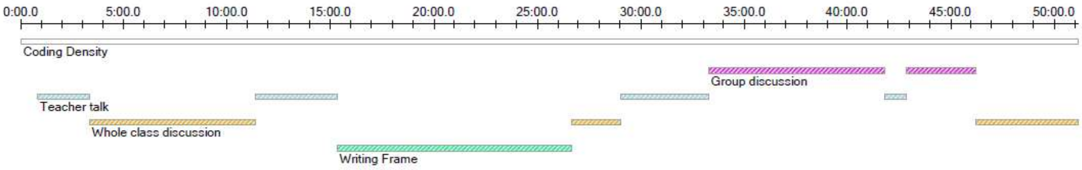

Figure 4.31 Phases of lesson structure for Mala's Leisure centre lesson in June 2019

As seen in Figure 4.31, the lesson structure for this lesson followed a similar pattern to her subsequent one, aside from applying a whole-class discussion at the beginning of the lesson to enable her students to understand the context. One difference between the two lessons is that she asked one of her students to share his letter with the class to evaluate his arguments.

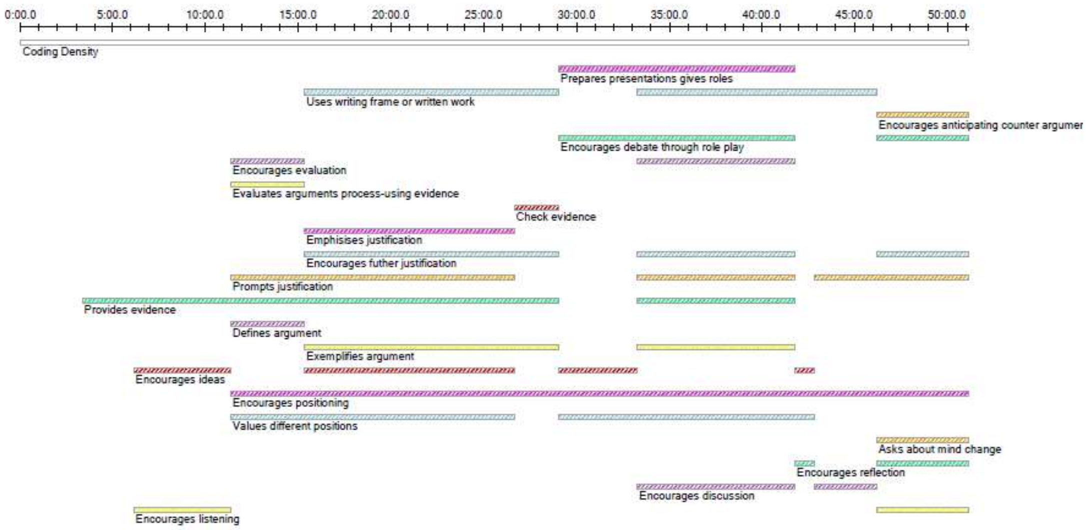

Figure 4.32 Phases of SAP for Mala's Leisure centre lesson in June 2019

Further investigation of the same lesson focusing on SAP is shown in Figure 4.32. Mala used a considerable variety of scientific argumentation processes and distributed them throughout the different phases of the lesson, i.e. small group and whole-class discussions.

A notable difference between the two lessons related to how she provided a general description of what a leisure centre and a nature reserve area are and what people do in both areas. This practice helped her students to effectively comprehend the content they were discussing. A further difference I observed is that she constantly highlighted her aim of providing evidence and reasons, effectively emphasising considering counter-arguments and the use of persuasive language (as discussed above in section 4.3.2.3). She expressed:

> I want you to tell me whether it (having a leisure centre in a nature reserve area) is a good or bad idea. You need to give me some reasons and evidence to support your argument. We know what a leisure centre is, what we can do, we know what a nature reserve is. Do you think it is a good idea to build a leisure centre in a nature reserve area? Just to remind you about the argument: you need a strong argument either for or against, a reason for your argument, evidence and facts. Also, use persuasive language to persuade others to your way of thinking.

First, her students were asked to write a letter about the issue being discussed. Letters were collected from all twenty-two students presented in the lesson. When given a free choice to choose their own positions, all the students approached this in the same way as they did in the Zoo activity, providing their own choice and the reasons for their choice. The individual written work produced by the students allowed Mala a window through which to evaluate their initial ideas about content, their ability to construct an argument, and support their argument. The majority of the students were able to choose a position regarding having a leisure centre in a nature reserve area and provide their reasons briefly accordingly. Considering the students' responses, fifteen were against, five of her students for, and one both for and against having a leisure centre in a nature reserve area. Only one student provided no reason to support his/her opinion.

Students provided a variety of reasons to support or justify their opinions. My focus was on capturing the students' reasons for and against having a leisure centre in a nature reserve area. Looking at the students' reasons, there was only one reason, entertainment; and they all provided this to support their opinions. For instance, Student 1 wrote:

> I say that I agree with your idea. As you see in a nature reserve, it is quiet and really nice. You sometimes have activities to do, but it would be nice to have a leisure centre in the middle of the reserve. So, if people want to swim or engage in a favourite activity, they can go to the building and have fun.

On the other hand, in particular, those who selected against the option varied in their views as a result of having discussed the context beforehand. Her students' reasons for not wanting to have a leisure centre in a nature reserve included the destruction of the environment (e.g., demolishing the environment / the reserve area / the wildlife), pollution (e.g., littering) and reducing the area of the nature reserve devoted to nature. Student 2 considered demolishing the environment and used structured scientific argumentation language, stating:

> I am against the idea of a leisure centre in a nature reserve area because a nature reserve is created for wildlife and plant life. If you do this, you would have to destroy a lot of nature. My evidence is that you need a lot of land on which to build a leisure centre. Nature reserves are for enjoying nature and can be placed to get away to, and to have a leisure centre there would ruin that. It also affects the animals and trees because if it was built, people would start littering, injuring the animals.

Another student offered further reasons to support his/her claims and even considered the counter-argument in his/her letter; he/she wrote:

> I am writing to tell you why your idea should not be acted on. First of all, your leisure centre would have a place where people eat, and there would be smoke coming out which is bad for the environment. Another problem is that people might take plastic with them and litter, which could harm the environment and the animals within it. Another reason is that to build it, there would need to be big trucks, and these might destroy habitat, and that might be bad for the animals. Some people might disagree with me, but a nature reserve is dedicated to animals, and the leisure centre could be built elsewhere.

Only one student expressed a mixture of opinions and reasons to support both sides, writing:

> Personally, I have mixed emotions about the idea. However, writing this letter may help me with a final decision. A reason as to why I believe it is not a good idea is because there are not many nature reserves to lose. It would mean there is one less nature reserve in England. However, if there was a leisure centre present, people

> could become more attached to the environment around it, which will bring it more attention. Not many people use their free time to explore nature; however, if there are activities within it, many more may come.

In conclusion, her students' written work shows, they wrote short letters and supported their ideas with just a few reasons. The main difference between the students' written work in the two lessons was that some of the students were observed using structured scientific argumentation language in their writing in the leisure centre lesson, demonstrating that they had developed their understanding of how to structure an argument.

A further difference between the two lessons is that in the Leisure centre lesson, Mala asked one of her students to share his letter with the class (see line 1) and then prompted her students to justify his opinions further (see line 3). After which, she and her students further evaluated his opinion concerning the issue (see line 5).

1	Mala	Student 1, can you read yours out? It was very good.
2	Student 1	In my opinion, I don't think we should build a leisure centre, because a nature reserve is an area reserved for animals and plants and other sorts of things. If we build a leisure centre on it, we will be destroying the natural environment. If we build a leisure centre, other people will want to build more buildings around it, which will then demolish the environment. Nothing will stay well.
3	Mala	Okay, excellent, and what was the other issue you were discussing? You are both opposed to what you were discussing.
4	Student 2	When they build it, some people might get plastic and might start littering. The animals will get ill from it and might die.
5	Mala	Excellent, so if people start using a leisure centre, they might start littering plastic, animals could get caught in this plastic. Why would you say that? What is the evidence for that? How do we know that animals can get caught in plastic? Where have you seen this?
6	Student 2	In documentaries and in oceans in real life, they are caught in plastic (inaudible comment).
7	Mala	So, he said documentaries where you see animals caught up in plastic, and sometimes you can see that in real life if

> you go to the park. You can see an animal caught up in plastic.

Similarly, in both lessons, Mala applied the same group strategy in the discussion phase. She distributed a template (see Appendix 9) for the group activity and requested that her students fill it out during the group discussion. Her students were observed, actively engaged in group discussions, listened to one another, and discussed the issue as a group. Mala devoted about the same amount of time to group discussions in both lessons.

During the small group discussions, Mala employed a variety of argumentation processes to encourage her students to discuss things as a group by considering their own roles and anticipating any counter-arguments. Another difference between the two lessons is that Mala encouraged her students to provide reasons for both viewpoints according to their roles taken in the leisure centre activity lessons. Her oral instructions placed even greater emphasis on the process of providing reasons to illustrate different perspectives:

> You need to take on the role of that particular group of people. You are going to fill in that sheet. The top box is the issue we are discussing. Suppose we should build a leisure centre on a nature reserve. In that case, you have two boxes on your sheet, this is really important and different to what we have done before, you have got two boxes on your sheet for and against, and ask these people what your arguments are for and against, and then in the bottom box, I want you to conclude. What is your conclusion? So, this time, you are not giving your opinion you are taking on the role that I have given you in the group. There is just one sheet, so place all of your opinions on that sheet.

A further difference in the leisure centre lesson is that Mala asked her students to reach a consensus and make a final decision about the issue, by considering their reasons both for and against.

At the end of the lesson, Mala employed a whole-class discussion, during which her students shared their final decision. This process helped her students consider the same issue from different perspectives and to discuss their counter-arguments. She also encouraged them to reflect on the process of what might alter their initial opinions. Mala included the idea that argumentation is a process in which you try to convince someone of a particular claim.

Even though Mala foregrounded this process in her instruction, she did not have sufficient time to ask her students whether they had changed their opinion after both the group and whole-class discussions. Therefore, we have no way of knowing the students' final opinions.

When looking at the reasons her students provided to support their opinions during group discussion, a wide range of reasons emerged on both sides, as Mala placed considerable emphasis on the process of providing reasons to support both arguments in the Leisure centre activity. Thus, her students' written work reflected this emphasis. For instance, one of the groups, whose role was bird watchers against building a leisure centre in a nature reserve area, discussed the issue from that perspective and provided reasons accordingly, which shows their written work was more comprehensive than in the Zoo activity. They wrote:

<table>
<tr><td colspan="2">The issue we are discussing is that the leisure centre should not be built because it would ruin birdwatching for everyone.</td></tr>
<tr><td>Arguments for</td><td>Arguments against</td></tr>
<tr><td>An argument for is that if birdwatchers get hungry, they have somewhere nearby where they can eat.
There is more food for the bird watchers to get so they can catch birds.</td><td>If it gets built, it would not be quiet or peaceful, which will scare the birds away.
Another reason against is that it might be built on some trees which might have some birds' nests.</td></tr>
<tr><td colspan="2">My conclusion is that the leisure centre should not be built because it would scare all the birds away and they might not have anywhere to live if their nests get destroyed. And the leisure centre could easily be built somewhere else.</td></tr>
</table>

As evident from their responses, her students provided a variety of different reasons from both sides to support their ideas, according to the role they had assumed. As seen in students' written work, some of the students attempted to structure scientific argumentation language specifically. Furthermore, Mala provided her students with some time to make their final decision by considering their reasoning from both sides.

4.4.3 Comparison of her students' individual and group written work in the Zoo and Leisure centre lessons

This section aims not only to show Mala's students' written work when engaging in both individual and group argumentation but also to compare their individual and group written work in both the Zoo and Leisure centre lessons over a year. Both lessons had the same aim: generate ideas for and against the issue being discussed and produce written work both independently and collaboratively. The individual written work produced prior to the group discussions reflects students' initial ideas and reasons for the issue. They were also asked to complete a group discussion and a writing task alongside both lessons. Thus, her students were provided with roughly the same amount of time to develop individual and collaborative written work.

Collecting the students' individual work at the beginning and end of the academic year allowed me to compare how they generated their written work. The main difference observed concerned the students' sophistication in constructing individual written work. The students only briefly provided their reasons due to the lack of experience and knowledge about the structure of argument in the Zoo lesson. In contrast, in the leisure centre lesson, some students utilised structured scientific argumentation language in their writing. The results show the majority of the students' work included their opinions and provided reasons for their claims to support their opinions in a more structured way within their individual writing with continuous instructional support (Ryu & Sandoval, 2012). Samples of two students' written work from both the Zoo and Leisure centre activities can be seen below.

Student 1:

The Zoo activity	The Leisure centre activity
I am pleased to answer your question about your valiant effort for this project. I am happy to say that I agree with this project. The reason for this is that it is great for society's education. This would be good for our education, for GCSE.	I am against the idea of a leisure centre in a nature reserve area because a nature reserve was made for wildlife and plant life. If you do this, you would have to destroy a lot of nature. My evidence is that you need a lot of

lands to build a leisure centre. This could lead to other people build buildings which will cause the environmental destruction of the nature reserve.

Student 2:

The Zoo activity

I agree that this Zoo should open and there are my reasons.

Firstly, it will attract children to learn about them and about their habitat, where and how they eat.

Secondly, if the zoo opens, we can save some endangered animals, and animals will be taken care of and fed.

The Leisure centre activity

I am pleased to tell you that a possible sitting of a leisure centre in a nature reserve is not a good idea. My reason for this is that nature is not man-made; therefore, it is also beautiful because the animals in the area will need to find a new home or be killed. Another reason is that trees are going to be cut down. Animals are going to be scared and run away. My last and final reason is that activities in a nature reserve area are different from a leisure centre and they both do different activities.

Organising groups with the same students in both lessons enabled me to compare students' collaborative written work. Regarding the students' sophistication in constructing written group work in both lessons, particularly in the Leisure centre activity, collaborative reasoning through group discussion encouraged her students to promote their thinking skills based on the roles taken. Moreover, Mala's emphasis on producing reasons from different perspectives encouraged her students to consider other opinions and produce a variety of reasons to support their opinions in the group work portion of the Leisure centre lesson. This indicated that collaboration between group members generates more complex arguments (Sampson & Clark, 2009) and facilitates reasoning from different perspectives.

A sample of Group 1's written work from both the Zoo and Leisure centre activities:

The issue we are discussing is that whether we should open up a zoo (somewhere)	
Arguments for	Arguments against
Protecting endangered species. People can look at animals in their spare time. It could help them increase their numbers. Children don't get to see an elephant walking on the road.	Too much noise at the night. Animals will not be happy. You are taking their home away from them. It is not a safe place to keep animals where people stay.
My conclusion is that We agree with making a zoo because it will help endangered species so people can look after them and the animals can give a good environment to people who are boarded.	

The issue we are discussing is that if we should build a leisure centre or not in a nature reserve.	
Arguments for	Arguments against
More people will come. We will get more money. If you get more money, then you could build more stuff.	It will stab animals. More pollution in the air pollution will kill animals. If we do lose a nature reserve, it can be rare. Birds will get scared and run away. Within a period of time there could be the extinction of animals. Flowers will die, then bees cannot get nectars and there will be no bees.
My conclusion is that we should not build a leisure centre because lots of animals can become extinct within a period of time. Pollution will increase as there will be fewer trees to take in carbon dioxide. We do lose a nature reserve.	

A sample of Group 3's written work from both the Zoo and Leisure centre activities:

The issue we are discussing is funding/opening a new zoo.	
Arguments for	Arguments against
	When we are studying about the animals in the zoo, we see that there is a problem with the animals. They do not like being trapped. They want to live in their natural habitat. We do not want them not to be happy and not to use their natural instinct.
My conclusion is	

The issue we are discussing is to build a leisure centre in a nature reserve.	
Arguments for	Arguments against
Bigger community. More access to the elderly. More money in the community.	Ruin the environment. Peace of the nature reserve will go. People would litter, and the animals would be affected. Once one building is built, lots of buildings are most likely to be built.
My conclusion is that overall, we think they should not build it as it will destroy our planet. There are so many leisure centres in the country that not many people come there so it would be a waste of money and space and will destroy nature and the world.	

When comparing individual and group performances in producing written work, the results indicated that the majority of individual work was simple and only consisted of sharing an opinion and offering a few reasons to support it. However, when in groups, her students had opportunities to share and listen to each other's ideas and reasons, which enabled them to generate a variety of reasons to support their opinions in both lessons. This shows that collaborative work develops students' points of view, allowing them to produce better-written work. Consequently, I can conclude that collaboration plays an important role in the construction of written work.

Therefore, group discussion activities need to be prioritised when teaching science and scientific argumentation.

Moreover, while the students demonstrated few changes to how they produced comprehensive written work and provided reasons, it is difficult to tell what other factors affected the production of the results, such as the nature of the argumentation task, the nature of the group-based task, or the nature of any SSI content. However, the results show that her students produced better-written work at the end of the academic year.

4.4.4 Comparison of the teacher's practices over an academic year

Differing from cases 1 and 2, this case aimed not only to compare Mala's instructional practices and approaches to implementing scientific argumentation within two SSI contexts, one at the beginning of the year and one at the end (the Zoo activity, previously discussed in section 4.3.2.3; the Leisure centre, section 4.5.1) with the same students, but also to identify changes in her pedagogy to facilitate and incorporate scientific argumentation into her practice, and to indicate whether the pattern of change was the same for SSI contexts across an academic year. A second, perhaps more significant, focus relates to how students' written work evolved over an academic year. The more emphasis on Mala's instructions aligns with previous scientific argumentation research, which has found it more structural (González-Howard et al., 2017; Jiménez-Aleixandre & Erduran, 2008; von Aufschnaiter et al., 2008). Better emphasis supported her students to produce a comprehensive written work. The argumentation approaches she developed were reflected in her emphasis on reasoning from opposition perspectives, counterargument, discussion, and reflection in both lessons, even more in the Leisure centre lesson. Her SAP profiles did not show her development from one lesson to another, but it emerged in her students' written work, as she made those objectives more explicit in the small group discussions.

In both lessons, she set up the group discussion activity as a role-play. By doing this, she encouraged them to anticipate counterarguments and argue from different perspectives. Between the Zoo and Leisure centre lessons, differences occurred; Mala introduced the aim of the lesson as ‘thinking of opinions’ in the zoo lesson, whereas in the leisure centre lesson, she focused on the process of producing a ‘strong’ argument with reasons and the use of ‘persuasive language’ to persuade others to one’s way of thinking. This helped her students consider alternative arguments and reflect on the argument process.

A further difference in the leisure centre lesson was that Mala asked one of her students to share his letter with the class. Also, she placed a greater emphasis on evaluations and the need of building on one another's ideas and arguments. Another critical difference between the two lessons is the focus placed by Mala on encouraging her students to provide reasons from two different perspectives in the Leisure centre lesson, using the assigning of roles.

Additionally, she implemented six argumentation activities over an academic year with this class (see Appendix 3). Her frequent implementation of this practice and her instructions (González-Howard et al., 2017) (e.g., whereby she encourages listening and discussion, prompt justification, constructing and evaluating argument, counterargument and reflection) for argument structure was reflected in how her students engaged with and participated in scientific argumentation more frequently, and the ways in which different rationales impacted on their engagement and their written work. The student's written work for each argumentation lesson reveals that their prior experiences with this practice were increasingly leveraged to support their capacity and engagement with this approach and the construction of their written work.

Overall, throughout this chapter, I have examined the processes by which science teachers develop their pedagogy of scientific argumentation by detailing the results. This chapter began by introducing the three science teachers' backgrounds, personal science learning goals, and initial beliefs about the value of teaching science through scientific argumentation (section 4.1.1). Later in the chapter, the findings from the three embedded cases, including the data from the overall principles and procedures of the lesson plans, the lesson practices and students’ written work, were presented. The first case compared the SAP for the three science teachers, as they had taught two argumentation activities within a scientific and a SSI context one year apart (section 4.2). The second case not only compared the SAP of two science teachers teaching the same two argumentation lessons but also emphasised the changes in their approach across two years (section 4.3). The third and final case focused on comparing the SAP of one science teacher when teaching this practice within the two SSI contexts to identify her changes in the pedagogy of scientific argumentation over a year (section 4.4). Following the presentation of the findings for each case, a comparison of the teachers' practice in each case revealed significant variations in emphasis and changes in practice. In the next chapter, I will evaluate how the teachers developed their agency and agentic practice over time. To accomplish that, I will utilise the concept of teacher agency as a lens for investigating science teachers' pedagogical development of scientific argumentation as they implement this new scientific practice in their practice.

Chapter 5: Supporting teacher agency in practice

This chapter aims to address RQ3 regarding how science teachers develop their agency and agentic practice while developing their pedagogy of scientific argumentation. To address this question, I used the concept of teacher agency as a lens for interpreting science teachers' pedagogical development in relation to scientific argumentation as a new scientific approach in their practice. I paid particular attention to both teachers' practice of scientific argumentation (as presented in chapter 4, sections 4.2, 4.3 and 4.4) and the teachers' reflective interviews on their practices. By examining reflective interview data and the teachers' practice through a lens of teacher agency, I identified 'instances of agency' as represented by a sense of purpose, mastery, autonomy to act, and reflexivity. I drew on studies by Pantić (2015) and van der Heijden et al. (2015), as well as King and Nomikou (2017), who applied the same frameworks to evaluate teachers' pedagogical development of scientific argumentation over time.

Additionally, I identified factors that seemed to either support or inhibit the development of agency. Before presenting the findings, I reiterate the concept of teacher agency in educational settings and further explain the rationale for my utilization of this concept as a lens in section 5.1. I then present instances of each component found within the data in section 5.2. Finally, in section 5.3, I identify factors derived from interview data that support/inhibit the development of agency in the practice of scientific argumentation.

5.1 Developing teacher agency in educational settings

This section reiterates the concept of teacher agency in educational settings and further explain four components of teacher agency. As previously discussed in chapter 2, section 2.5.2, the concept of teacher agency is recognised as a critical component of teachers' professional learning, suggesting that teacher agency is required to maintain a teacher's (re)construction of professional knowledge and practices (Jones & Charteris 2017; Lai et al., 2016; Oolbekkink-Marchand et al. 2017; Vähäsantanen et al. 2017). In recent years, this concept has been utilised to characterise and understand the components of teachers' activities in the context of educational reform (Buchanan, 2015; Eteläpelto et al., 2013; King & Nomikou, 2017; Pantić 2015; Rajala & Kumpulainen, 2017; van der Heijden et al. 2015; Vähäsantanen 2013). It also has been used to evaluate teachers' decision-making processes and their level of support for or opposition to educational reform initiatives (Sannino, 2010; Vähäsantanen, 2013). Thus, the degree to which teachers engage agency in their decision-making may make a significant impact on how (and if) the teacher implements practice in ways that directly support their students' engagement and learning. Buchanan (2015) likewise acknowledges the value of agency in influencing teachers' responses to reform initiatives, referring to the procedure by which teachers actively use their previous experiences and identities in carrying out their educational responsibilities as carving out agency

However, there is currently a lack of understanding of the nature of teacher agency and how it occurs in practice (Pantić, 2015). It is critical to identify key factors and those that support or prevent its implementation. This highlights the need of undertaking research on how agency might manifest itself in practice, how agency might evolve over time, which factors and instructional settings facilitate the development of agency. To address these points, my own study (which lasted two years) was designed to support teachers in developing their pedagogy of science teaching through scientific argumentation. As such, the objective of my own study is to examine teacher agency as a way of interpreting teachers' pedagogical development and also to get a better understanding of the development of a new pedagogy.

Moreover, determining the influence of teachers' personal backgrounds (e.g., beliefs and values) and dispositions on their agency is necessary to improve their agency and practice (Biesta et al., 2015; Bonner et al., 2020; Hadar & Benish-Weisman, 2019; van der Heijden et al. 2015; Tao & Gao, 2017). As such, variations of this phenomenon in practice cannot be understood without taking into account the personal/professional knowledge, belief, values, prior experiences, which shapes teachers' agentic practice in their own classrooms. These include the experiences that form teachers' professional beliefs, values, knowledge, and skills in their teaching and the structure and culture of schooling that provides space for teachers to develop and shape their agency in practice. I, therefore, placed great emphasis on the teachers' beliefs/values (as previously presented in chapter 4, section 4.1.1), as I examined their development of agency over time, taking Emirbayer and Mische's (1998) view that agency builds upon past achievements and patterns of actions/practice. From this point of view, the teachers' past patterns of agentic practice were critical in developing their agency.

As mentioned earlier, in my own study, I have drawn on the work of both Pantic (2015) and van der Heijden et al. (2015) to identify instances of agency in teachers' pedagogical development of scientific argumentation. Pantić (2015) suggested that agency can be identified by a sense of purpose, competence to accomplish that purpose, and some degree of autonomy to act. These three components enable a person to reflect on their actions and conceptualise possibilities for their improvement, thereby embracing the fourth aspect-reflexivity (Pantić, 2015). As such, I put forward, as does Pantić (2015), that teachers have the ability to make autonomous decisions about how they teach and manage their classrooms. Similarly, van der Heijden et al. (2015) identify similar components of agency, including mastery, risk-taking, reflection on practice, and being collaborative to explain agency in practice. Teachers also would be capable of identifying difficulties in their work, taking 'creative risks', and recognising the need for a remedy when they have mastery in connection with reflexivity (van der Heijden et al., 2015). These authors suggest that collegiality and working collaboratively in a work environment are necessary conditions to take risks and acknowledge that issues exist. Teacher agency is not a naturally occurring personal characteristic that teachers bring to their work, but a socially constructed attribute which is developed in the course of 'uncertainty, struggle, and conflict around professional-pedagogical practices' (Toom, Pyhältö, & Rust, 2015) and in the willingness to take risks and be open to giving and receiving support from others.

This chapter focuses on how (if at all) the participant teachers develop their agency while implementing the scientific argumentation approach in their practices. Through reflective interviews with the teachers following each argumentation lesson and at the end of the two years, the teachers' approaches to using these argumentation lessons, their implementation of argumentation processes, their scaffolding of argumentation pedagogy and the extent of their encouragement of students' practices were seen as indicators of how they emphasise teaching science through scientific argumentation. Previous literature on teacher agency has influenced my own study's rationale and conceptualisation of this concept, particularly the work of Pantić (2015) and van der Heijden et al. (2015). Taking these scholars' conceptualisations of teacher agency into account, I described teacher agency as consisting of four components: a teacher's sense of purpose (the belief that a particular practice is valuable in terms of achieving a specific outcome), mastery (understanding how to influence the desired outcome in practice), autonomy to act (ability to take risks and make a difference within a given context), and reflexivity (capacity to monitor, evaluate and change one's own practices). To identify a sense of purpose, I looked for instances of teacher commitment, motivation, belief, or value alignment with regard to the implementation of scientific argumentation in science teaching. For mastery, I looked for instances of teachers' competence and confidence in their use of the scientific argumentation pedagogy. I looked for instances of decision-making and risk-taking in their practice in order to determine autonomy to act. Finally, I identified instances in which the participant teachers engaged in their reflections on their practice to make appropriate changes for reflexivity. Instances of each component of agency are given based on the teachers' reflective interviews and practices in the three embedded cases (as presented in chapter 4). Given the dependent character of agency and its iterative development throughout time, the illustrative cases are not distinct but overlap. The results are discussed in terms of these four components of agency in the section below.

5.2 Developing agency in the pedagogy of scientific argumentation

This section addresses RQ3 regarding how science teachers develop agency and agentic practice while implementing the scientific argumentation approach over time. Throughout the two-year period, while all three teachers demonstrated some development in agency and agentic practice during their implementation of the scientific argumentation approach, some seemed to develop more agentic practice than others. As shown by my observation of the argumentation lessons, Ray implemented a few argumentation lessons in his classes. Therefore, he provided only a few examples of the developed agency during this study. Mala and Padma provided various instances of developed agency in terms of the four components of agency. I was able to identify instances in which all the teachers seemed to be using the argumentation approach flexibly and critically in their practice, motivated by their belief about the value of incorporating this approach into their practice, newly developed confidence and autonomy to act.

While analysing these findings, I also explored the following questions derived from my observations: Do science teachers working collaboratively in the same science department make different or similar agentic decisions in similar circumstances? Do science teachers develop their agency in similar or different manners? Is there a shift in the development of scientific argumentation pedagogy and the nature of their agentic practice over time? Examining these questions was necessary to identify differences in the teachers' development of agency and agentic practice in scientific argumentation.

5.2.1 A sense of purpose

With regard to this component of agency, there is a need to focus on how science teachers engage in their intended purposes, which they know or believe will result in a particular quality or outcome in practice. To determine this component, I identified instances of teachers' purpose, motivation, and commitment towards utilising the argumentation approach in their practice for their own and students' development and how teaching science through scientific argumentation meets their beliefs about the values of science teaching. The data from the lesson observations (as previously presented in chapter 4) reveal considerable variations in how the three teachers used and scaffolded the argumentation approach in their practice. Additionally, in relation to their implementation of the argumentation lessons, all three teachers showed signs of developing a sense of purpose in their endeavours closely linked to their beliefs, emphasis on teaching science, and prior experiences of teaching science using the argumentation approach.

At the beginning of this study, none of the participant teachers had prior experience teaching science through scientific argumentation. However, as outlined in section 4.1.1, all three teachers pointed out that teaching science through scientific argumentation was a critical and valuable way to improve students' understanding of science and to discover students' misconceptions about science contexts. Throughout this study, the three teachers kept their students' needs in mind while planning and implementing the argumentation lessons. They used various alternative instructions and objectives of the argumentation approach in their practice, which indicates that they each individually had a sense of purpose and made their own decisions regarding their pedagogical approach that would best meet their students' needs.

The analysis of data derived from the teachers' practices and reflective interviews following each argumentation lesson reveals the teachers' diverse purposes and different displays of developing agency in the same situation. The ways in which the teachers developed agency in the component of purpose depended on how keen they were about using this approach in their practice. For instance, case 1 showed how the teachers varied in their decision to implement scientific argumentation within a scientific and SSI context (as presented in chapter 4, section 4.2). Ray spoke his efforts to provide explanations to resolve his students' conceptual understandings in the science context. This reveals that his purpose centred on providing established knowledge in the scientific context through a teacher-centred approach rather than engaging with the argumentation approach. Padma and Mala, on the other hand, prioritised giving support to encourage their students' discussions and justification in argumentation. Additionally, Mala focused on supporting her students' evaluation of each other responses during small group discussions.

The extracts below from Ray, Mala and Padma’s reflective interviews show how they implemented the same argumentation lesson in different ways that reflected their main purposes. Ray said:

> I tried to help them (students) figure out the correct answers and then gave some explanations on the right answers. I was trying to guide them towards the correct answer by asking questions and getting them to draw from their experience to answer the questions rather than to say no (Ray, December 2017).

In contrast, Mala stated:

> The way I did was they had to write their justification for each one (statement), and then they moved around to see if they agreed with other groups’ works. If they were telling me, ‘We think this because this and it was right’. I was trying to get them to justify why they think it is right scientifically. My scientific questions were slightly different as I was not trying to tease out the correct answer. I was trying to get them to explain why they think that answer is right scientifically (Mala, December 2017).

Similarly, Padma said:

> I was trying to get them to justify what they were saying, and I just let them have a bit of discussion (Padma, December 2017).

As evident from the extracts above, although the teachers were responding to a similar situation, their practice was based on their purpose for teaching science through scientific argumentation. Additionally, the teachers’ different practices can be understood within the context of their own teaching approaches. The observational data and interview extracts show that the teachers define their purposes as part of their agentic practice in individualised ways when confronted with different pedagogical approaches.

When all three teachers were asked their purpose for incorporating group discussions into argumentation lessons, they said that having group discussions in argumentation lessons was important to encourage students to share their ideas and learn from their peers, as well as help teachers identify misconceptions held by students. When I asked the main purposes of using group discussions in their lessons, the teachers' responses helped me understand the diversity of their purposes and why group work was not implemented widely or consistently. In the second year of this study, in the last interview, Mala commented that:

> I am thinking of using group work in nearly all my lessons. They (students) work with somebody else, which is basically with the person next to them. That helps teachers a lot as well because sometimes students can help each other. While you get around, you can learn more about students' understandings and misconceptions about the topics (Mala, July 2019).

However, it is interesting to note that Ray raised some concerns regarding using group discussions in his lessons. Early on in his teaching experience, he found that group work was insufficient for students' learning and problematised classroom management. In his last interview, he stated:

> I do not do a lot of group work in my lessons. When it comes to doing group work, it tends to be more practical based on equipment, rather than out of a desire for them to be working together. I have phased out a little bit because it's been more effective to get them to be working independently rather than with each other. It can be relatively inefficient and more challenging to monitor the classroom as a teacher in terms of behaviour as well (Ray, July 2019).

All three teachers reported having difficulty implementing group strategies effectively in their lessons. Padma experienced some behavioural issues and was forced to change her plans. The teachers mentioned that they preferred to use group discussions with students that they felt better able to manage. The observational data shows that Mala was the only one who experimented with various group strategies in her lessons because her purposes when giving the lesson were different, as illustrated by her practice in each case, she developed a sense of purpose.

Throughout this study, when explaining how and when they incorporated the argumentation approaches into science lessons, all three teachers stated that they used argumentation lessons to review science topics and assess students' understanding of them. For example, in one of her reflective interviews, Padma commented:

> For argumentation lessons, my purpose was to get them to follow through with their ideas; they've already gone through the topic. My purpose was to recap and develop

> their ideas and skills, assess their understandings and correct their misconceptions (Padma, May 2018).

This purpose the teachers hold encouraged them to use argumentation lessons at the end of the science topics being taught to assess their students' understanding and correct their misconceptions about it. Later on, Mala mentioned how motivated she became about using this approach in her lessons to assess students' understanding of topics. This exemplifies how Mala's 'revision' purpose developed as part of her developing agency, as the following comment demonstrates:

> We did a formative assessment with Y7, we gave them a scenario, and they had to write it down. I think this is a nicer way to do it because you can collect their sheets afterwards and look at what has been said. As teachers, you can go around and observe the students who are having good conversations and the students who struggle and need support. So, it is a nice way of assessing them without telling them that you are assessing them. I think it's a good way of checking their understanding as well (Mala, July 2019).

Mala also expressed a desire to include more argumentation approaches and activities into her practice, which encouraged her to take the initiative to speak with the head of the science department about using this approach to assess students' understanding, thereby potentially widening its use and impact.

When Padma and Mala were asked their purpose for incorporating whole-class discussions into argumentation lessons, they actively evaluated and interpreted their purpose of using whole-class discussions in different ways. Padma said:

> I think stopping them and going through their answers with more detail would be more beneficial during the whole-class discussion if I taught them the first lesson. I think that if this fell in the scheme of work and I had to make sure they fully understood it before moving on, and then I would stop them and maybe correct those who had misunderstood. I think my purpose and my outcome for this was to get them into a discussion without stopping them for whole-class discussion and that as long as they were discussing it and listening to each other (Padma, June 2018).

Mala said:

> The reason I stopped them after the first sheet was to hear class feedback. I think it was mainly to see whether they (students) were following what I told them to do, were they using the right language? or did they reckon their ideas using the food web? and did they have the right ideas? And also, to sort of help the students who were struggling because perhaps hearing what other groups were doing rather than having it come from the teacher to hear, the more confident students could help them or make them feel more confident. Without you having to go to every pair and make sure they are on the right track. I think that's the only reason I stopped them and had a whole-class discussion (Mala, June 2018).

While observing Padma and Mala during this study, I noticed that Mala consistently applied whole-class discussion throughout and at the end of each lesson to check her students' understanding and support their argumentation skills, illustrating her specific purpose. On the other hand, Padma only applied whole-class discussions to explain either science content or the argumentation approach. This shows that the two teachers made different decisions in similar situations according to their sense of purpose.

All three teachers identified what they perceived to be a pedagogical deficiency when supporting their students in discussions and writing. This concern influenced their purpose and their agentic practice. Padma, for instance, observed students in her class who were less able to use scientific language to explain their opinions than others. This made her question her practice:

> Is the purpose making them (students) use more scientific language? Or is it just to aid their writing? Because if it is to help their writing, we may have written something simpler that they would use. Whereas if you want them to use more scientific language, then they have access to those words. So, for example, for some of them, they will never use the word disagree or agree. They might use the word agree, but they will never use the word disagree. They will say I think they are wrong. They do not fully understand how it (scientific argumentation) fits into their thinking (Padma, May 2019).

Mala highlighted the same point in one of her interviews:

> They (students) can use scientific language in their oral discussions. It is not easy for them to use this kind of scientific language in their written arguments. I think that

> is something I need to work on because I believe writing is challenging - you know the language could improve easily (Mala, June 2019).

Finally, I could see from the data that the teachers' purposes usually depended on how keen they were to utilise the argumentation approach in their classrooms and how they perceived their own pedagogical development, indicating their development of purpose in their own learning. The results also show the teachers constructed their own argumentation pedagogy to fit their individual purposes. Some empirical studies (Priestley et al., 2012) support the idea that teacher agency develops as a result of the way teachers make pedagogical decisions and implement them in their practice. The teachers in my own study developed agency in the practice of scientific argumentation by making pedagogical decisions about what and how to engage in scientific argumentation and acted with varying degrees of engagement to shape their own professional approach in their practice (Billett, 2006). Moreover, the teachers actively sought out opportunities for professional learning in light of changing situations that influenced their pedagogical practices and their own purposes about their practice for argumentation lessons.

5.2.2 Mastery

Regarding the mastery component of agency, I identified teachers' demonstrations of competence and confidence in their use of scientific argumentation pedagogy, such as a) their knowledge of scientific argumentation in a variety of contexts, b) confidence using and adapting this approach in their practice, and c) changes in their practice over a period of time. Increased mastery was apparent in how the teachers evolved their pedagogy of scientific argumentation and assumed a greater level of competence in their practice as a result of experience (van der Heijden et al., 2015). Such mastery extends beyond pedagogical knowledge and is consistent with what Pantić and Florian (2015) refer to as 'core expertise - the knowing, doing, and believing' (p. 340) incorporates in an inclusive educational approach.

After gaining pedagogical knowledge and experience in teaching science through scientific argumentation in different contexts, within both a scientific and SSI context (as presented in case 1, in section 4.2), all three teachers concluded that scientific argumentation would be a suitable approach to teaching SSI topics in science and argumentation activities can be used at the conclusion of teaching scientific context to assess students' understanding. Ray, for instance, commented that:

> The zoo was more the ethical kind of scenario. That was more looking at arguments from two sides of a situation and thinking about it in more depth, which can be a bit easier to do, and more students can do it. They already had an idea and knowledge about the situation. There was not too much scientific knowledge needed to answer the problem - if you are trying to decide which explanation is correct or incorrect. If you do not have solid knowledge, you can't do that. I think this is better than with a scientific topic (Ray, October 2018).

At the end of the second year, Ray once again touched on utilising the argumentation approach related to the SSI context with the younger age group and the scientific context with the older age group. This illustrates both his mastery and his reflexivity: it shows how his experiences with different argumentation activities affected the implementation of this approach in his practice, as the following comment illustrates:

> I think the Dropping a box lesson last year was more useful for older students studying this subject in depth. They have better subject knowledge which they used as a way for them to go through that. They can provide reasoning based on statements, explain why that one is right, why that one is wrong scientifically. These would be the better activities for students with more knowledge. For younger students, it would be associated with socio-scientific issues. I think this is more achievable and probably a better source of context for Y7 (Ray, July 2019).

Ray developed his skills in a slightly different way than the other two teachers. Mala and Padma felt that SSI context topics would be more accessible for students who struggle academically in a science class due to lack of background knowledge or a language barrier. However, they both thought it an ideal approach in both scientific and SSI contexts providing that the activity was chosen according to the student's level of understanding, indicating that they were open to using the argumentation approach in any context with students and developed their mastery.

All three teachers also identified their weaknesses when planning their lesson and instructions that would allow all students to access the activities and the language used in their lessons. On this account, Mala, in particular, focused explicitly on language to support her students' development of argumentation skills and better scaffold this process. Additionally, the teachers tried to enhance their pedagogical knowledge of scientific argumentation through the planning and implementation of the argumentation lessons. The lesson plans and the implementation of their lessons varied most notably in the second year of this study, illustrating increased mastery. Mala said:

> I have concerns only in the way I am planning it. I need to consider more things. As I do more argumentation lessons, more things come to me. Maybe I should have thought about the language I am using. I do not think it's difficult for them if it is planned well and planned to a level for them all to access, which we do in our lessons anyway. We try to make them accessible to all students to scaffold and differentiate (Mala, October 2018).

Although Mala and Padma had more experience with scientific argumentation than Ray, they developed their mastery at a different level (as presented in case 2, section 4.3). In the first year, they felt that the planning stage should be more structured to help them make better decisions, and the implementation stage could be more flexible to assist them in developing their practice. Both Mala and Padma commented that they should use scientific argumentation more often in their teaching with a greater range of topics. Mala stated:

> I need to consider my class and look more at the teaching strategies that I use and not see an argumentation lesson as something separate or something different. Instead of planning an argumentation as a stand-alone lesson, it should just be, here is my scheme of work; I am going to fit argumentation in there (Mala, April 2018).

Padma said:

> I think the argumentation lessons are so different and so novel even though it fits in a range of topics. I think I will try to use this approach outside of the argumentation

> lessons, then it would not be so much of a surprise, and it will be helpful to students as well in their writing (Padma, May 2018).

In the second year, they started planning to incorporate scientific argumentation into their scheme of work instead of approaching it as a separate lesson. They were observed using their previous experiences to further their understanding of scientific argumentation, thereby developing their agency. This experience increased their confidence in their practice. Their confidence increased when they demonstrated ownership of the argumentation pedagogy in their practice. As Mala said:

> I am getting more comfortable with it; I think I understand that it doesn’t need to be a big stand-alone lesson; it can just fit into my normal lesson plan. So in that way, I feel like I understand it more and enjoy it more, and I think it will help with future planning, as a tool, so we can have lessons like that where it doesn’t have to take the whole lesson (Mala, June 2019).

Padma told me:

> In the beginning, it was a lot more about the activity itself, whereas now it is more about the students and what they’re doing and what they are thinking. This is what I think that has been the biggest change from the beginning. I thought it was the activity that was bringing about the argumentation. Whereas the activity is a big part of it, but it’s also how you manage that in a classroom and whether your plan allows them to discuss it with each other (Padma, June 2019).

The above statements indicate that these two teachers had come to see that their own experiences were valuable when making more appropriate decisions, which shows that they were open to engaging with argumentation in a meaningful way. The final parts of their reflections suggest that they further considered how to incorporate scientific argumentation into their own teaching approach, which illustrates how they increased their confidence as part of their developing agency in their pedagogy of scientific argumentation.

As they gained more experience using scientific argumentation in their practice, Padma and Mala made better constructive decisions about organising their students for group discussion, structuring their lessons, and scaffolding argumentation processes. This shows that these two teachers developed mastery as part of their increasing agency in their practice; they demonstrated different practices concerning the argumentation approach in terms of their own understanding and knowledge of argumentation across the two years. Mala, for instance, experimented with a diverse group of strategies to support her students' engagement in discussions and scientific argumentation. During her reflective interview, she evaluated her practice of assisting students in their argumentation skills, demonstrating how she expanded her knowledge and her perceived competence and mastery, as the following comment illustrates:

> I had an idea in my mind of what I wanted them (students) to do. For example, if this group thought the statement was true and another group thought it was false, I wanted them to see the other groups' reasoning and change their minds by providing reasoning and evidence. I also wanted them to decide if the argument was correct for you to be persuaded. So, that was the purpose of sharing. If you did that, you, as the teacher, go around and check who is true and who is false and then merge those pairs with conflicting pairs. If a lot of them agree with the same thing, but pairs together have different reasons and arguments to support the same conclusion (Mala, May 2019).

The data of case 2 (previously presented in section 4.3) reveals that having sustained practice with argumentation helped Padma and Mala make more effective decisions and thereby developing their mastery in their practice. Additionally, as presented in case 3 (see section 4.4), Mala made similar agentic decisions in her endeavours in the argumentation lessons, which were more closely linked to her increasing competency, having had prior experience in argumentation practice, and her overall development of agency, which was an indicator of one aspect of competence in the pedagogy of argumentation. Moreover, both Padma and Mala also reflected that they needed to work more on the language of argumentation that they used and use this same language more often in their instructions. Padma, for instance, felt that there were still some areas that needed to be improved with sustained and regular practice, which shows that she realised that she needed more time and practice to make changes in her pedagogy. Padma showed criticality when she stated that, although she was feeling more confident and masterful, she could still do more:

> I think I get it, but there is still room for some more improvement. I feel like there have been some lessons where it has just been, yes, that was good argumentation.

> I think I need to be a bit more consistent. My pace and timing are still my concerns. I think I often get involved in helping them (students) with what they are doing. I think it needs to be hands-off, and I need to know better what is happening and when. I think the pace was one of my targets for this year, on which I am working by using more timers. So, that is getting better. I still need improvements to be consistent (Padma, June 2019).

Throughout this study, Mala, for instance, employed a comprehensive range of scaffolding argumentation processes in her interactions with her students, which indicates that she understood how argumentation could be encouraged in both group and whole-class discussions. This suggests that her evaluation and interpretation of her own practice supported her agency and confidence in her implementation of argumentation pedagogy. The clearest examples of the teachers viewing themselves as capable individuals and highly reflexive ones occurred during the later stages of this study, as Mala confirms:

> I think it is much easier now. I feel more confident. This is the activity that I know works, like with the group activity. When we were doing the zoo, most groups really got into it. Even the quiet ones think about it. So, I know this will work. And actually, planning was quick. I think I still need to work on - a little bit more - the language of argumentation. I think spending more time on it would be good; getting more skilled on that like this is evidence because studies show it. I think I should have perhaps reminded them of the language. I should have done an example on the board and given my reasons and why and given evidence: they know, 'OK, I need to do this. I think just in general, like teaching across the year, if I used argumentation within my lessons more frequently, they would have built up more (Mala, July 2019).

In the final interview with Mala, she described how her teaching style had changed during this study. Her description implies that she had gained mastery in her practice. She highlighted how the scientific argumentation approach helped her advance her own pedagogical learning and her mastery, stating:

> It (scientific argumentation) has helped me to think more about being a scientist, how to express our ideas, how to change opinions, how to explain to students why something is wrong. It has given me a whole other tool to use in planning and it's made me think a lot more about what students think and how something might come across to them. It has made me want to find out students' ideas as well with these

> questions. Whereas before, it was probably just-- I had an idea about misconceptions, obviously, but it was like, 'I need to teach them this', but I need to let them express their ideas as well (Mala, July 2019).

The above extracts show how Mala made changes in her own pedagogy of teaching science by considering her students to a greater extent when planning and implementing the science lessons. This illustrates how Mala developed a sense of mastery as part of developing agency in her practice.

Several issues emerged that had an impact on the teachers' development of mastery as a component of agency. All three teachers emphasised how to organise student's groups effectively so that all students contribute and work well, and balance talking and writing during group discussion in argumentation lessons. This balance was described as a tension between the drive to enhance students' thinking, reasoning, and discussion versus the value of writing as a way of expressing and documenting students' understanding and thinking process. In addition, all three teachers considered scientific argumentation to be a challenging approach for less capable and uninterested students, which affected their confidence while implementing scientific argumentation in what both teachers perceived to be less controlled and structured classrooms that had behaviour management issues. Ray said:

> The behaviour of the class has a big impact on how and where it goes. If the class is good, well-behaved, follows instructions well, and stays focused, then that is quite useful. But a number of students have difficulty in doing that. Group work is challenging; it's a bit tricky for the argumentation lessons because it relies on the students staying focused on the work; they have to hear the conversation about what they are supposed to be doing. So, for me, along with Y7's level of less subject knowledge, those are the two main barriers to effectively implementing the lessons from the ideas plan (Ray, July 2019).

Additionally, Ray was concerned that the argumentation approach might not be as effective with younger students because of their lack of background knowledge and their lack of ability to focus on tasks. Ray said:

> There can be a more structured lesson and less discussion time if they stay focused. Time could be wasted quite easily, and if you are going around each group, having a little discussion with them which is necessary because you don't know what each

> group is discussing and talking about. So, in general, I think it's the behaviour: how much they are concentrating, how much knowledge they have. Y9 would do the task quite well. Generally, they stay focused on the topic and their work, less waste of time in those lessons, you can get deeper arguments, explain every single thing, and elaborate the situation (Ray, July 2019).

As seen in the extracts above, Ray's unfavourable experiences with his students affected his use of this approach in his practice. This also influenced his mastery.

Moreover, all three teachers expressed concerns regarding how frequently they should implement this approach in their lessons, as well as which science contexts from the scheme of work should be chosen for argumentation lessons, and how to effectively utilise 50 minutes of the whole lesson. These constraints informed and shaped the teachers' agency when they felt a sense of incompetence. Mala, for instance, remarked:

> Especially with the argumentation lessons, it is essential to choose the topic from the scheme of work. There's an hour lesson: how much can we fit in an hour? It's a shame we don't have two-hour slots with them. Last year I saw Y7 classes once a week for two hours, so doing something like this in a two-hour lesson would be much better. You could really spend a lot of time on it and do mini activities first to get them used to it, then the main and then there would be time for feedback (Mala, July 2019).

Notably, Mala and Padma remained committed to this study, indicating their intent to enhance their knowledge and understandings of this approach and achieve a higher level of mastery in their work. Significantly, as van der Heijden et al. (2015) stated, when teachers commit to an approach or perceive its benefits, they engage with it, and as a consequence, their mastery is most likely to develop. Mala and Padma, and to a lesser extent Ray, were observed engaging with this practice in their lessons and developed their mastery to some extent during this study.

5.2.3 Autonomy to act

For this component of agency, I collated instances of decision-making and risk-taking to ascertain the participant teachers' autonomy to act, such as their willingness to make decisions, take risks, and make changes in their practice over a period of time. As previously mentioned, all three participant teachers had had no previous experience with the scientific argumentation approach in their practice. Thus, by volunteering to participate in this study and trying to use it in their practices, they demonstrated autonomy to act as a component of agency from the very beginning. They engaged with this strategy and took responsibility for all decision-making associated with this approach while planning to introduce argumentation more and more in their lessons. However, not all three of the teachers engaged with this approach to the same extent.

As mentioned previously, all three teachers were willing to make decisions and take risks using this new approach in their teaching from the very beginning. While showing agency through their willingness to make decisions, take risks, and engage in continuous reflective learning, the teachers exhibited their engagement in a variety of practices related to the argumentation approach to enhance their own professional learning. When planning the first activity, all three teachers attempted to follow the suggested instructions given in the IDEAS pack resource, which indicates that they had a limited agency to make decisions for their practice. Later on, as presented in case 2, Padma and Mala were willing to make their own plan for their lessons and try different group strategies as they attempted to make decisions, which is an indicator of developing autonomy to act. Not all their decisions worked well. For example, one of the group strategies that they implemented in the classroom, the envoys, did not work out and was deemed unsuitable for Y7 students as it was not accessible to all students and was too challenging for them. As seen from both Padma and Mala' comments below, in response to the strategy of using envoys, they suggested that the group strategy and instructions should have been presented in a way that was simpler to understand and follow during the group discussion, illustrating their autonomy in suggesting adaptation to an action. Padma said:

> I like envoys; I just think it depends on the students and how confident they are at sharing with the other groups. The confident ones will just stand there and tell them the whole story. They fully explained what they were talking about. But others just took their sheet with them (Padma, May 2018).

Mala said:

> When I tried the envoy, I wouldn't say I liked that; I think with Y7 students, they are too busy trying to figure out who the scriber is, who the envoy is, and which way they will move around. They are just not paying attention to the task because it is too much information for them. Older students can deal with that. But I feel like when I said you could do this in pairs, it was easier, they know the person sitting next to them is going to work with them- I think if you are going to have a bigger group it needs to be quite simple instructions like you are a group of this, this is your role, rather than saying you're going to write then you're going to move around - is too much (Mala, April 2018).

These experiences enabled the teachers to seek and seize opportunities to experiment with and create "rich and meaningful educational experiences for their students" (Priestley et al., 2012, p. 210) to help them engage more in this practice showing a degree of autonomy in their action. Later on, Mala touched on the same point in her interview. She showed her autonomy to act when she mentioned that this strategy differed from her own teaching pedagogy; therefore, her students were not familiar with it. She reasoned that if she used similar strategies in her classroom more often, her students might benefit from group discussions. This shows that both Padma and Mala were willing to make decisions that they felt allowed them to manage their practice. Padma and Mala, particularly Mala, considered alternative group strategies when their students did not actively engage in the argumentation lesson. This shows their autonomy to adapt their actions, based on past teaching experience, to get their students on board with the argumentation task, sustain group discussion, and enhance their students' argumentation skills. This also shows that the teachers continued to make decisions on their pedagogical practice of scientific argumentation (Priestley et al., 2013).

van der Heijden et al. (2015) state that increased agency in acting with autonomy is associated with risk-taking. At the beginning of this study, Mala was the only one who wanted to try different group strategies in her practice. As previously presented in case 3, Mala took risks when she used role-play as a group strategy in her practice, which indicates that she made decisions by considering alternatives and taking risks, showing her autonomy to act and developing their agency. Throughout this study, Mala used various group strategies in her lessons and was willing to incorporate this approach in her instructions, thereby demonstrating a high degree of autonomy in her actions. Mala said:

> It is such a shame; I feel like I wish we could have done just some more lessons around it. I know it is impossible with everything, but it would have been nice to do it (scientific argumentation) a little bit more (Mala, June 2018).

Padma and Mala's sustained dedication to improving their pedagogy of teaching argumentation, making autonomous decisions, and facing risks was an indicator of developing autonomy to act, as reflected in their practice during the two-year period.

5.2.4 Reflexivity

I identified instances as reflexivity where the teachers participated in practice, reflected on practice, and implemented changes as a result of having reflected on practice. Larrivee (2000) suggests that reflective practice requires teachers to engage in thoughtful thinking and regular self-reflection. The purpose of reflection is to help teachers become aware of their own assumptions, values, and practices and how these impact on their decisions, practice and pedagogical outcomes. The design of this study included collaborative lesson planning meetings in which the participant teachers discussed how to incorporate scientific argumentation approaches into their practice. Following each argumentation lesson, the teachers participated in individual reflective interviews on their practice. Consequently, reflection was fostered, and instances of reflexivity were seen across all data sets as a consequence of this approach. During this study, all three teachers reflected on their practice of scientific argumentation and made subsequent changes to their practice in the following areas: argumentation activities within the scientific and socio-scientific contexts; concerns about students' background knowledge and prior experiences and engagements with scientific argumentation; scaffolding this approach; their lesson plans and teaching approaches; introducing argument and argumentation; organising student groups; classroom management; time management; and, science curriculum. All three teachers developed a degree of reflexivity in their practice.

All three teachers agreed that participating in discussions on how to plan the next lesson helped them build their understanding of scientific argumentation. The discussions included planning the lesson from start to end, discussing how to guide students' argumentation, what argumentation skills would be taught and what kind of resources would be used. In particular, they reflected on their past and current teaching practice, paying attention to how to incorporate argumentation approaches into their usual teaching practice. Padma spoke about what had prompted her to change her practice:

> I think I learned that I should not make it (argumentation) overly complicated, not be overwhelmed with the instructions I am giving. I need to have shorter times for them to do things. Just like how I do in normal teaching. The main thing that I have learned is that I should not have put the argumentation lessons on this separate pedestal from my normal way of teaching. So, I don't suddenly start teaching differently (Padma, June 2019).

All three teachers emphasised the importance of considering self-reflection in their practice after each argumentation lesson to get more engagement with this practice, which perhaps facilitated their reflexivity, as the following comment illustrates:

> I think I thought about it more, like what is a good argument in science because we don't really think about it daily. We just teach it as a very narrow view sometimes. You don't think actually outside the box. It (scientific argumentation) gives you a wider view and makes you think. It gives students a chance to improve their skills and express themselves when we ask them why. I think it did prompt me to think about science as a bigger thing other than just a topic I'm teaching (Mala, July 2019).

Additionally, all three teachers reflected post-practice on a need to reconsider the instructions that they gave out to the students, which should be simple and accessible for all students. On the basis of their experiences, they believed that argumentation lessons should be more structured and include differentiated resources for students who are less interested in science. They reflected on the best way to organise their students for group discussion, paying attention to their students' engagement, interaction with one another, and responses to their instructions in the argumentation lessons. All three teachers identified concerns about how their students had responded to the group discussions and how they handled expressing their opinions with others. Mala commented:

> For that (scientific argumentation) activity, we did get them into groups of four or five, which may have been too big because we had some pupils who just did not say anything. I think sometimes those that are more confident take responsibility. Others are just going along with whatever they say. Like they say, 'What do you think?' and 'Yeah, I agree with them!'. Do you really or are you just (saying that) because you are not confident that you can voice your opinion?. We need to tell them that, show them that is ok. That is what we want you to do rather than just agree with the majority. If we give them a role, like students know exactly what they need to do, they can voice their opinions (Mala, December 2017).

Their reflections on what actually happened in the classroom helped them come up with alternative ideas for implementation in future argumentation lessons, such as organising students into smaller groups, empowering them to participate in group discussions, modelling this participation process and encouraging them to voice their opinions. This illustrates their degree of reflexivity on their actions.

All three teachers emphasised the value of sustained practice, especially Padma and Mala, and the importance of devoting more time to thinking about argumentation and its impact on the students' abilities and science learning. Instead of spending time coming up with new argumentation activities, the teachers were observed spending time adapting existing activities to their own classes. This indicates that, after having some experience of scientific argumentation, the teachers were able to reflect upon their practice, their students' dynamic, their students' background knowledge and their pedagogical approaches, indicating that they had developed reflexivity to enhance their pedagogy as part of their increasing agency, as the following comment indicates:

> I do think that I am thinking more about it than last year. When I want to get them (students), I think about my classes. I will put them in threes because they will discuss in groups. But I was perhaps having said that in twos, they can be forced to

> like I was thinking about the class dynamic when I was trying to plan the lesson (Mala, October 2018).

The teachers' reflections provided insight into their decisions and practice. This process of reflection led to further development of their reflexivity and supported their learning and practice in the pedagogy of scientific argumentation. The teachers' approach to overcoming difficulties with teaching scientific argumentation demonstrates a renewed practice that helped their reflexivity develop. Despite their continuous learning efforts during this study, all three teachers were aware of the pedagogical challenges of organising students for group discussion, encouraging them to sustain discussion, and managing their time more effectively during the argumentation lessons. They were also critical about their students' engagement and interaction with one another and their willingness to be part of the discussion and take the lead in group discussions. Teachers demonstrated a growing sense of reflexivity in response to these challenges, as showed in how they, as Mala said, consistently engaged with their own learning to enhance their understandings and knowledge of scientific argumentation, thus also illustrating their reflexivity.

5.2.5 Summary of developing agency in the pedagogy of scientific argumentation

Overall, the findings show that all three teachers acquired some degree of agency throughout their participation in this study, with some teachers developing a greater level of agency and agentic practice in the argumentation approach than others. I examined instances of agency by drawing on Pantić's (2015) and van der Heijden et al.'s (2015) work, covering the four components of a sense of purpose, mastery, autonomy to act and reflexivity. Pantić (2015) developed the model to characterise teacher agency needed to advance social justice. In my own study, I utilised this model to illustrate the instances of agency in teachers' pedagogical development of scientific argumentation.

5.3 Factors that support or hinder teacher agency in the pedagogy of scientific argumentation

5.3.1 Factors that support teacher agency in the pedagogy of scientific argumentation

I now turn to an overview of the conditions that affected teacher agency and agentic practice in general. In reviewing the reflective interview data, I also identified a number of factors that either supported or hindered teacher agency. While my categorisation was data-driven, it was also guided by the literature review findings that highlighted the critical role of social and environmental factors in influencing agency. Among the highlighted important factors were the degree of collaboration, ecological factors (prior experience, resources) and noticeable differences in teachers' responses to practice. A heavy science curriculum content and lack of time were identified as factors that hindered teacher agency.

5.3.1.1 Collaboration

Throughout this study, the teachers and I planned the argumentation lessons collaboratively (as presented in section 4.2), sharing our opinions and experiences, as well as considering alternative options to plan further argumentation lessons. At the beginning of this study, the teachers were unfamiliar with planning science lessons collaboratively. Later, in their reflective interviews, they acknowledged the value of planning lessons collaboratively and highlighted the importance of this practice in their pedagogical development and its need for change. Ray, for instance, shared the following in his reflective interview:

> It (collaboration) is something that we have not been very good at in the past in terms of planning, co-planning, or sharing work. Now that is something that I have been thinking about quite a lot. I think collaborative work is important to learn more about argumentation as well (Ray, December 2017).

A year later, Ray highlighted once again the value of planning argumentation lessons collaboratively rather than individually:

> I want to start to develop this (collaboration through planning) this year at the school. From my experience with your study, I think if we have an agreed lesson plan and how a lesson will run, it will be easier for us to produce sharable work - more collaborative work would be better (Ray, October 2018).

In his last interview, he mentioned a need for sustained collaborative work across the science department and opportunities for meaningful reflective dialogues with other teachers about lesson plans and practices. Afterwards, he broached this subject with the science department. The other teachers agreed to consider changing their schools' lesson planning process and adopt this idea for all science lessons. Thus, Ray's positive experience with collaborative work encouraged him to take responsibility for his own professional learning and the school community by monitoring their collaborative efforts (Pyhältö et al., 2012). The new forms of collaboration that emerged from Ray's actions were an important step towards creating a whole department approach to supporting teachers' learning and agency.

As mentioned before, Mala and Padma each had only a few years of teaching experience in science. They both acknowledged the advantages of working with an experienced teacher or an expert and the benefits in terms of their professional learning and agency. Working collaboratively on the planning process and implementing a range of argumentation lessons enabled them to focus on what pedagogical strategies they might use, consider alternatives to support students' engagement (i.e. act with autonomy), and helped them develop their pedagogical understanding of argumentation (i.e. increased mastery). In short, the teachers considered collaborative work with other colleagues and with me as a valuable influence on their learning, which helped them develop their agency and agentic practice in scientific argumentation. Mala stated:

> I think through this discussion (for argumentation lessons), I think I am starting to realise that this (collaboration through planning) is what we have not done. The lesson that you, me and Padma planned is a little bit more productive. That is because we were thinking along the lines of starting an activity, how we would do it, what we would give the students, like scaffolding, prompt cards. That is what we have not done before (Mala, May 2018).

This extract shows that the teachers believed that this process supported their planning process for the argumentation lessons, which helped them develop their mastery. The teachers recognised their ability to influence their classroom practice (Biesta et al., 2017) and improve their pedagogical understanding of argumentation in a collaborative setting where colleagues offered ideas and support. The teachers, especially Mala, actively joined group discussions, openly shared their opinions and struggles, and trusted one another, suggesting that both the teachers and I could learn from one another. The teachers supported their own and their colleagues' learning during lesson planning sessions by sharing their own experiences and practices and encouraging one another to develop their agency. Therefore, the process through which the teachers learned through collaborative work was necessary for both their learning and agency. Similarly, King and Nomikou (2017) and Vähäsantanen (2013) discovered that agentic teachers are intensely aware of the need for peer support in order to feel competent enough to make changes in their practice. Padma commented on this factor:

> Sometimes you focus on doing something in one way, and you are missing out on something that someone would know all about. I think it was very useful to plan together (Padma, June 2018).

In the second year of the study, during the planning processes, the teachers gave greater consideration to the particular needs of their own classrooms and their students while planning the argumentation lessons, such as how best to organise their students for group discussion, how to introduce scaffolding argumentation processes, and how to structure the lesson. This shows how the teachers developed their agency in a more meaningful and effective way to engage further in the instructional strategies (Calvert, 2016).

In addition, Padma and Mala found it useful to observe each other's lessons as a way to improve their own pedagogical learning and enhance their agency. Through this process, they could observe another teacher's agentic practice to enhance their agency. Mala, for instance, commented:

> I found it (observing each other's lesson) helpful because it allowed us to see how another teacher would teach the same lesson. I have two classes, and it was interesting to see how a third-class responded to it, which is completely different from

> my classes' way of how my classes responded to it. It was a completely different atmosphere. Although we planned it together, it helped to see things. It gave me a chance not to be the teacher in the scenario so I could observe the scenario. I can see how stuff needs to be changed, and it gave the observer the chance to observe the children and see what they are doing. So, I found it very useful (Mala, June 2018).

As a consequence of their positive experience with collaborative work, the teachers valued collaboration for planning argumentation lessons, which supported their practice and agency. However, this process was also challenging for them because of their busy timetables. Thus, opportunities for collaborative lesson planning were limited, especially in the second year of this study. This lack of professional discussion impacted teachers' ability to exercise their agency, as they were seen to focus more on their prior experiences than on their interactions with colleagues. The findings suggest that it would be beneficial to facilitate collaborative work among teachers in school communities through reflections on their decisions and practices regarding the interplay between the past, present, and future dimensions of their achievement of agency (Emirbayer & Mische, 1998).

The findings give weight to a conceptualisation of teacher agency as "individually varied … and both socially and individually resourced" (Vähäsantanen, 2015, p. 1). When confronted with comparable contextual opportunities and constraints, the participating teachers made varied decisions and implemented different practices as a result of their values, knowledge, and previous experiences. These findings align with the concept of teacher agency as participation in collaborative effort within a learning community and giving and receiving support to and from others (e.g., Lipponen & Kumpulainen, 2010). In other words, these results indicate that teacher agency develops in a context where teachers work collaboratively and reflect on their practice.

5.3.1.2 Prior experiences

The observational and reflective interview accounts indicate that the three teachers' decisions on how far to engage in professional learning and what and how to learn were highly varied and mediated by their agency, resources, and previous experiences. Similarly, Tao and Gao (2017) indicated that teachers' previous experiences influence their agentic decisions and actions about professional learning. In the first year of this study, the teachers' practices and reflections on their experiences showed they were willing to take risks while planning and implementing the argumentation lessons, including risks relating to organising students for discussion. Whereas, in the second year, they were observed doing the same things and also considering their students' potential, the classroom culture, and using the strategies they felt most confident about. The teachers also underscored the value of having sustained experiences to enhance their knowledge and pedagogy of scientific argumentation and identified the importance of trying to utilise various strategies across time.

Over the two-year period, the highest number of instances of practice indicating agentic practice came from Mala. However, there were examples from the other teachers' practices that also indicated that they were developing agentic practice in the pedagogy of scientific argumentation. Mala, however, implemented the scientific argumentation approach in her teaching within a variety of contexts and displayed a higher level of willingness to improve her own capacity for sustained professional learning (Lipponen & Kumpulainen, 2011). In her words:

> I think since we have started it (implementation scientific argumentation) -because we are not doing it that often - but now, personally, we are starting to understand it a bit more and start to see it and reflect more, it's like let's develop it more and see how it can grow further (Mala, July 2019).

Mala was the only teacher who applied scientific argumentation in various lessons in her practice throughout this study. She was happy with her pedagogical development throughout these two years. Mala, in particular, used a wider range of scaffolding processes in her interaction with students, indicating she had more extensive knowledge of how argumentation can be incorporated into science lessons, as the following comment illustrates:

> Over the last two years, with this new scheme of learning we have begun, I'm definitely incorporating it (scientific argumentation) into my lessons more. I have started planning energy at KS4 and, I am also using all these techniques in my lesson for energy. Using argumentation is getting them to naturally be constantly using this language and constantly knowing that if I say something, I have to say why because of this or because the graph shows this. I think that is what science is

> about; you cannot just come up with a theory or scientific terms. They have got reasons, evidence. I think that is building up their skills as a scientist. Also, to ask questions as well, to challenge what they think and why they think. I feel like as teachers in this school perhaps we are not doing this enough. Teaching with argumentation has made me realise that it is a good approach (Mala, July 2019).

Like Mala, Ray and Padma also commented that their experience with the scientific argumentation pedagogy provided a great resource for them to use in the future. They believed that teaching science through scientific argumentation improved their pedagogical knowledge and understanding and developed the students' argumentation skills, as well as enhanced their agency. Continuous practice over time helped them develop agentic practice.

5.3.1.3 Resources

Two objectives of using the particular educational resources were that it gave the teachers a rationale for instructional decisions and enabled them to effectively adjust the resources to the particular requirements of their students and setting. Throughout this study, the teachers used the IDEAS pack (Osborne et al., 2004b) and CPD units website (Simon & Davies, 2019), as resources to develop their pedagogical knowledge and understanding of scientific argumentation and their agency in the four components, a sense of purpose, mastery, autonomy to act and reflexivity. These materials assisted the teachers in developing a deeper understanding of a specific area of teaching (e.g., organising students for group discussion, designing activities and lesson plans) and, importantly, also supported them in acquiring knowledge that could be applied to new situations. All three teachers stated that having resources to work with and the flexibility to make their own decisions about using them (i.e. autonomy to act) assisted them in planning and implementing more engaging argumentation lessons. They also became aware of the importance of evaluating resources to use in their lessons. Padma, for instance, stated:

> Having resources to use and having the freedom to change them, I think that would be the best. I think you also should not be relying solely on the resources (Padma, May 2018).

Watching experienced teachers engage with scientific argumentation with their students through multimedia representations of actual classroom activities may have given them ideas as starting points on how to incorporate this approach in their practice. These resources also helped them develop their agency. Mala commented on the benefits and drawbacks of watching the videos:

> Even the videos I was watching for argumentation, the teachers are explaining, the kids are listening, you have this idea that it's going to be like that, but it's harder than that (Mala, May 2018).

On the whole, the teachers indicated that the materials were beneficial as they found scientific argumentation a challenging approach to take in the classroom. As seen from the observational data, this is significant to note that the practice varied in each teacher's account and each classroom.

5.3.2 Factors that hinder teacher agency in the pedagogy of scientific argumentation

5.3.2.1 Curriculum, examination, lack of time

There are also factors that hinder the development of agency in the context of the scientific argumentation approach. Schools and teachers are evaluated on the basis of their student's test results, and curriculum is therefore influenced by the procedures used to determine progress. Teachers may feel unwilling to engage with new pedagogies in their teaching when faced with such pressures. Their educational mission may easily devolve into one of preparing students to pass examinations. The teachers decided to utilise scientific argumentation in their Y7 classrooms due to the pressures of examinations in the higher years. While they recognised the significance of incorporating scientific argumentation into science teaching and learning, they partly complied with the system's requirements that they cover a certain body of content in preparation for exams. Padma commented on this:

> There's also a lot of pressure on at the moment. There are also some changes in the curriculum, like dropping down all these contents just because of exams. It was better in the old days when they did more-- I don't know. That's not really to do with

the kids and it's not really to do with the teachers. That's just like external pressure (Padma, May 2018).

All three teachers faced external pressure (i.e. a great deal of content to cover, assessments). Buchanan (2015) argues that, although teachers do not like the idea of standardised testing, they have a sense of professional accomplishment when their students achieve academic success. While professional learning activities could be viewed as an integral part of improvement, I would argue that the emphasis on self-reflection and the opportunities for collaboration underlying this study at least challenged some institutional structures and ways of working.

Lack of time and having a considerable amount of content to cover were two factors that hindered teachers' development of agency. At the beginning of this study, all three teachers identified Y7 students as the most suited for this study as they did not have to face the pressure of exams during that year. After gaining some experience with the scientific argumentation approach, Ray believed that it would be more suitable to use with the older students in KS4. Padma and Mala, however, came to believe that students needed to gain argumentation skills at an early age.

Overall, this chapter investigated how science teachers develop their agency and their agentic practice when engaging with teaching science through scientific argumentation. I used the concept of teacher agency as a lens through which I investigated science teachers' pedagogical development of scientific argumentation as a new scientific approach in their practice according to four components of agency: a sense of purpose, mastery, autonomy to act and reflexivity, drawing on Pantić's (2015) and van der Heijden et al.'s (2015) studies. I identified instances of agency in the teachers' reflective interviews and practices. Additionally, I also pointed out the factors that supported and hindered teacher agency in the pedagogy of scientific argumentation.

In the next and final chapter, I will discuss the results of the RQs, focusing on whether the science teachers who participated in this study developed their pedagogy of scientific argumentation over a two-year period, and evaluating their pedagogical development of scientific argumentation through the lens of agency. I will summarise the results of this investigation in light of the RQs. I will then provide a critique of this study, questioning some of its methodological choices and limitations. Finally, I will discuss the study's contribution to educational knowledge and science education, as well as provide recommendations for future research and explore the implications for many areas (e.g., professional teacher learning, teacher agency, teaching, and learning science through scientific argumentation).

Chapter 6: Discussion and Conclusion

Despite scientific argumentation being considered an essential scientific practice in science education for several decades, it still rarely appears in science classrooms (Osborne, 2010). It also remains a key challenge for both teachers and students (Henderson et al., 2018; Osborne et al., 2004a), leading a number of researchers (e.g., Simon et al., 2006; Osborne et al., 2013) to emphasise the need for further investigations on how to support teachers' pedagogical development of scientific argumentation. The current study has therefore examined how science teachers developed their pedagogy of scientific argumentation in the process of planning, implementing, reflecting on practice, and evolving it in their practice. It also examined teachers' use of scientific argumentation in the classroom, with an emphasis on a range of science contexts and across years. With this final chapter, I will be discussing the results of the RQs, focusing on whether the science teachers participating in this study developed their pedagogy of scientific argumentation over a two-year period and investigating their pedagogical development of scientific argumentation through the concept of teacher agency as a lens.

This final chapter is organised as follows. Firstly, in section 6.1, I discuss the findings of teachers' pedagogical development of scientific argumentation, including the lesson plans, the implementation of scientific argumentation, and students' written work across different contexts and years according to the embedded cases, as well as investigate teachers' pedagogical development of scientific argumentation and their agentic practice through the concept of agency. Secondly, in section 6.2, I draw together the findings of this study considering the RQs. Thirdly, in section 6.3, I provide a critique of this study, re-examining some of the methodological decisions and limitations. Finally, in section 6.4, I discuss the contribution of this study to educational knowledge to science education, followed by suggestions for future research and implications for the different fields (e.g., professional teacher learning, teacher agency, teaching, and learning science through scientific argumentation).

6.1 Teachers' pedagogical development of scientific argumentation

This section draws on previous research to discuss the three science teachers' pedagogical development of scientific argumentation in their practice, as they worked collaboratively in a secondary science department over time. The findings are based on lesson plans for the argumentation lessons, observations from the classroom practices in terms of lesson structure and SAP (as examined in chapter 4, sections 4.2, 4.3, and 4.4) and reflective interviews. Moreover, I have used the concept of agency as a lens for my investigation of science teachers' pedagogical development of scientific argumentation as a new scientific practice. In the first interview, the participant teachers were asked questions concerning their professional background and experience of teaching science, as well as their initial beliefs about the value of scientific argumentation in science teaching and learning. This information was used to 'profile' each teacher and provide a baseline for comparing changes in both practice and agency.

This small-scale research employed three RQs to create an overall picture of the teachers' pedagogical development of scientific argumentation and their implementation of this scientific approach, including how they plan their lessons, how they scaffold this approach in their practice and develop their agency and agentic practice in this regard. More specifically, this section of the study sought to gain insight into the following:

RQ1. How do science teachers develop their pedagogy of scientific argumentation in their practice?

- How do three science teachers plan and implement the same argumentation lessons in their classrooms one year apart in a scientific and SSI context?
- How do two science teachers plan and implement the same two argumentation lessons in the two scientific contexts in their

classrooms across two years? To what extent does the pedagogy of scientific argumentation of the two science teachers evolve across the two years?
- How do one science teacher's scientific argumentation pedagogy and her student's written work change over a year?

RQ2: How does students' written work provide insight into their teachers' scientific argumentation approaches?

RQ3. How (if at all) do science teachers develop their agency and agentic practice in this regard?

I addressed RQ1 and RQ2 by comparing the teachers' scientific argumentation practices by visualising their lesson structure and SAP in different contexts and across years, as well as using students' written work to provide insight into the teachers' scientific argumentation approaches (see chapter 4). To answer RQ3, I examined the reflective interview data, alongside the teachers' practice, through the lens of teacher agency according to four components of agency: a sense of purpose (i.e. intentionality), mastery (i.e. competence to achieve such purpose), autonomy to act, and reflexivity (see chapter 5). Now, I will be discussing these findings in the light of previous literature in the following sections.

6.1.1 Science teachers' pedagogical development of scientific argumentation in different contexts one year apart

The first case aimed to compare the practice of three science teachers while implementing scientific argumentation in a scientific and SSI context one year apart by highlighting critical variations and similarities in their practices. I list below the significant findings of science teachers' pedagogical development and classroom practices in different contexts:

- Classroom practices took a number of forms to address various argumentation approaches and changes in the scientific and SSI contexts according to the science teachers' perspectives and approaches to teaching science.

- The variations in the pattern of lesson structure and SAP for each teacher across the two different contexts demonstrates the uniqueness of their pedagogy of scientific argumentation.
- Even with collaborative planning and shared resources (which provided explicit guidance about how to incorporate scientific argumentation into science lessons), this case demonstrated that the three science teachers' practices differed in terms of lesson content and structures, their practice, approaches and scaffolding scientific argumentation processes, timing and the organisation of their students.

These findings are discussed in more detail below.

It should be acknowledged that the participant teachers and their students were unfamiliar with this practice at the start of this study. Therefore, teachers' current practice and initial perspectives on teaching science through scientific argumentation influenced their practice and the implementation of resources with differing purposes, i.e. argumentation activities to stimulate students' discussions and written work (Berland & Hammer, 2012). While previous research on teachers' pedagogical development of scientific argumentation (e.g. Simon et al., 2006) demonstrated that teachers' scientific argumentation practices diverged in relation to their existing practice of teaching science and their approaches to scientific argumentation, this study showed similar findings. The results indicated that each teacher's starting points, their account of the development of argumentation pedagogy and practice varied. The profiles of lesson structures and teachers’ SAP revealed the variations and differences in each teacher. For instance, Mala's existing teaching included questioning and justification approaches. Mala's SAP profiles also indicated that she used a variety of scaffolding processes in her instructions with her students during her lessons, indicating that she had a better understanding of how argumentation might be encouraged during discussions. Ray was also seen utilising a number of argumentation processes in his lessons, most notably during teacher talk rather than discussions. In contrast, Padma utilised a few argumentation processes in her instructions during discussions. The teachers who utilised a wider range of SAP in their interactions with students, as in the case of Mala, had more extensive knowledge and understanding of how scientific argumentation can be incorporated into science teaching and learning.

The teachers’ instructions and approaches to these lessons varied, as did the amount of time they reserved for the argumentation lessons. While several research conducted to investigate the effect of teachers' instructions on students' argumentation practice (Kim & Hand, 2015; Pimentel & McNeill, 2013) have demonstrated the critical role of teachers' instructions in achieving specific learning objectives, their impact on students' engagement with lessons such as students’ written work remains underexplored, particularly in the domain of the differences in teaching argumentation in scientific and SSI contexts (Osborne et al., 2004a). As Dawson and Venville (2010) emphasise, as the result of this study supports a similar point, the context in which argumentation occurs is critical to the development of scientific argumentation. When we planned the lesson with a scientific context (i.e. Dropping a box, as presented in chapter 4, section 4.2.1.1), all teachers agreed to use the activity as a recap of the scientific context, stated that their students need to have prior knowledge of content to engage with and participate in this practice. Therefore, the findings, supporting similar conclusions of previous studies on teachers’ perceptions of students’ background (e.g. Sampson & Blanchard, 2012), indicate that all three teachers assumed they should consider their students' prior content knowledge and experience when planning and implementing the argumentation lessons. The teachers emphasised that their students need scientific content knowledge as a necessary condition of argument construction in a scientific context. Some teachers, particularly Ray, provided clear directions when their students were uncertain about the science content and followed a 'triadic dialogue' (Lemke, 1990), initiating a question and then selecting a student to respond, followed by providing feedback to the answers and accompanying detailed explanations. For Ray resolving the scientific concept seemed more important than engaging in scientific argumentation processes (McNeill et al., 2013). It appeared students' involvement in scientific argumentation was limited, with little opportunity to justify their responses in this lesson. In contrast, Padma and Mala tended to talk less and encouraged their students to communicate more with one another, as well as take responsibility for exploring content knowledge using argumentation practice (Kim & Hand, 2015). They not only considered their students' prior knowledge and abilities but also recognised the importance of encouraging discussion, thinking and reasoning as an essential component of scientific argumentation (McNeill et al., 2013; McNeill & Krajcik, 2008). They, especially Mala, assisted their students in developing their reasoning skills throughout the lesson (i.e. a different sense of purpose as a component of agency). The findings of this study reveal the teachers' differing approaches and instructions during the argumentation lessons were undertaken according to their current practice of science teaching and their understanding of scientific argumentation.

When students are unfamiliar with science context or argumentation processes, such as providing evidence and reasons, or the teacher with this approach, teachers may be hesitant to participate in scientific argumentation. These findings demonstrate that when the teachers emphasised resolving science content knowledge within a scientific context, they struggled to provide sufficient opportunities and time for students to explore content knowledge with their peers. I consider that these results also suggest if the purpose of the scientific argumentation approach is to support students in developing their thinking and reasoning abilities, students may not need substantial scientific content knowledge, and teachers may not need to reinforce students' content knowledge in order to participate in this practice. This led me to conclude that science teachers require greater support and more examples of classroom practice to help them develop a new set of values concerning teaching science through scientific argumentation by addressing their existing beliefs about the teaching of science (Simon & Connolly, 2020) and understand that content knowledge may not be necessary for student-centred dialogic discussions in scientific argumentation.

In comparison, I found that when planning the scientific argumentation within a SSI context (e.g., Zoo lesson, as presented in chapter 4, section 4.2.1.2), the teachers expected their students to draw on their own experiences to engage with this practice, make informed decisions by using their experiences (Chen & Xiao, 2021) and discuss their points in talk and writing. Therefore, all three teachers encouraged their students to communicate with one another since they were unconcerned with their students' scientific context knowledge. The results also show that each of the three teachers' instructions and approaches varied depending on their emphasis on scientific argumentation practice during the discussion. Ray, for example, facilitated brainstorming and decision-making in order to encourage his students to explore a variety of perspectives. Mala, on the other hand, emphasised both individual and collaborative decision-making. On the other hand, Padma emphasised the significance of considering counter-arguments that provide possible reasons for varied views. In addition, Padma did not provide any formal instruction in scientific argumentation; however, the result of students' written work supports the argument made by Berland and Hammer (2012b) that without having formal preparation in scientific argumentation, her students were capable of making claims, supported with evidence and reasoning in the SSI context. When the teachers planned this lesson, they used their previous experiences as resources to make informed decisions on their instructions and approaches to scientific argumentation. I thus concluded that the teachers' instructions and approaches to either scientific or SSI context reflected their knowledge and understandings on key aspects of scientific argumentation and their development of this practice.

While different studies about teachers' use of similar instructions and prompt questions (e.g., Ryu & Sandoval, 2012) have already considered a crucial aspect of supporting students' argumentation, assisting in recognising the importance of argumentation and interpreting its significance. As recently suggested in the area (McNeill et al., 2017), asking prompt questions and allowing students time to explore the use of evidence to support a claim by asking, "What is your evidence?" assist students in developing their argumentation abilities. In both lessons, the teachers consistently used prompt questions to highlight scientific argumentation processes (i.e., 'How do you know?'; 'What is your evidence?'; or 'How do you persuade others?'), thus indicating that they understood the importance of developing the students' argumentation skills. Additionally, all three teachers reported that the writing frames provided a scaffold to guide their students in recording their thinking and reasoning in tasks within both the scientific and SSI contexts (Dawson & Venville, 2010).

While organising students for group discussions, Ray and Padma agreed to group their students into four or five, while Mala was the only one who suggested experimenting with a different group strategy. One year apart, Mala demonstrated an active interest and was the only one willing to take risks related to applying a diverse group strategy (e.g. role-play) within the SSI context lesson. By contrast, Ray organised his students into groups of four, while Padma preferred pair discussion. This indicated that the three diverged in their openness to taking risks, revealing that teachers only adopt approaches they feel able to manage in the argumentation lessons. I, therefore, conclude that this demonstrated an instance of autonomy to act as a component of developing agency and an indicator of developing agentic practice in scientific argumentation.

This study's findings indicate that the students were taught to participate in class discussions and construct their written work according to their teachers' scientific argumentation approaches and emphasis. However, written work was only one indication, with differences also attributed to the amount of time each teacher spent on scientific and SSI context lessons that influenced students' written work. Ray, for instance, devoted two lessons on the argumentation lesson within a scientific context to ensure that his students understood the content knowledge and produced their collaborative written work during group discussions. On the other hand, Mala encouraged her students to discuss and work collaboratively in groups, as well as evaluate the work of other groups during the small group discussion. Padma, however, tended to focus only on group discussion, with less emphasis on written work.

Moreover, the teachers' approaches varied when it came to argumentation lessons in a SSI context. Mala encouraged her students to produce their written work individually and then collaboratively. Padma focused on constructing written work after discussions and provided considerable time. On the other hand, Ray used this task as homework following an extensive discussion in class. The results demonstrate that the variations in teachers' approaches in different contexts influenced students' written work, which also varied in complexity and sophistication across teachers and science contexts. Consistent with other studies on students' involvement in argumentation practice (Osborne et al., 2004; Osborne et al., 2016; von Aufschnaiter et al., 2008), the students in my own study were more comfortable with tasks situated in SSI contexts. The results also support Dawson and Venville's (2010) findings, demonstrating that students appeared more engaged in the SSI context, including being willing to express their views and listen to their teacher and peers.

In summary, this case, where three teachers were involved in planning and implementing the argumentation lessons within a scientific and SSI context, highlighted how the design and implementation of materials were heavily reliant on explicitly teachers' existing practice, previous experiences, approaches and understanding of scientific argumentation, as well as their belief about values of teaching science through scientific argumentation. Furthermore, the teachers' patterns of SAP revealed the differences in their pedagogy. Thus, each teacher undertook a unique interpretation of the use of new materials and ideas, resulting in varied lesson content and structure, along with their instructions and approaches, scaffolding argumentation processes, timing and student organisation. Hence the findings reveal differences in the teachers' sense of purpose in using resources, decision-making as autonomy to act and practices, so the case begins to show differences in practice and agency between the teachers. Case 2 explored such differences by comparing just two teachers, Padma and Mala, more extensively.

6.1.2 Science teachers' pedagogical development of scientific argumentation across two years

Differing from case 1, the second case provided an opportunity to first explore the practice of two science teachers, implementing the same two argumentation lessons in two scientific contexts, and secondly, focus on their pedagogical changes in practice over a period of two years. Additionally, this case examined the teachers' design of an argumentation activity (i.e. Food chain) using the resources and materials provided. It is essential to acknowledge that the classes observed were different each year. Nevertheless, all consisted of mixed-ability groups of Y7 students. Therefore, I was able to compare two teachers' practices in scientific argumentation across two years with different students.

I list below the significant findings of science teachers' pedagogical development and changes in classroom practices across two years:

- Classroom practices took several forms to address various argumentation approaches and changes in argumentation pedagogy across two years according to the science teachers' previous experiences and approaches to implementing scientific argumentation.
- The variations in the pattern of lesson structure and SAP for each teacher across the two years demonstrate the development of pedagogy of scientific argumentation.
- Despite collaborative planning and shared materials, this case revealed that the two teachers implemented scientific argumentation in various ways, including differences in instructional focus and structure, timing, and organisation of their students. Additionally, the degree of change shown by each teacher displayed their pedagogical development and the development of agency.

These findings are discussed in more detail below.

Previous studies on teachers' pedagogical development of scientific argumentation (e.g. McNeill & Knight, 2013; Osborne et al., 2013; Simon et al., 2006) demonstrated that teachers' scientific argumentation practices diverged in relation to their existing practice of teaching science and their approaches to scientific argumentation, this study showed similar findings. However, their research was not specifically intended to analyse teachers' approaches and classroom practice across contexts systematically and comprehensively. The results also show that the pedagogical changes in a range of argumentation processes employed were mainly influenced by the teachers' pre-existing argumentation practices, their instructions, approaches, and beliefs concerning which aspect of argumentation processes are essential to support students' argumentation skills. This implies that teachers hold different perceptions of new materials and ideas and use them for various purposes, as well as develop their pedagogy in a varied manner (i.e. develop different a sense of purpose as a component of agency), which was the reason for the variation in their lessons across the two years.

The SAP profiles indicate that the teachers used a range of argumentation processes in their practice with their students. The results suggest that the teachers' instructions and approaches to implementing scientific argumentation evolved in a varied manner over the two years. For instance, Mala's instructions included a clear focus on scientific argumentation, with a broad range of argumentation processes, i.e. counter-argument and reflection, inferring that she was willing to consider new ideas to a substantial understanding of the nature and purpose of teaching science through scientific argumentation. Similarly, Padma’s instructions included a strong emphasis on scientific argumentation, with a few argumentation processes, i.e. encouraging discussions and evaluating arguments.

When it came to developing their instructions and approaches of scientific argumentation Padma and Mala utilised over two years, they both encouraged their students to 'listen to, and discuss with each other, i.e. to engage directly in small group discussions. Especially, in the Phases of the Moon lessons, they differed in their approaches that Mala subsequently provided a general explanation about the topic, encouraged her students to engage with science argumentation and showed a video to reinforce her students' content knowledge, followed by asking students to reflect on their understanding and mind-change at the end of the lesson, especially in year two. This demonstrated that she dedicated time to both expanding students' understanding of science content and the argumentation approach. On the other hand, despite facing several behavioural issues, Padma attempted to provide additional opportunities to assist students in understanding scientific argumentation in year two. This ensured that she was more focused and had the potential to utilise her students' written work to examine their understanding.

An important result of this study is that while the teachers organised their students for group discussion, Padma and Mala utilised envoys in year one in the Phases of the Moon lesson. Due to the difficulties experienced by their students, they chose separate group strategies for year two, with Mala employing both pair and joint-pair discussions and Padma using individual work and pair discussion. These differences indicate that Mala was more willing to try different strategies to enhance her pedagogical understanding of argumentation, so indicating increasing her agency. Additionally, while similar findings regarding teachers' perceptions of their students' ability to engage in scientific argumentation have been found in the field (Katsh-Singer et al., 2016; Sampson & Blanchard, 2012), this result also demonstrates that teachers' prior experiences and beliefs about their students' ability to engage in scientific argumentation influenced their instructional decisions.

Moreover, the teachers found the use of a variety of strategies for incorporating scientific argumentation into practice helpful for determining which approach might prove effective, so illustrating the teachers’ autonomy to act and reflexivity. This result suggests that teachers should be given opportunities to experiment with various types of instructions and develop their pedagogy and agency in the light of their own experiences and reflections on their practice. In the food chain lessons, Mala and Padma used pair discussions for both years, so suggesting that teachers tend to use strategies they feel capable of managing. Furthermore, the way the teachers organised students for small group discussions suggested that confidence in their abilities (i.e. mastery component of agency) enabled them to master various activities and instructional methods in their practice, indicating agentic practice. Additionally, Mala was observed applying whole-class discussions for both years, which enabled her to control and monitor student input, thus ensuring that students were engaged both in the scientific argumentation activity and processes.

Another important result of this study is that the teachers utilised both the Phases of the Moon and the Food web activities to assess their students' understanding of the science content and support their discussions and engagement with scientific argumentation. The timing was deliberate, as it had been previously shown (Dawson & Venville, 2010; Lewis & Leach, 2006; von Aufschnaiter et al., 2008); some previous knowledge and experiences would enable students of this age to improve their argumentation skills. As argued by several researchers (e.g. Pimentel & McNeill, 2013), teachers are concerned with their students' prior experience, knowledge and motivation to engage in and extend classroom discussion and their own capacity to manage discussions. The result shows that both teachers considered that their students required some familiarity with science contexts to successfully engage in scientific argumentation and therefore drew on their previous experiences and their awareness of students' content knowledge. This illustrates how teachers developed their existing mastery as part of developing pedagogy and agency in scientific argumentation practice, so enabling them to provide further information to students when required. This prompted their students to use their prior knowledge while providing reasons for explanations, as shown in their written work. The results, therefore, suggest that argumentation activity forms a useful tool to assess students' understanding of science context and find out about their misunderstandings. As argued by several researchers (Dawson & Venville, 2010; Lewis & Leach, 2006; von Aufschnaiter et al., 2008), the results also support that the students only engaged in scientific argumentation when they identified a familiar aspect in the tasks presented. It shows that both teachers recognised the importance of utilising argumentation resources to assess their students' understanding (Duschl & Osborne, 2002; Osborne et al., 2004a) and assist them in discussing explanations and producing written work.

When examining their students' written work, the food chain lessons were not used to obtain their written work but utilised to encourage their discussions. Written work collected in the Phases of the Moon lessons across two years shows that the teachers found this context complex and challenging. This was addressed by utilising this activity to recap the context and providing support that was both scientific argumentation and content knowledge. Consequently, when planning argumentation lessons, the teachers considered means of having students prior knowledge about science context, applying simpler instructions, along with additional support. The teachers used a variety of instructional strategies (i.e. modelling, everyday examples, prompt and evaluation cards and sentence starters) to support the goals of scientific argumentation (González-Howard et al., 2017).

Both teachers encouraged students to participate in a more scaffolded approach in year two, showing that they developed their argumentation pedagogy from one year to the next. As few researchers (Berland & McNeill, 2010) reported, an explicit scaffolding supported students in understanding the requirements for the argumentation discussions. For instance, both teachers discussed with their students how to construct a strong argument in support of a claim with evidence and reasons, encouraging them by using prompts such as: "What is needed to make a good argument?". The result supported previous research on teachers' explicit instructions in argument construction (e.g., McNeill et al., 2017) highlights the ways teachers clarify the importance of constructing their arguments and employing evaluation and justifying ideas with evidence and scientific reasoning help students understand the process of argumentation and its requirements. This also indicates that to support students effectively with a broad range of needs, science teachers may need to use a variety of argumentation processes, i.e. diversified scaffolding strategies. Using certain types of scaffolding argumentation processes can help students engage and strengthen their argumentation skills. For instance, Mala incorporating certain types of scaffolding argumentation processes more extensively with her students in all of her lessons, including asking prompt questions while circulating the classroom and developing a broader range of scaffolding processes, indicating a more inclusive approach of how argumentation can be encouraged in discussions; as a result, her students engaged actively in and contributed to argumentation. However, Padma rarely prompted her students during group discussions but developed a variety of scaffolding processes in selected parts of her lessons, which indicates she had a limited view of how argumentation can be encouraged in discussions.

Lastly, a further important result of this case is that the teachers designed and planned the food chain activity using materials and resources, encouraging their students to develop their own ideas around the tasks and design classroom instruction by considering their own teaching. This practice improved awareness and knowledge of this approach, illustrating how a teacher can develop their agentic practice. A critical point here is that resources, IDEAS pack (Osborne et al., 2004b) and online website (Simon & Davies, 2019) enable teachers to create their own classroom argumentation activities. By providing multimedia materials and the option for improved user flexibility, online modules provide innovative support for teacher learning (Marco-Bujosa et al., 2017; Simon & Davies, 2019).

In summary, this case, where two teachers were involved in planning and implementing the same two activities across the two years, highlighted how the design and implementation of materials were heavily reliant on explicitly teachers' previous experiences, approaches, beliefs and understanding and development of scientific argumentation. As evidenced from the results, the teachers preferred to follow their own individual lesson plans when implementing the lessons in their classrooms after having experiences with scientific argumentation. This indicates that they had various understandings of the teaching scientific argumentation and shaped their own understanding and knowledge according to their own experiences. Furthermore, the teachers' patterns of SAP revealed the differences and changes in particular in their pedagogy across two years. Thus, each teacher undertook a unique interpretation of the use of the materials and ideas, resulting in varied lesson content and structure, along with their approaches, scaffolding argumentation processes, timing and student organisation. Hence the findings reveal differences in the teachers' sense of purpose in using resources, decision-making as autonomy to act and practices, so the case highlighted the differences and changes in their agency and development of pedagogy between the teachers. Case 3 explored the changes more comprehensively by comparing one teacher's practice, Mala, with her students over a year.

6.1.3 A science teacher's pedagogical development of scientific argumentation over a year

Differing from case 1 and 2, the design of the last and final case study provided both an opportunity to examine the practice and of a science teacher, implementing two argumentation lessons within two similar SSI contexts, but more importantly, to see her changes in her pedagogy of scientific argumentation and practice. Mala was selected for this due to demonstrating a wider range of argumentation processes and understanding, suggesting that it would be beneficial to see if she developed her pedagogy further over time. The additional focus of this case was to examine changes in her students' written work as their response to her approaches.

I include a list of the key results of a science teacher's pedagogical development and changes in classroom practices over a year and changes in her students' argumentation:

- Classroom practices took similar forms to address various argumentation approaches but with more emphasis and changes in argumentation pedagogy over a year according to the science teacher's previous experiences and approaches to scientific argumentation.
- Students' written work improved over a year with additional support and sustained practice. The main difference observed concerned the students' sophistication in constructing individual and collaborative written work.

The findings show that Mala adopted comparable patterns to address a range of scientific argumentation processes, with slight changes observed across two SSI context lessons over a year. While planning the Leisure Centre Activity, she was observed being reflexive in her belief about the value of teaching science through scientific argumentation, using her prior experiences with argumentation and her students and accomplishments in this approach. The results reveal that, once Mala became aware that such strategies could prove beneficial (i.e. an increased sense of mastery), she sought to use more ambitious strategies (i.e. role-play) for both argumentation lessons. This also reveals that Mala was confident she could handle a number of activities and instructional strategies in her classroom by means of sustained practice. In addition, she believed that using this science approach increased her awareness of her teaching goals (i.e. she became increasingly aware of her purposes). Her attempt at using various group strategies and instructions demonstrates her willingness to take risks and experiment, which is indicative of increasing agency (Loucks-Horsley et al., 2010).

When comparing students’ written work at the beginning and end of the year, the results of this study and previous research on students’ improvement of argumentation skills (e.g. Ryu & Sandoval, 2012) showed that continuous instructional support over time strengthens students’ capacity for argumentation practice and their comprehension of epistemic requirements for scientific reasoning. Mala provided adequate scaffolding for her students to articulate their viewpoints in writing, supported by evidence and reasons. The results of students' written work at the end of the year demonstrate that implementing instructional strategies that are scaffolded effectively was critical for students’ written work produced individually and collaboratively; it was shown that the majority of individual work was straightforward, consisting only of stating a viewpoint and providing a few reasons to support it. This demonstrated that collaborative group work results in more sophisticating arguments (Sampson & Clark, 2009) and promotes thinking from several viewpoints. Additionally, the results of this case show that Mala’s students' written work improved as they were seen justifying their positions with reasons and using the argument structure over the year in which she incorporated various scientific argumentation instructional strategies with more emphasis into her classroom practice (McNeill, 2009). The results confirm Simon et al.’s (2006) conclusion that was enhancing students' argumentation skills tend to be associated with their teachers' instructions, including emphasising the importance of justifying it with evidence, constructing arguments and counter-arguments, and reflecting and modelling argumentation skills. Mala included various scientific argumentation approaches in order to give her students multiple opportunities to understand this science practice, i.e. the use of a writing frame assisted her students in organising their thinking, constructing and developing their ideas during small group discussion while constructing their written work (Dawson & Venville, 2010). Mala’s increased knowledge and awareness of the nature and purpose of this practice ensured she was more open to this new approach to science education and taking ownership of its goals and objectives. This supports the claim that teachers' underlying potential for change may be contingent on their prior knowledge, understandings and beliefs, as well as any direct input.

A further significant finding from this study was that, while it is possible to gain insight into teachers' instructions and approaches, the findings suggest that students' written work is helpful. Mala’s clear expectations and approaches to improving support for her students impacted her students’ engagement in different forms of discussion and the construction of their written work. Her student's prior experiences with argumentation were leveraged to support engagement in this science practice, as shown in their written work (Berland & Hammer, 2012). Developing an understanding of factors supporting students' written arguments forms the first step towards encouraging them to use templates (Dawson & Venville, 2010) and sentence starters, which can be integrated into classroom instruction to further support any students who are found to struggle.

6.2 Supporting teachers' agentic practice in the pedagogy of scientific argumentation

Understanding how science teachers develop their pedagogy of scientific argumentation, along with the variation in science teachers' practice with this approach, is critical for the study of science teaching and learning. This is particularly important as, despite decades of research, scientific argumentation is not yet widely incorporated into science classrooms (Osborne, 2010).

One of the reasons for the current lack of understanding of scientific argumentation in science education may be a lack of familiarity with how science teachers develop and evolve their argumentation pedagogies and approaches over time through a detailed analysis of planning and implementing and reflecting on practice. Therefore, this study aimed to add to a better understanding of how science teachers developed their pedagogy of scientific argumentation over time and scaffolded this approach throughout their practice. All three teachers in this study used the same resources and materials (the IDEAS pack and the CPD unit's website) to assist their pedagogical learning and understanding of scientific argumentation. They implemented this new practice in their classroom practices as soon as it was introduced to them (Berland, 2011). Thus, they became familiar with scientific argumentation through utilising these resources as guidance, along with their prior experiences, collaborative work, reflecting on their practice and changing it in their practice in the light of their experiences and reflections, as observed in their classroom practice and reflective interviews.

The teachers developed their argumentation pedagogy and agency in a varied manner arose from their beliefs concerning the value of science teaching through scientific argumentation, their willingness to try a new strategy in their practice, their beliefs concerning students' capabilities and content knowledge, prior experience, and their existing teaching style. This examination has thus enabled me to uncover significant differences between their instructions and approaches to implementing scientific argumentation in science lessons, including those based in scientific or SSI contexts, to structuring argumentation lessons, scaffolding argumentation processes, and developing their pedagogy and agency.

An important learning from this study is related to the importance of examining the various ways in which science teachers establish a learning environment beneficial to scientific argumentation —by considering the ‘how’ (e.g., lesson structure, teachers' practices) and ‘why’ (e.g., teachers' instructions, approaches and purposes) of the activities organised during these argumentation lessons; it highlighted exactly *how* the teachers develop and evolve their pedagogy over time, as well as the instructions with their students. A few researchers (e.g. Berland & Hammer, 2012; Pimental & McNeill, 2013)) investigated teachers' instructional practice of scientific argumentation to influence the way students understand and engage in science. I noticed that not only teachers’ instructional practice but also their argumentation approaches and purposes have an effect on how students participate in and engage with science lessons and construct their written work. The ways in which the teachers in this study utilised unique strategies and teaching approaches suggests that teachers tend to adopt methods they feel able to manage in practice. This is a novel insight not previously highlighted in previous studies. The result also shows that some teachers, like Padma, might prefer to use familiar and less risky strategies (such as pair discussion and well-structured writing frames) in their argumentation practice. Other teachers, like Mala, might be more willing to take risks and choose more ambitious strategies (i.e. role-play) once convinced that such strategies could work. The results suggest that teachers should provide clear instructions and purposes to encourage students to engage with this practice, followed by progressively increasing the complexity once students improve their understanding of argumentation practice.

Another important learning from this study for argumentation practice is that I concur with Dawson and Venville's (2010) findings concerning the importance of the choice of contexts and topics for argumentation lessons, particularly as teachers believe students should possess the prior knowledge to engage in meaningful discussion and construct their arguments. I conclude that teachers and researchers should carefully select the context for argumentation lessons (i.e. a scientific or SSI context) not only to ensure that students possess sufficient background knowledge to engage in scientific argumentation but also to promote students' skills of thinking and reasoning. The results of this study also suggest that some teachers, like Ray, may consider that argumentation lessons (particularly those involving scientific context) should be more structured to maintain students' engagement and encourage group discussions. This result was not supported by Pimental and McNeill (2013), and other studies (e.g., Berland & Hammer, 2009; Berland & Reiser, 2009) found that the lack of structure in argumentation lessons tends to motivate students to engage in active discussion. As seen by the profile of lesson structure (particularly the lessons of Mala and Ray), there is a clear structure of applying small-group discussion followed by whole-class discussion, suggesting that the argumentation lessons should be organised in a structured way.

My concerns are similar to those expressed by Pimental and Mcneill (2013) stated that teachers' current perceptions of their students' lack of motivation, abilities and content knowledge concerning science can serve as a barrier to improving classroom discussions and incorporating scientific argumentation into science teaching. These aspects formed the primary concerns raised by the teachers, especially Ray and Padma, regarding their students' readiness to engage in this science practice. The findings of this study suggest concurring with existing research (e.g. González-Howard & McNeill 2019) that it is vital for teachers to offer frequent and varied encouragement to their students to promote their engagement in this practice. This study also found that teachers' instructions, approaches, and emphasises influenced students' engagement, participation in small group and whole-class discussions and written work, as well. This study and previous research (e.g., Scott, Mortimer, & Aguiar, 2006) have suggested that teachers may not be aware of the importance of their impact, particularly when it comes to students' engagement. As a result, it is critical to assist teachers in improving their understanding of argumentation norms, along with the roles of teachers and students in these practices, to implement this practice in science lessons.

A critical point that should be addressed in incorporating argumentation into science learning is that the participant teachers struggled to find a balance between dedicating sufficient time to expanding students' understanding of science content and addressing the argumentation approach. This deterred them from employing this practice when teaching new scientific context. They, therefore, believed that argumentation activities should be used to assess students' understanding and find out about any misconceptions students might have. The teachers emphasised the importance of using argumentation to evaluate students’ understanding of science learning, so assisting them in expressing their thinking and reasoning and enhancing their capacity to discuss their ideas and uncover misunderstandings. Although this study was not primarily concerned with students’ science learning, I observed that the student's knowledge of science benefited from the teacher's scaffolding of argumentation approaches, both socially through discussions and cognitively through written work. I suggest that attention to scaffolding instructions may be one way to address concerns about students' science learning and engagement to become involved in class discussions. I also concur with McNeill and Pimentel's (2013) conclusion that argumentation should not be the sole source of discourse in a science classroom. A more dialogic style could prove more beneficial if the purpose of the lesson is to examine and probe students' opinions; a more traditional authoritative dialogue pattern may be more effective if the purpose is to teach scientific content.

The existing literature supports the claim that few students are currently being offered opportunities to practice scientific argumentation

(Duschl et al., 2007) as it is challenging for students of all backgrounds to effectively participate in this practice (Driver et al., 2000; Sadler, 2004). The data from the reflective interviews indicates that Ray considered the argumentation approach appropriate for older students with sufficient scientific knowledge. On the other hand, Padma and Mala believed that younger students would benefit from this approach through effective scaffolding and modelling. This indicates that the teachers' practice was influenced by their views of their students' capabilities with science. This result suggests that attention should be given to teachers' negative perspectives of their students' capabilities. Sustained practice by providing additional support through resources and demonstrating to teachers that even younger students can participate in this activity, as also shown in several studies (e.g. McNeill, 2011; Reznitskaya et al., 2007; Ryu & Sandoval, 2012), could be one way to address this.

Another fundamental learning from this study is related to teachers' scaffolding argumentation processes. It is vital to recognise the variety of scaffolding argumentation processes teachers utilise in the different components of science lessons. The variation prompts the question of whether a particular form of scaffolding can be more appropriate or productive. For instance, if a teacher realises that he or she is not able to encourage students to evaluate each other's arguments, it would be beneficial for her to scaffold the next argumentation task towards this process. This finding suggests that intentionally scaffolding argumentation processes and structuring argumentation activities in particular ways (i.e. evaluating arguments) could prove an effective approach to supporting students with particular aspects of this science practice.

Additionally, this study confirms similar points made by Simon et al. (2006) and Zohar (2008) that teaching science through scientific argumentation requires a considerable shift in teachers' pedagogies, instructions, and practices, which may result in some, such as Ray, continuing to follow traditional forms of classroom instructions and discourse (e.g., Initiation, Response, Evaluation pattern) even if they feel the new approach can support their students' science learning (Alozie, Moje, & Krajcik, 2010). A recurrent conclusion found in this study and research concerning the incorporation of scientific argumentation into science learning (Bell & Linn, 2000; Berland & Reiser, 2009; Jimenez-Aleixandre et al., 2000; Osborne et al., 2004; Sadler, 2004; McNeill & Pimental, 2013) is that students experience difficulty engaging in this practice and require instructional support. I concur with suggestions that it is vital to understand specific instructional strategies that help students understand this practice in relation to teachers' purposes and emphasis of using this approach (McNeill et al., 2017; Sandoval et al., 2019).

The findings reveal that teaching science through scientific argumentation is a complex process while indicating that the structure of lessons and scaffolding argumentation practice can be varied and effectively evolved over time (Simon et al., 2006). The factors, such as sustained practice, collaborative work and reflection on practice, that assist teachers' pedagogical development have already been found by similar research in the field (e.g., Christodoulou, 2011; Osborne et al., 2013). Findings from classroom practice and reflective interviews suggest that pedagogical development of scientific argumentation in school science can only occur through intensive and sustained practice, requiring teachers to dedicate additional time and use collaborative work and reflection, reflective practice, and classroom examples or models of the major identifiable steps. It is also suggested that science teachers require adequate resources, including activities they can modify or use; guidance on organising and managing small group discussions; instructions on how to introduce, sustain, and complete argumentation tasks and support students' argumentation skills; and seek feedback on the approach's theoretical assumptions and self-reflection.

I learned from the results that the teachers developing the pedagogy of scientific argumentation most effectively were those who actively engaged in their own learning while implementing this approach, indicating a need for active and reflective practices of new learning. The results of this study highlight that the benefit of collaborative lesson planning sessions for sharing ideas, reviewing and discussing materials, and reflecting on practice cannot be underestimated. The lesson planning meetings were essential to facilitate teachers' interactions with others and stimulate their own experiences and ideas. The teachers were able to see their own classroom practices as a beneficial and necessary step toward pedagogical learning and change. Similar to previous research (i.e. Reiser, 2004) demonstrating the critical role of reflection and active involvement in the learning process, my study also highlighted the importance of reflexivity, as teachers use their previous experiences to make changes in future practice within their unique instructional context. This result has not been highlighted before. This study suggests that the participant teachers achieved additional knowledge and agency through a reflexive process that included planning, implementing, reflecting on and evolving their argumentation pedagogy.

More significantly, the concept of agency was used to investigate teachers' pedagogical development of scientific argumentation through the examination of teacher reflective interviews. This concept helped me investigate the developments in agency in terms of a sense of purpose, mastery, autonomy to act and reflexivity while developing the scientific argumentation pedagogy in practice. In accordance with earlier research on the development of agency (e.g., Oolbekkink-Marchand et al., 2017), the results indicate that the teachers developed their agency in a varied manner as they incorporated scientific argumentation into their practice to improve their teaching abilities and establish confidence (Priestley et al., 2012). Agentic teachers, such as Mala, sought out possibilities for their students to learn in response to changing circumstances that changed their pedagogic practices and their own perspectives on future practice. As shown by the observational data, the teachers' decisions and practices were diverse, as evidenced by their unique learning and teaching approaches (Vähäsantanen & Eteläpelto, 2009). The teachers with a high degree of agency, like Mala, recognised areas in which they lack knowledge and skills and made an effort to acquire them. Their positive experiences with this practice strengthened their dedication to ongoing practice throughout the two years, particularly their beliefs about the values of teaching science through scientific argumentation (Biesta et al., 2015; Priestley et al., 2012; Oolbekkink-Marchand et al., 2017). Additionally, the findings demonstrate clearly how teachers' interactions with their students, as well as their past experience and accomplishments, developed their agency and practice (Bonner et al., 2020, Lu et al., 2021).

6.3 A critique of this study

This section critiques the current study by re-examining some of the methodological decisions and limitations. As previously noted in chapter 3, the case study approach includes the examination of a single phenomenon (Yin, 2003), i.e. the pedagogy of scientific argumentation. The in-depth and intense quality of this analytical technique was critical in this study for identifying patterns in science practices, as well as attempting to examine the realities (i.e. classrooms and contexts) underpinning these situations. Thus, in addition to assisting the examination of patterns within the investigated 'embedded instances,' this case study approach enabled me to obtain a deeper understanding of the influence of contextual variables on these situations, i.e. a variety of science contexts, teachers' practices and years. The position taken in my own study was that knowledge is socially constructed and that I could not assume that all of the interpretations, explanations and connections established between lesson observations and interviews could be viewed as a complete representation of the cases explored throughout this study.

Despite the positive outcomes arising from the methodological use of case studies, I recognised that there were a number of limitations, primarily related to sampling procedure and size, the methods of data generation and analysis. This study only included a small sample of three science teachers who expressed an interest in participating. I found that teachers engaging from the outset in utilising this scientific approach for each half term were not successful in their investigations. The teachers' busy schedules (which included sharing a classroom with another science teacher) meant that such lessons were given less frequently than intended, which may have restricted the practices I was able to observe, as well as the opinions I obtained from the interviews. Moreover, despite their collaboration when planning and designing lessons, the teachers implemented this practice in several ways, providing me with a variety of observations and instances of practices. As a result, this form of the sample may initially provide a barrier to the development of relevant findings for other teachers (e.g., those with little interest in teaching science through scientific argumentation). Therefore, this study has only enabled me to provide evidence with regard to the pedagogy of scientific argumentation and change I observed in teachers' pedagogy, practice, and instructions, rather than offering a theory of instruction to improve student learning.

While the combination of a variety of data generation methods did not always result in a strict triangulation of the findings (i.e. looking at the same research question in various ways), the interconnecting observations, along with the interviews with teachers and students' written work, enabled me to cross-check and expand my own interpretations. I recognise that these data generation methods have their limitations and do not represent all of the opinions and practices of the participant teachers. In addition, I could have studied other contexts with the observations, particularly those first identified by the teachers as opportunities to compare and contrast their practices in various science contexts.

However, I was prevented from this due to obstacles associated with being a single researcher responsible for all of the data generated in my study. Additionally, my active participation in their classes may have influenced the teaching methods used, i.e. knowing I was interested in how they implemented scientific argumentation in their practice, they may have adjusted their approach to match my study objectives. In order to overcome this obstacle, I chose to observe them teaching different contexts over a two-year period, which I consider 'weakened' their initial willingness to please me in their routines.

To assure the validity of this study's findings, which are often difficult to obtain with case studies, I followed the suggested procedures in the literature: detailed description (Guba & Lincoln, 1989) and triangulation of various datasets (Creswell & Miller, 2000). Additionally, I prefer to use the term relatability, which refers to the degree to which information learned in one context is relevant to or applicable to other situations or to the same context in a different time frame (Bassey, 2001). Therefore, the main focus is that a detailed explanation of a single case or a small number of instances, if written well, can assist other practitioners in seeing their own circumstances represented and determining what is appropriate in their own practice while presenting the results of this study. I provided an in-depth account of the circumstances in which the participant teachers engaged scientific argumentation in their classrooms throughout time. By providing a detailed description of the classroom environment and activities, including the teachers' scaffolding of scientific argumentation and students' written work, I enabled what Guba and Lincoln (1989) referred to as 'transferability judgments on the part of others who may wish to apply the study to their own situations (or situations in which they have an interest) (p. 242).

The teachers taking part in my own study gained knowledge and experience as a result of the collaborative work and reflection on their practice. These processes helped the teachers feel empowered to use a new approach in their practice and evolve their pedagogy. Fullan (2007) argued that teacher-to-teacher interactions in everyday school life could significantly impact educational change by establishing a personalised professional learning community within the school. However, I was only able to observe this aspect during the collaborative lesson planning. In the reflective interviews, the teachers noted wishing to expand this process to the entire science department. However, I acknowledge the potential limitations of the questions, primarily as they were drawn up to identify instances of agency in teachers' practice in scientific argumentation.

Additionally, the range of issues raised in this research demonstrates the complexity of this professional learning process, which was not entirely anticipated. I initially arranged with the teachers to employ the argumentation lessons on a single occasion in each half term to ensure constant teaching with scientific argumentation. However, such meetings, and therefore the lessons, were held less frequently because of the teachers' busy timetable, demanding subject content and sharing their classrooms with another teacher. This led to a variation in their participation. Therefore, there was considerable variation in the way the teachers utilised argumentation-based activities in their classrooms, partially due to being asked to implement a set of instructional practices rather than any specific curriculum materials.

However, this study concludes that teacher professional learning should recognise that alteration and customisation are inherent features of learning (O'Donnell, 2008). I agree with the view of Osborne et al. (2013) that each teacher is unique, while no student responds in an identical manner to stimulus. Due to acknowledging the complexity of working with teachers in highly variable contexts (Opfer & Pedder, 2011), I did not seek to establish any identifiable differences when it came to outcomes. My concern was not with the fidelity of the implementation of scientific argumentation in the classroom, but rather that teachers took ownership and incorporated scientific argumentation in their practice (Simon et al., 2006).

Even though similar results relating to the implementation of science lessons with scientific argumentation have been previously explored (e.g., McNeill et al., 2017; McNeill & Knight, 2013; Osborne et al., 2013; Simon et al., 2006), I feel my own study makes specific contributions to educational knowledge through providing a comprehensive analysis of teachers practices in the processes of planning and implementing in different contexts and across years, applying embedded case study and investigating teachers' pedagogical development through the lens of agency. The next section will discuss the unique contributions of the study to educational knowledge and the implications of this study for future research.

6.4 Contributions to educational knowledge and implications of the study for future research

Throughout this thesis, I have argued for the importance of incorporating scientific argumentation into science education, as well as the necessity of examining teachers' approaches and purposes in this practice as they develop their pedagogy of scientific argumentation and utilise resources addressing this practice. And I believe that the data and analyses offered in my findings chapters have provided some insight on the possibilities associated with scientific argumentation, science teachers' pedagogical development and practices, as well as students' engagement with this practice. This section provides contributions to the existing literature and methodology in three ways, most notably by: (i) developing a holistic understanding of the key characteristics of teachers' pedagogical development of scientific argumentation as a new pedagogy, (ii) using an embedded case study to identify the variations of teachers' approaches, purposes and classroom practices that incorporate scientific argumentation into science lessons, and

(iii) using the concept of agency as a lens to investigate teachers’ pedagogical development. I will discuss these key contributions in further detail below. This section also offers recommendations for future research and implications for policy and practice in teacher learning and practice.

This study contributes to the more than two decades of work that investigated teachers’ pedagogical development of scientific argumentation into science classrooms by giving new insights into the complexity of classroom practices. First, I believe there is essential learning from this study that could be relevant to the field of teacher pedagogical development. In terms of assisting teachers in developing a sophisticated understanding of scientific argumentation pedagogy, including scaffolding argumentation pedagogy, structuring argumentation lessons, organising students for group discussions, comprehending activity design, and selecting and effectively utilising argumentation activities and resources (Simon & Richardson, 2009), my own study builds on previous research focusing on the development of teachers’ argumentation pedagogy (Martin & Hand, 2008; McNeill & Knight, 2013; Osborne et al., 2013; Simon et al., 2006) and the importance of continuous pedagogical learning, alongside collaboration and reflection (Darling-Hammond et al., 2017). It is worth noting that several researchers (e.g. McNeill & Knight, 2013; Osborne et al., 2013; Simon et al., 2006) conducted their research on secondary science teachers' pedagogical development of scientific argumentation as a part of their research. However, these studies were not specifically designed to examine how science teacher develop their pedagogy of scientific argumentation through collaborative work and reflection over a period of time in the processes of planning and implementing this practice. Therefore, although the current study was limited to three science teachers, it extends beyond these previous studies’ focus in terms of providing in-depth insights into the development of argumentation pedagogy in the processes of planning and implementing this practice, examining variations of teachers' argumentation approaches and purposes in the different contexts and across years, as well as identifying potential reasons why teachers continue to struggle with scaffolding their lessons, incorporating this approach into practice, structuring their lessons and orchestrating discussions in their classrooms. The findings also contributed to our understandings of how science teachers plan and implement argumentation lessons collaboratively with their colleagues and a researcher. The results may be utilised to develop more focused PD materials and courses to assist teachers in implementing scientific argumentation in their classrooms for teaching science. The results, in particular, on how various teachers implemented this approach and scaffolded it in their practice may serve as an inspiration for other teachers working in similar contexts.

Second, this study has contributed to knowledge in terms of research methodology, designed using an embedded case study, which included numerous units of analysis that focus on various aspects of the main case of the pedagogy of scientific argumentation. Most of the previous research (e.g. Martin & Hand, 2008; McNeill & Knight, 2013; McNeill et al., 2017; Simon et al., 2006) used a case study as a methodology to identify commonalities and differences in teachers' pedagogical changes and practices. Through the embedded case study, I was able to demonstrate teachers' pedagogical development and practice from three distinct perspectives. These embedded cases were created based on the unique characteristics of a selected case in order to examine the embedded case's uniqueness and provide further interpretation for these data. Additionally, visualising the findings of the lesson structure and SAP using Nvivo 12 scripts, which had not been previously used, helped me not only identify commonalities and differences in teachers' practices and changes in their pedagogy of scientific argumentation but also to make comparisons of how argumentation lessons were scaffolded and implemented over time and across contexts. I believe the data and analysis offered in my empirical chapters provide some insight into the practices employed by science teachers, using scientific argumentation as a novel strategy, as well as students' construction of written work as an indication of their teachers' approaches and teachers' development of practice.

Thirdly, this study has provided a theoretical contribution as it illustrates the potential of using the concept of teacher agency as a lens for investigating teachers’ pedagogical development of scientific argumentation in terms of the interconnected four components of agency, including a sense of purpose, mastery, autonomy to act, and reflexivity. The findings contributed to our understandings of how the concept of agency in practice provided insights into teacher learning. Using the concept of agency as a lens enabled me to examine how science teachers develop and implement their pedagogy of scientific argumentation and identify the factors that support or hinder the development of agency in practice. I agree with Buchanan's (2015) claim that agency was manifested itself in a variety of ways in practice while teachers implemented scientific argumentation in their practice. Thus, broadening our knowledge of teacher agency by incorporating a study of teacher agency in action would deepen our knowledge and understanding of the relationship between teacher learning and teacher since this may influence our future efforts to assist teachers in their pedagogical development. This concept may serve as a valuable basis for evaluating the pedagogical development of a new scientific approach. Therefore, I believe that examining teacher professional learning through the lens of agency might be an additional lens.

Additionally, the findings of this study raise a number of important implications for in-service science teacher education, their professional learning, as well as innovative curricular resources. It led to a number of key ideas I feel to be worthy of further consideration.

Firstly, this study benefited from the use of its unique environment as a long-term professional learning initiative to investigate how science teachers develop their pedagogy of scientific argumentation and their agency in this regard through collaborative work and reflection. It establishes that collaborative ways of working and learning over a period of time, alongside reflection, form significant factors when planning in-service professional learning projects (Darling-Hammond et al., 2017). Throughout this study, I have highlighted the significance of collaborative work, reflections, and sustained practice, as well as their incorporation into teacher learning. This study also has revealed that when teachers willing to take risks, despite lacking in confidence, are provided with time for collaborative work, reflection, and sharing, they have opportunities to build on a sophisticated understanding of the new approach. This is particularly important because practices must be critically commented upon and shared among colleagues through collaborative effort to be effective in school communities (Hairon et al., 2017). The teachers also brought their own understandings and knowledge to these meetings, which I concluded to be crucial for the teachers' own learning to plan and implement a new pedagogy. An implication of my findings for the creation of an environment in which teachers share their experiences and challenges when it comes to advancing their learning, including interpreting how any new practice could be modified for their own students and teaching context.

Secondly, the current study findings emphasise the importance of finding the balance between encouraging science teachers to take risks necessary for their professional learning and providing them with adequate support (i.e. collaborative work, adequate time and resources) to apply new instructional strategies. These materials encourage teachers to develop their own ideas and activities around the new approaches, incorporate scientific argumentation into practice and assist teachers in developing future lessons. I recommend that future research might investigate how science teachers use materials in diverse ways and whether they require different types of support to use materials and resources in their lessons.

This study also suggests that professional learning could be customised to the specific needs of individual teachers and raised awareness of when scientific argumentation is taking place, including when it commences and whether it arises organically or by design, thereby supporting their existing practice and agency. Science teachers also require further support and appropriate resources to handle their unique challenges during the implementation of this approach. The present study suggests that investigating individual argumentation approaches in more detail could identify what is needed to prompt teachers to utilise and evolve these strategies. Moreover, this study suggest that teachers only implement a new approach if they internalise a clear picture of why an approach is critical for science teaching and learning, as well as how it could be applied effectively in science classrooms, build on their current teaching pedagogy and pedagogical understanding. I, therefore, consider that professional learning activities should be customised to individual teachers': (1) pedagogical knowledge and experience with both small and whole-class discussions; (2) previous teaching of scientific and SSI contexts; and (3) familiarity with argumentation processes. It is vital that teachers lacking expertise familiarity with any (or all) of these elements be offered additional time to practice in familiar contexts. I believe that communicating these perspectives by using in-depth case studies has the potential to assist teachers in promoting long-term educational change. Future research could thus focus on the role of scientific argumentation in impacting on teachers' general pedagogical abilities and on the developmental phases of various components of argumentation lessons, i.e. small or whole-class discussion.

Moreover, through lesson planning meetings, the teachers engaged in collaborative and continuous learning to improve their knowledge and understandings of scientific argumentation for professional learning (Hairon et al., 2017; Stoll et al., 2006; Vangrieken et al., 2017), which included supporting teacher agency (van der Heijden et al., 2015) (i.e. collaborative work, resources, and reflective practice), developing competence and confidence in their practice, utilising this competence and confidence to make effective decisions, and developing their agency. I conclude that the combination of various aspects of agency can be fruitful for enhancing teachers' learning, both in terms of their own learning and within their professional community (Vähäsantanen et al., 2017). Therefore, my study suggests that it would be valuable for the complete school community to take part in collaborative in-service teacher education (Darling-Hammond et al., 2017). In this way, teachers lacking motivation would benefit from community-wide activities, while such experiences would support teachers' agentic practice of scientific argumentation in order to focus on new pedagogical skills and practices. In addition, this would encourage interpretation of how the new practice could be modified for their students and differing aspects of science. Building upon previous studies and the findings of this study, further exploration is needed to identify the connections between teacher agency and professional learning to further enhance students' learning.

Thirdly, science teachers also need intensive professional learning projects to understand the main goals of teaching through scientific argumentation. The science teachers in this research participated in a two-year study and discussed their teaching experience by means of follow-up reflective interviews and lesson planning meetings. Reiser (2013) noted that continuous and intense professional learning initiatives entail more than sixty hours of support during the summer break, followed by thirty hours distributed throughout the school year. In addition, a minimum of two years of continuous teaching experience is necessary to be able to observe any significant changes in teachers' knowledge, beliefs, and practices (Osborne et al., 2013). I, therefore, consider that further research could follow these suggestions by focusing on how different aspects of professional learning projects influence argumentation instructions, including (1) time (i.e. length of professional learning); (2) participants' characteristics (i.e. gender, age, years of teaching experience); and (3) context (both scientific and SSI context). Moreover, I suggest that it may prove beneficial to examine the effectiveness and durability of professional learning initiatives through the lens of agency. I also suggest that a closer examination of the personal and social dimensions of teacher learning can highlight the provision of opportunities for teachers to engage in continuous processes of implementation of innovative ideas and reflection, with an emphasis on both knowledge innovation (new content) and also on 'innovativeness' (capacity building based on a sense of autonomy to act) (Fullan, 2007). According to Fullan (2007), "ownership (...) is more of an outcome of a quality change process than it is a precondition for success."

Lastly, I consider that future versions of the science curriculum highlighting further scientific argumentation could provide greater support for science teachers who have previously applied fewer student-centred strategies, indicating reasons for changing their teaching style to support students' learning (McNeill et al., 2013). Curriculum resources have the ability to assist teachers in promoting scientific argumentation (Lopez et al., 2017). This could also include guided argumentation activities to encourage teachers to utilise this instruction in their practice. Furthermore, reflective practice is important for teachers to identify their successes and weaknesses, thus fostering reflexivity.

Overall, my own study supports the conclusions of previous studies of teacher learning that an important aspect of learning is reflection and collaboration with others (Hoban, 2002). Additionally, face-to-face lesson planning sessions was found to be constructive and enabled teachers to discuss their ideas. I feel that the content of collaborative lesson planning meetings may have contributed to both the teachers' understanding of scientific argumentation and its value for science learning. Therefore, the planning meetings in my study concentrated on two aspects of teacher learning concerning scientific argumentation: their sophisticated understanding of argumentation as a scientific practice and their pedagogical acceptance of the benefit of incorporating scientific argumentation into teaching. While some of these skills can be acquired through experience, more structured support is required to improve pedagogical proficiency. I hope that they will be able to go further as they continue using the argumentation strategy in their practice.

What I learned through my own study is that continuous practice, reflection, and collaboration with each other (even other schools teachers) may help us, as science teachers, develop our pedagogical knowledge and agency in our teaching practices. We should be able to give these opportunities to deepen our pedagogical knowledge and practice. In Turkey, teachers are expected to use the same resources in the same way. However, each teacher is unique; therefore, we cannot expect science teachers to teach science in the same manner, even if they are provided with the same materials, resources, and plans.

The study's findings include several critical suggestions for Turkish policy and practice. In Turkey, professional learning takes the form of a series of compulsory and isolated activities, the content of which often falls short of addressing teachers' needs and demands. The present reform movement promotes school-wide professional learning by encouraging teachers to cooperate and share their expertise and practices. My study indicates that collaborative work, reflection and reflective practice may contribute significantly to schools developing the ability to build school-based learning activities for teachers.

If the MoNE intends to assist teachers' workplace professional learning, it should prioritise developing teachers' agency as a significant focus. While the literature has stressed the significance of teacher agency, empirical research on the development of teacher agency are inadequate (Oolbekkink-Marchand et al., 2017). Especially, there has not yet been adequately research investigated the concept of agency in the Turkish context. There is also no compromise on the concept in Turkish translation. The discussions about the quality of education in Turkey mostly concern the educational system, the techniques used to transition among school levels, and instructional resources.

In contrast, the centralised and hierarchical nature of Turkish education and schooling may seem incompatible with the concept of teacher agency and school-based teacher learning. However, it should not be forgotten that the primary determinant of educational quality is the teacher. Teacher agency is a significant component impacting teachers' actions. As a result, emphasising teacher agency as a component of teacher learning may contribute to resolving educational challenges in Turkey. I believe that the development of teacher agency for educational development in such a context, such as Turkey, could be the key motivators for promoting teacher pedagogical development and creating effective workplace professional learning opportunities for teachers.

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Appendices

Appendix 1: Reflective interview with science teachers

- Do you think you have used argumentation activities in your classrooms before participating in this study? What do you think argumentation is?
- What are your thoughts on argumentation-based science teaching so far? How do you think your ideas about argumentation-based science teaching have changed?
- How is argumentation different from other ways you teach science?
- What do you think is the value of argumentation for science teaching and learning? What is the value for your students' learning?
- Which resources did you use in your lesson(s)? Why were these important? What types of resources do you think you would use to implement scientific argumentation effectively? Probe for science lesson plans.
- When you implemented your lesson(s), what were some things that helped you? What are the strengths and challenges you experienced in implementing scientific argumentation in your classroom? Probe for: timeframe for planning, guidelines for lesson plans
- How did the lesson go? What went well? What didn't go so well?
- What are the difficulties you experienced in implementing scientific argumentation? What are the challenges your students experienced in your lesson?
- Did anything go differently than you expected? If so, please describe how. (Please refer back to the lesson plan)
- Have you made any arrangements or changes to your lesson before implementing it? Why or why not?

- Did your students meet your learning goals? Probe for: analysis of students' work and look for things they wrote that show their success and difficulties
- What did you learn from this experience? How did this experience influence your understanding of science teaching through scientific argumentation, and factors you need to consider in teaching science through scientific argumentation?
- Based on what you learned from this experience, would you further modify this lesson? If so, how would you modify it for the next time you teach it?
- What aspects of this lesson will shape your plans for your next lesson?
- What resources will you use to plan for the next lesson?
- What skills will you consider in planning for your next lesson?
- What additional changes, if any, would you make to your lesson? Why would you make these changes?
- Please feel free to address anything else you think is relevant.

Appendix 2: Demographic Information about the participant students

Table 1. Information about participant students 2017/2018

Teacher Name	Class / Ability		Students	Gender
Ray	Y7	Mixed	25	Female: 9 Male: 16
Padma	Y7	Mixed	25	Female: 9 Male: 14
Mala	Y7	Mixed	24	Female: 11 Male: 13

Table 2. Information about participant students 2018/2019

Teacher Name	Class / Ability		Students	Gender
Ray	Y7	Mixed	24	Female: 10 Male: 14
Padma	Y7	Mixed	24	Female: 10 Male: 14
Mala	Y7	Mixed	24	Female: 9 Male: 15

Appendix 3: Two-year timeline for data generation

First year of this study	**September 2017- Getting a contact with the school**			
	September 2017- First introductory session with the participant teachers			
	16 Novermber 2017- Argumentation lesson planning meeting- Dropping a box[11]			
		Mala	Padma	Ray
	Date of observation	**30/11/2017** 07/12/2017	**21/11/2017** 27/11/2017	**05/12/2017**[12] 29/11/2017
	Date of reflective interview	12/12/2017	18/12/2017	14/12/2017
	February 2018- Argumentation lesson planning meeting- Circuits			
		Mala	Padma	Ray
	Date of observation		20/02/2018 19/02/2018	27/02/2018 28/02/2018
	Date of reflective interview			
	15 March 2018- Argumentation lesson planning meeting- Phases of the Moon			
		Mala	Padma	Ray
	Date of observation	**23/04/2018** 23/03/2018	**17/04/2018**	
	Date of reflective interview	23/04/2018	02/05/2018	
	10 May 2018- Second introductory session			
	17 May 2018- Argumentation lesson planning meeting- Food chain			
		Mala	Padma	Ray
	Date of observation	**24/05/2018** 24/05/2018	**05/06/2018**	
	Date of reflective interview	07/06/2018	11/06/2018	
	June 2018- Argumentation lesson planning meeting- Sound waves			
		Mala	Padma	Ray
	Date of observation	21/06/2018	19/06/2018	19/06/2018
	Date of reflective interview			
Second year of this study	**18 September 2018- Argumentation lesson planning meeting- Funding a Zoo**			
		Mala	Padma	Ray
	Date of observation	**25/09/2018**	**24/09/2018**	**16/10/2018**
	Date of reflective interview	18/10/2018	20/10/2018	20/10/2018
	November 2018- Argumentation lesson planning meeting- The effects of forces			

[11] The lessons being analysed were highlighted in bold.
[12] The underlined date of lessons were examined.

		Mala	Padma	Ray
	Date of observation	18/12/2018	17/12/2018	04/12/2018
	Date of reflective interview			
	January 2019- Argumentation lesson planning meeting- Metal-Nonmetal			
		Mala	Padma	Ray
	Date of observation	31/01/2019		
	Date of reflective interview			
	10 April 2019- Argumentation lesson planning meeting- Phases of the Moon			
		Mala	Padma	Ray
	Date of observation	**25/04/2019**	**25/04/2019**	
	Date of reflective interview	07/05/2019	01/05/2019	
	3 May 2019- Argumentation lesson planning meeting- Food chain			
		Mala	Padma	Ray
	Date of observation	**21/05/2019**	**12/06/2019**	
	Date of reflective interview	05/06/2019	12/06/2019	
	10 July 2019- Argumentation lesson planning meeting- Leisure centre			
		Mala	Padma	Ray
	Date of observation	**16/07/2019**		
	Date of reflective interview	16/07/2019		
	Date of general reflective interview	17/07/2019	26/06/2019	09/07/2019

Appendix 4: Dropping a box

Dropping a box[13]

This activity is an opportunity for pupils to construct an argument from a set of statements to provide an explanation for a phenomenon – in this case an object falling under gravity. The pupils are asked to select statements from a list of statements arranged in a sequence and to justify their choices.

Aims

The aim of this exercise is to develop pupils' understanding of forces by exploring forces that act upon a dropping stone and to provide an opportunity to reason and argue in a scientific context to develop an explanation for how an object falls.

Learning goals

In this activity pupils will learn to:

justify their choices of statements using reasons drawn from their knowledge of forces and their effects on objects.

learn to identify what kind of forces act upon an object when it falls.

Teaching points

Pupils will need some knowledge of forces such as gravity and the idea that forces can be added to produce a net resultant force. Encourage the pupils to search for more information in the textbooks if they are not clear. While the pupils work in groups, it may be helpful to go to each group and encourage them to draw some pictures to represent the forces acting on the object and their likely effects.

Teaching sequence

Distribute the activity sheet and ask the pupils to work in groups of 3 or 4. Take them through the activity telling them that their task is to decide on which is the

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[13] All activities were taken directly from IDEAS pack (Osborne et al., 2004b).

correct choice of statement whenever there is a choice to be made. The aim is to produce a correct explanation of what happens.

Explain to the pupils that they should provide reasons for choosing a particular statement and not another one. The groups should discuss the reasoning behind choices at each step of the statement sequence.

Ask pupils to select a representative who will present their line of statements to the class. Allow about 15 minutes for group work.

Finish by conducting a plenary discussion on the outcome. Begin by asking for box 3, who wants to argue for choice (a). Ask them their reasons why. Then ask if there is anybody who would like to argue for (b) or (c). Ask them why they think (a) is wrong. Continue like this through the list till you and the class have reached a consensus.

Dropping a box from a plane

Imagine that a box is dropped from an aeroplane, flying at a height of 1000 metres. It falls to the ground. The statements in the boxes below link together to explain how the box falls.

Some boxes contain more than one statement. In each of these boxes, pick the statement that you think is correct, and fits into the whole explanation. Indicate your choice by putting a line through the other statement(s) in the box.

Continue until you have chosen one statement from every box, to produce a complete explanation for the way the box falls.

1 There is a force of gravity on the box.

↓

2 This acts downwards.

↓

3a It is roughly the same size throughout the fall.

3b It gets a lot bigger as the box gets closer to the Earth.

3c It is biggest when the box is high up and gets a lot smaller as it falls.

↓

4a This force makes the box begin to accelerate downwards.

4b This force makes the box begin to move downwards at a steady speed.

↓

5 Once the box begins to move, there is also an air resistance force on it.

↓

6a This acts downwards, in the direction the box is going.

6b This acts upwards, in the opposite direction to the box's motion.

↓

7a The size of the air resistance force on the box is constant throughout the fall.

7b The air resistance force gets bigger as the box gets faster.

↓

8a The air resistance force on the box is much smaller than the force of gravity, and so it can be ignored.

8b The air resistance force on the box becomes quite large, and has to be taken into account.

↓

9a So the total force on the box is equal to the force of gravity, and is constant.

9b The total force on the box is the sum of the gravity force and air resistance, and this gets gradually less as it falls, because the air resistance increases.

↓

10a Therefore the box has a uniform acceleration throughout its fall.

10b Therefore acceleration of the box is biggest to begin with, and gets gradually less. Once the air resistance force becomes equal to the gravity force, the acceleration is zero and the box then falls at a steady speed.

10c Therefore the box falls at a steady speed throughout its fall.

Appendix 5: Should we have a new zoo?

SHOULD WE HAVE A NEW ZOO?

This activity is an opportunity to engage in argumentation about a socio-scientific issue. The issue is described in a letter distributed to the pupils and they are asked to argue for and against an issue in small groups – in this case, the funding of a new zoo – and provide justifications for their point of view.

Aims

The aim of this exercise is for pupils to generate arguments for and against the funding of a new zoo.

Learning goals

In this activity pupils will have the opportunity to:

generate ideas for and against the funding of a new zoo;

learn to use evidence to justify their conclusions about the desirability of a zoo;

work in groups to construct arguments collaboratively.

Teaching points

For this activity, pupils will need to carry out some research to use as an evidence base when justifying their positions. For instance, they could do internet research to find out more about zoos. Many students will have visited zoos and their personal experiences will provide a useful evidence base.

There are different ways this activity can be structured, for which there are different possible outcomes.

Teaching sequence

Distribute the letter and ask a student to read it aloud. Emphasise the purpose of the activity – to construct arguments, justified with evidence, either for or against the new zoo.

There are two different strategies that can now be adopted in this activity. The following guidance suggests two possible alternatives.

Group brainstorm and decision making

Organise the students into groups of 3 or 4 and ask them to generate arguments for and against the funding of the zoo. Give them about 15 minutes to do this, and provide some paper to record the outcomes of their discussions.

While the students are working, encourage discussion by asking the following questions to help generate thinking and argument. The questions may stimulate agreement or disagreement. The themes associated with keeping animals in zoos and animal survival are addressed by the questions shown in brackets.

Questions to stimulate agreement with zoos

1. Are wild animals killed by hunters and poachers? [Hunting]

2. Are animals in zoos well fed? [Food]

3. Are animals in zoos safe from predators that want to kill them? [Safety]

4. Do zoos allow you to see a large number of different animals? [Education]

5. Would animals have become extinct if it wasn't for zoos? [Survival/protection]

6. Can you see wild animals on the television living in their natural homes? [Alternative education]

7. Do wild animals have to find their own food? [Food]

8. Can zoos release animals back to the wild? [Recovery/protection]

9. Do zoos allow scientists to study rare animals? [Research]

Questions to stimulate disagreement with zoos

1. Do animals in the wild have lots of places to live in? [Space]

2. Is it cruel to keep animals in cages? [Ethics]

3. Can wild animals be protected in parks and nature reserves? [Protection]

4. Are wild animals afraid of human beings? [Ethical/psychological]

5. Can animals be bored and lonely in zoos? [Ethical/psychological]

6. Can animals breed in zoos? [Reproduction/survival]

Once students generate arguments, a further group activity is to ask them to rank the arguments from most important to the least important, and provide reasons to justify the ranking. This process will encourage further argumentation and should take about 10 – 15 minutes.

A useful ending to this strategy of presenting the zoo activity is to ask groups to present the outcomes of their discussions. Tell them that you want them to present what they have decided about the zoo and to give their reasons. Asking all the groups to present orally, one at a time is not necessary. Instead, pick a few groups and hold a whole-class debate after two or three presentations. Alternatively, each group could produce an OHT or poster to provide a visual resource for whole-class discussion.

Role play and individual decision-making

Plan to assign roles to students, using your knowledge of people who would have an opinion on the funding of a new zoo. For example:

Local residents

School teachers

School students

The council

Zoologists

Conservationists

Organise students into pairs and assign a role to each pair. Give 5-10 minutes for the pairs to take a position for or against the zoo, bearing in mind their role. Ask them to justify their arguments with evidence.

While this discussion is underway, listen to the groups to establish who is arguing for and against the zoo.

Reorganise the pairs, so that each person is now paired with a student who has taken on a different role with an opposing position. Give the students 5 to 10 minutes to present their arguments to each other, and to construct counter-arguments.

Now hold a plenary discussion where you ask whether any pupils changed their minds and why. You could also ask the pupils to vote for or against the zoo, then pick on some individuals to share their reasoning with the class.

Whichever strategy you choose, you can follow up by asking students to prepare their own written answer to the letter for homework.

INTERNATIONAL AGENCY

FOR PUBLIC FUNDING

LONDON, GREAT BRITAIN

Dear Student,

I am pleased to invite you to take part in a new project that will take place at your school. We are currently asking students to let us know if our agency should fund the opening of a new zoo.

Some people believe that zoos should be banned. Others think that zoos serve a good role in our society. We need your help in deciding whether or not we should provide financial support for a new zoo.

Your job as a class is to *provide arguments for or against the funding of the new zoo. There is no right or wrong answer for this project. It is important, however, that you provide reasons and evidence to support the claims you are making.*

As a reward for successfully finishing this work, you will receive a certificate and you will become an honorary member of the International Agency for Public Funding.

I hope that you will enjoy your task. I look forward to reading your reports.

Yours sincerely,

Dr. M. Smith

Director

Appendix 6: Why does the Moon have phases?

Why does the Moon have phases?

This activity presents a set of explanations about the phases of the moon that the pupils evaluate through discussions in small groups. Their task is to choose the best explanation and explain why they think their choice is the best explanation. The second part of the activity asks the pupils to indicate why the rest of the explanations are not as good and provide justifications for why not.

Aims

The aim of this exercise is to evaluate different arguments for what causes the phases of the moon. Pupils will be required to justify with reasons their choice of claims and also their reasons why they do not agree with other claims.

Learning goals

The learning goals of this activity are for pupils:

to learn to evaluate arguments and provide justifications for what they believe in;

to provide justifications for why they think alternative arguments are not plausible;

to learn the arguments for the scientific explanation.

Teaching points

For this activity pupils will need to know about the phases of the moon. It would be useful to demonstrate the different phases beforehand by using a model or other means.

Teaching sequence

Distribute the activity sheet and explain the task.

Probe the pupils’ understandings of the phases of the moon through a brainstorming session. This should take about 10 minutes.

Now explain that the pupils will need to choose the best explanation for the phases of the moon from the list in the table on the sheet and give reasons why they think it is the best explanation. They will also need to provide reasons for why the other explanations are not so good or they are wrong. Ask the pupils to get into groups of 4 or 5 and discuss each explanation together before putting their responses in the boxes on the sheet. Allow about 15 minutes for the group task.

Finally conduct a plenary of the results from all the groups. Go through each card and ask who would like to argue for this explanation. Then ask who would like to argue against it.

Phases of the Moon

Most people who have looked up in the sky and seen the Moon notice that it does not always have the same shape. Scientists say that the Moon has different phases. Many adults however cannot explain why the Moon has different phases. The following are some ideas which have been suggested to explain why the Moon has different phases.

Read the explanations carefully and discuss them in your group.

Choose the best explanation and give your reasons why you decided this was the best.

Then try to give reasons why you think the other explanations are not so good or are wrong.

A	The Moon spins around so that the half of the moon that gives out light is not always facing us
B	The Moon shrinks and then gets bigger during each month
C	The rest of the Moon is blocked out by clouds
D	We cannot always see all the part of the Moon which is lit up by the sun
E	The Moon moves in and out of the Earth's shadow and so light from the sun cannot always reach the Moon

I believe the best argument is

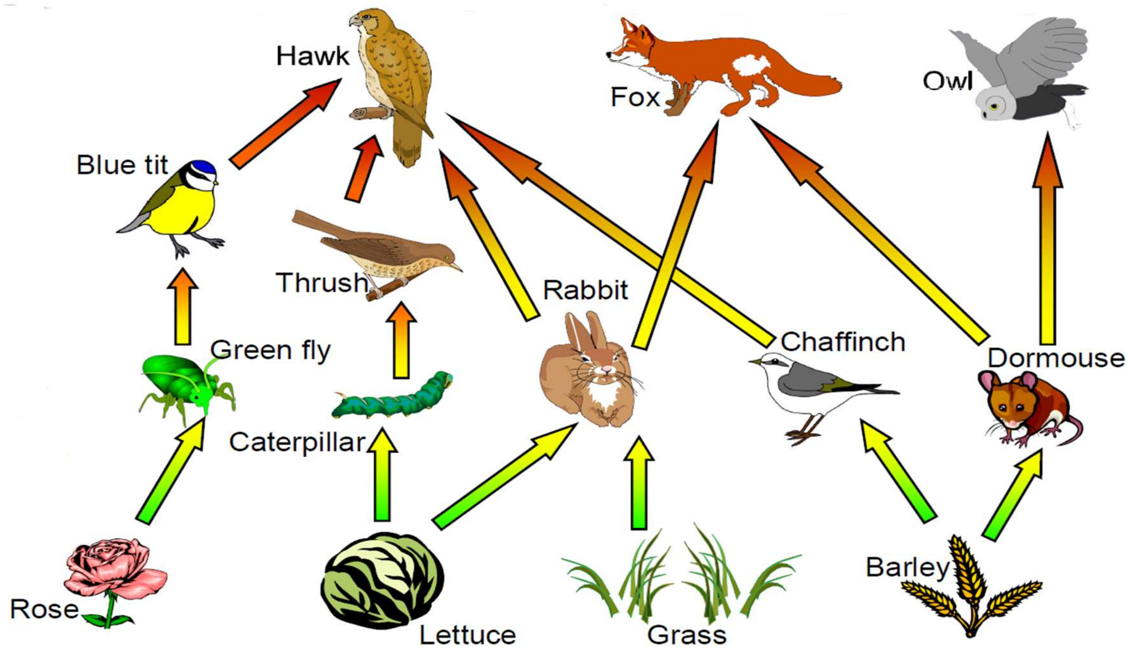
I believe this is the best argument because

Now use the boxes below to give reasons why you think the other explanations are either not so good or wrong. Write in the left hand box the letter for the explanation about which you are giving reasons.

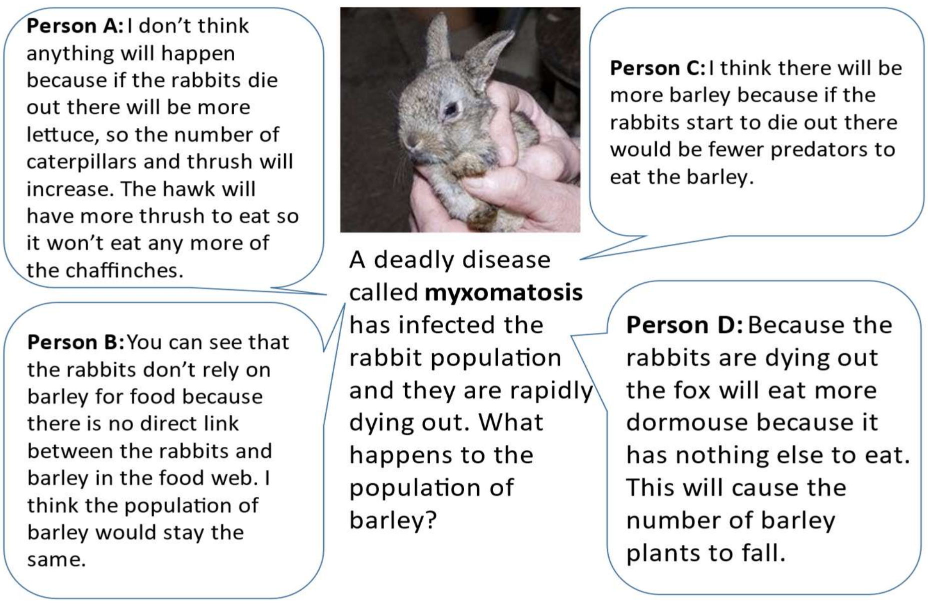
Appendix 7: Food chain

This activity presents a set of explanations about the distribution in food web that the students evaluate through discussions in small groups. Their task is to choose the best explanation and explain why they think their choice is the best explanation. The food web was designed to use as data and evaluate each explanation.

Food Web



Activity Sheet 1



Activity Sheet 2

Person A: I don't think anything will happen to the hawks because they are fast enough to steal lettuce from other organisms. They also a sharp bill and talons so they can fight other organisms for the lettuce. They could also swoop down and eat fish or anything they wanted off the ground.

After an especially cold winter, not many **lettuce** plants have survived. What happens to the **number of hawks**?

Person C: I don't think anything will happen to the number of hawks because you can see that they have other prey in case there aren't enough thrush, e.g. blue tits, rabbits, chaffinches.

Person B: If the lettuce plants die out the number of hawks will go down.

Person D: The food web shows that the lettuce is eaten by the caterpillar which is eaten by the thrush, which is eaten by the hawk. The rabbits also rely on lettuce for food. So, I think the number of hawks will go down because they won't have enough food.

Activity Sheet 3

Person A: When the roses die out the number of blue tits will decrease.

A disease called rose black spot infects rose bushes in the ecosystem and **all of the roses die out**. What happens to the number of **blue tits**?

Person C: When the greenflies eat the roses they are infected by the disease. When the blue tits eat the greenflies they also get the disease and die out.

Person B: You might think that the blue tits will run out of food and die out. However, I think that the number of blue tits will stay the same because they can eat other insects like mealworms. They could also get their energy from seeds and nuts.

Person D: I think the numbers of blue tits will decrease because the food web shows us that blue tits only eat greenflies which only eat the roses. If the greenflies don't have enough food to eat they will die out, which means the blue tits also won't have enough food so they will die out too.

Appendix 8: Should we locate a leisure centre in a nature reserve area?

SHOULD WE LOCATE A LEISURE CENTRE

IN A NATURE RESERVE AREA?

This activity is an opportunity to engage in argumentation about a socio-scientific issue. The issue is described in a letter distributed to the pupils and they are asked to argue for and against an issue in small groups – in this case, the possible siting of a leisure centre in a nature reserve area– and provide justifications for their point of view.

Aims

The aim of this exercise is for pupils to generate arguments for and against the possible siting of a leisure centre in a nature reserve area.

Learning goals

In this activity pupils will have the opportunity to:

generate ideas for and against the possible siting of a leisure centre in a nature reserve area;

learn to use evidence to justify their conclusions about the possible siting of a leisure centre in a nature reserve area;

work in groups to construct arguments collaboratively.

Teaching points

For this activity, pupils will need to carry out some research to use as an evidence base when justifying their positions. For instance, they could do internet research to find out more about leisure centres. Many students will have visited leisure centres and their personal experiences will provide a useful evidence base.

There are different ways this activity can be structured, for which there are different possible outcomes.

Teaching sequence

Distribute the letter and ask a student to read it aloud. Emphasise the purpose of the activity – to construct arguments, justified with evidence, either for or against the possible siting of a leisure centre in a nature reserve area.

There are two different strategies that can now be adopted in this activity. The following guidance suggests two possible alternatives.

Group brainstorm and decision making

Organise the students into groups of 3 or 4 and ask them to generate arguments for and against the possible siting of a leisure centre in a nature reserve area. Give them about 15 minutes to do this, and provide some paper to record the outcomes of their discussions.

While the students are working, encourage discussion by asking some questions to help generate thinking and argument. The questions may stimulate agreement or disagreement.

Once students generate arguments, a further group activity is to ask them to rank the arguments from most important to the least important, and provide reasons to justify the ranking. This process will encourage further argumentation and should take about 10 – 15 minutes.

A useful ending to this strategy of presenting the possible siting of a leisure centre in a nature reserve area activity is to ask groups to present the outcomes of their discussions. Tell them that you want them to present what they have decided about the possible siting of a leisure centre in a nature reserve area and to give their reasons. Asking all the groups to present orally, one at a time is not necessary. Instead, pick a few groups and hold a whole-class debate after two or three presentations. Alternatively, each group could produce an OHT or poster to provide a visual resource for whole-class discussion.

Role play and individual decision-making

Plan to assign roles to students, using your knowledge of people who would have an opinion on the possible siting of a leisure centre in a nature reserve area. For example:

Local residents

School teachers

School students

The council

Conservationists

Organise students into pairs and assign a role to each pair. Give 5-10 minutes for the pairs to take a position for or against the possible siting of a leisure centre in a nature reserve area, bearing in mind their role. Ask them to justify their arguments with evidence.

While this discussion is underway, listen to the groups to establish who is arguing for and against the possible siting of a leisure centre in a nature reserve area.

Reorganise the pairs, so that each person is now paired with a student who has taken on a different role with an opposing position. Give the students 5 to 10 minutes to present their arguments to each other, and to construct counter-arguments.

Now hold a plenary discussion where you ask whether any pupils changed their minds and why. You could also ask the pupils to vote for or against the possible siting of a leisure centre in a nature reserve area, then pick on some individuals to share their reasoning with the class.

Whichever strategy you choose, you can follow up by asking students to prepare their own written answer to the letter for homework.

LONDON, THE UK

Dear Student,

I am pleased to invite you to take part in a new project that will take place at your school. We are currently asking students to let us know about the possible siting of a leisure centre in a nature reserve area.

We need your help in deciding whether or not we should locate a leisure centre in a nature reserve area.

Your job as a class is to *provide arguments for or against the possible siting of a leisure centre in a nature reserve area. There is no right or wrong answer for this project. It is important, however, that you provide reasons and evidence to support the claims you are making.*

I hope that you will enjoy your task. I look forward to reading your reports.

Yours sincerely,

Ms. Samantha

Director

Appendix 9: Written template for the Zoo and Leisure centre activities

The issue we are discussing	
Arguments for	Arguments against
My conclusion is that	

Appendix 10: Prompts and content of argument cards

Argument Prompts (Evaluation)

- Why do you think that?
- What is your reason for that?
- Can you think of another argument for your view?
- Can you think of an argument against your view?
- How do you know?
- What is your evidence?
- Is there another argument for what you believe?

Content of Argument (Sentences starter)

My idea is…

The evidence to support my idea is…

This evidence supports my idea because…

Arguments against my idea are…

I would convince someone who doesn't believe me by…

Extended argument

There is a lot of discussion about whether…

The people who agree with this idea claim that…

They also argue that…

A further point they make is…

However, there are also strong arguments or evidence against this view.

They believe that…

Furthermore they claim that…

After looking at different points of view and the evidence I think that…

Appendix 11: Students' written work in each activity

Table 3. Ray' s students written argument in the Dropping a box activity

Student Groups/ Statements	Student Group 1		Student Group 2		Student Group 3		Student Group 4		Student Group 5		Student Group 6		Student Group 7	
3a	+	It was a relevant point it is usually constant because of air resistance and gravity someone might disagree it might seem bigger when it comes closer to the Earth, we crossed out the other statements because there were irrelevant	+	If you climb a thousand meter than you will still weigh the same, A is right because the box stays the same, b and c are wrong because the box doesn't change size.	+	This is true because the weight does not change. The box will not change size just because it is falling out of a plane the weight does not change	+	Because the box is light the wind pushes upwards on the box making it harder for gravity to grip.	+	I know this because when you are on the airplane you do not lose or gain weight. I chose this because and such a small distance the weight and the force of the gravity won't change much.	+	We know this as air resistance acts upwards, so it has …downwards. As if you check your weight at 1000m up, it would be the same as your normal weight. If you would not get quicker because gravity pulls you down and it is the same size.	+	Because if you get to the top of a tall building your weight will change slightly and will not make a difference
3b														
3c														
4a	+	This is the correct statement because at first air resistance is low and gravity which is much stronger pulls it down it makes the other statements wrong because the more gravity and less	+	It gets faster because the gravity is pulling it down to the ground.	+	This is because gravity is pulling it down.	+	When you drop something, it accelerates.	+	I know this because when an object is dropped the gravity causes it to speed up.	+	When you drop something, it gets faster when it falls (the second choice)	+	Because it is a weak object with no weight gravity would pull it down, but air resistance will make the box a parachute stile and would slow it down.

		air resistance makes it faster air resistance is lower than gravity												
4b											+	As if the gravity size is the same that means you fall at a speed which is steady (the first choice)		
6a					+	Gravity is pulling it down not the other way around.							+	Because it is the opposite of a …. direction to gravity that could help it.
6b	+	6A is wrong because it is not showing air resistance, somebody else might disagree because they do not think about air resistance because it was the most relevant.	+	Air resistance moves opposite direction to the object.			+	When falling the box has to push through the air therefore slowing it down as it descends.	+	I know this because when you put your hand out of a moving car you can feel this wind pushing out it.	+	Because we know that gravity acts downwards, so it (air resistance) should act upwards and we know that as gravity doesn't act stronger. also if you ride a bike when you…. resistance is stronger than the …..force		
7a					+	The box moves at the same speed however when you get closer to the ground air resistance is pulling you up whereas gravity pulling you down This is because it is falling in the same direction.								

7b	+	The air resistance gets bigger when the box gets faster because it's trying to make the box land safely, somebody else might disagree because number 3 it's roughly the same size, therefore they might believe that the size of the air resistance force is constant.	+	Because it gets closer to the ground.			+	Even though it has to push through air the gravity is still pulling down on it.	+	I know this because if you sit out while the car is accelerating the wind that is pushing feels harder.	+	If you put your hand out of a car at 20 mph, then your hand get pulled back however if you put your hand at 70 mph, then your hand gets pulled back very quick then it did at 20 mph.	+	
8a														
8b	+	We think this is right because without air resistance the box will not slow down, somebody might disagree because they believe air resistance is not relevant.	+	Air resistance become quite large it has to be taken into account.	+	People might disagree because they believe air resistance isn't relevant, Although gravity is pulling the box the box is still carrying weight.	+	The faster the box accelerates the more the air resistance increases.	+	This is because when you drop something the air resistance slows the object down.	+	It can become larger as it falls down slower so we need to know that it has to slow down.	+	
9a	+	We chose this statement because it seems relevant and when air resistance becomes the same as gravity the speed is constant, somebody might disagree because they believe that air resistance			+	As the box get closer to the ground air resistance is taking more control.								

		might become higher than gravity.												
9b							+	The air pushes on the underside of the box.	+	and....point it loses all speed……	+	As if you ride a bike and you have to pedal harder to go faster. and it is true as the two forces add up to the same force so gravity and air resistance are equally ….force	+	
10a														
10b	+	We chose this statement because air resistance is used to make the box land safely and the speed decreases because of the air resistance, somebody might disagree because they believe that there's less air resistance, so it means the speed it steady afterwards			+	Gravity forces control of the box and pulls it down.	+	This is because of the constant air resistance.	+	When something is dropped the speed is getting lowered by gravity and air resistance also faster it loses all speed the box cannot accelerate so it moves down at a slow steady speed.	+	As when you pedal at first it is easier but it get harder to go forward showing that it gets harder. when you pedal steady then you would be more at the same speed.	+	
10c														

Table 4. Padma' s students' written argument in the Dropping a box activity

Student Groups/ Statements	Student Group 1		Student Group 2		Student Group 3		Student Group 4		Student Group 5		Student Group 6	
3a	+	The size of gravity will never change			+		+	We thought that when you drop a pen it stays at the same speed all the time	+	Because gravity does not change, because the earth does not large.	+	It does not change.
3b												
3c			+									
4a	+		+		+				+	Because the gravity is pulling it down and it gets faster.	+	At the beginning, it (the box) is slower than faster.
4b							+	Because of our mini practical experiment with the pen				
6a			+									
6b	+				+		+	If the air resistance is acting down, there will not be an opposite reaction of gravity.	+	Gravity is downwards so air resistance is upwards there is a reaction force.	+	
7a							+	If the air resistance is bigger than the gravity, then the box would be going up	+	It (the size of the air resistance) will pull upwards if it gets stronger than gravity.		
7b	+		+		+						+	If it (the size of air resistance) changed shape, it would have changed the size of force
8a			+				+					

8b	+				+				+	It (the air resistance) cannot be ignored as it is still there, and it would go into the ground.	+	
9a							+					
9b			+		+						+	
10a			+									
10b	+											
10c					+		+				+	Unless it was very high, it went through the atmosphere.

Table 5. Mala's students' written arguments in the Dropping a box activity

Student Groups/ Statements	Student Group 1		Student Group 2		Student Group 3		Student Group 4		Student Group 5	
3a					+	Because as it goes down it (the box) changes speed. Disagree, because gravity acts faster once it is dropped and the air resistance increases, slowing down.	+	Gravitational forces will not change regardless of whether the box gets bigger or smaller Disagree, it inflates the faster it goes.		
3b	+	The air gets through inside the box. It inflates. I disagree because they need to explain more. Because this does not prove the point.							+	Because it (gravity) gets faster as it (the box) goes down. We agree because gravity needs to increase to be able to make the box fall.
3c			+	Trust Karina, she is always right. Air resistance increases. We disagree and not a good reason.						
4a	+	Gravity pulls the box down. I agree but need more explanation to prove			+	It accelerates downwards as the box falls down. Disagree because it decreases speed when it goes downwards.	+	Because the box is heavy. Disagree, gravity pulls it down.	+	Because the gravity force increases as it gets closer to the earth. We agree because gravity usually pulls things down.
4b			+	Because the box cannot first begin to accelerate instantly. Because the air resistance is slowing the box down.						
6a										

6b	+	The box goes down slowly because the force make it pull up.	+	The box is falling down, it will slow it down. Because air resistance follows the box will slow it down.	+	Air resistance acts upwards it, the opposite of gravity. Agree.	+	Air resistance will always be reacting upwards. Agree, this is because air resistance always makes objects slower not faster if it is acting downwards it would be faster.	+	Because the air resistance stops the box from going down, stops it. We agree but our reason was that the gravity always goes the opposite of air resistance.
7a							+			
7b	+	The faster it goes, the more the air goes through it	+	The faster the box falls, the faster the air resistance below it, it will hit the box.	+	It (the size of the air resistance) gets bigger as gravity seems to increase. Agree.			+	The air resistance increases as the gravity increases.
8a					+	This can happen because gravity needs to bring the box to make it towards the Earth. Disagree because the air resistance will not stop the box but will make it slower.			+	There is more gravity near the Earth, so the gravity force is larger than the air resistance.
8b	+	At a certain time, it (the box) cannot got any faster.	+	The force of gravity is weaker than the air resistance.						
9a					+	Disagree. Because I know you are wrong. 9B is correct. Because forces act in pairs not alone.			+	
9b	+	Because forces work in pairs and they must always have an opposing force acting in the other direction.	+	We know that forces act in pairs.						
10a					+	Disagree. 10B is correct.			+	
10b	+	At that point, it cannot change because it already reached a certain speed.	+							

10c										

Note: Underlined written work was obtained while students were evaluating each other work.

Table 6. Padma' s students' written argument in the Phases of the Moon activity in year one

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Students' group response / Students' response for each explanation	D	D	E	A	D	A
A	The moon doesn't spin in just orbit the earth it doesn't spin on its axis like the earth.	The whole moon faces us, but half is in shadow.	This is not only half of the moon that is covered.	Because in the video it doesn't show the moon orbiting which means you only see on side of the moon.	Because it's saying that the reason it orbits the earth it's to not give us light.	The moon doesn't spin it just orbits the earth while the earth spins.
B	The moon doesn't shrink.	The moon always stays the same size but it only looks like it shrinks and gets bigger as some parts are in shadow.	It's not possible because the moon is not able to shrink.	It's wrong because the moon never shrinks.	It doesn't make sense and the moon wouldn't shrink or get bigger only when the lights hits the moon our eyes see it bigger when it's a full moon it's bigger when it's half a moon it looks smaller but in general it doesn't get bigger or smaller.	The moon doesn't shrink it just covered by the earth's shadow.
C	Clouds are much lower than the moon and are closer to the surface of the earth	Clouds cannot block the moon in the same position the whole night clouds are much lower.	Clouds are not in space.	Because there aren't always clouds in the sky.	The moon doesn't get blocked because the clouds are transparent, and you can see the moon through it.	There aren't any clouds in space, clouds are created when water evaporates and there is no water to be evaporated in space.
D	The sun reflects light onto the moon since the moon orbits the earth…parts of being blocked and the part of that…have light reflecting on them could be facing us	This is correct because the moon orbits around the earth so that a part of the moon is not lit up and we cannot see it.	The sun doesn't light up the moon.		It makes more sense than the rest of them, D is a true fact.	It's true because the light is on the moon from the sun.

	on the other side of the world.					
E	The moon doesn’t move in and out of anything it just orbits the earth while the earth orbits the sun.	The moon has one set of orbits and cannot move out of the earth’s shadow.	Because you can only see certain parts of the moon.	It’s never gone, it’s always there.	The light always hits the moon and you can see it every night.	It is the clearest explanation and explain what we have learned when the moon is behind the earth the light from the sun cannot reach it.

Table 7. Padma’ s students’ written argument in the Phases of the Moon activity in year two

	Students' responses	Students' reasons for their responses
1	B	The moon shrinks and gets bigger each month. Old people go smaller so when it's a full moon which mean it's oldest, so it then shrinks and becomes a new moon and starts growing as a new-born does.
2	B	The moon shrinks since as it is getting older it shrinks like old people. When it is old it shrinks then a new moon makes it big since it is a new-born and grown up.
3	A	I believe this statement is true. This is explained by the different phases of the moon. For example, the new moon doesn't project light. This is because the side which projects light isn't facing the earth.
4	D	Because the moon doesn't belong to you, so it won't always shine for you.
5	D	We cannot always see all the parts of the moon which is lit up by the sun.
6	E	It has been explained thoroughly and fully it's clear what their point was and used relevant evidence to support their points, so E is the best explanation due to the reasons.
7	E	Because it gives solid evidence and you can see yourself if you look at the moon. C is wrong because there is no evidence and the clouds have a wavy outline and the moon always has sharp and clear edges.
8	E	Because the fact that we cannot see all parts of the moon as of the phases of the moon. We can see the new moon and others like crescent, first quarter, gibbous, full, last quarter, because they orbit the earth and it moves in and out the earth so that's why we say.
9	E	This proves that the moon moves in and out of the earth's shadow.
10	D	Because we know it does not rotate on its own axis. My evidence is that since the moon is smaller than the Earth, we should be able to see it move faster than a day and since we cannot see it. It shows that my point is right I think this is a strong argument.
11	A	Because when the moon is in front of the sun, the sun light behind the moon will not be lit up which means it will be dark for that area.
12	E	Because when the moon is in new, the sun cannot always reach it
13	D	I think D because the moon is way up in the sky and we do not have proof from people to see what is behind the moon and we also do not even think there is even anything behind the moon. It might be just circle.
14	B	The moon is made of cheese. A rat eats it. So, it gets smaller.
15	D	I think D is right because it makes sense.
16	A	I believe this statement is true. This is explained by the different phases of the moon. For example, the new moon doesn't project light.
17	D	Because science proves it. Also, if you think about it, it makes senses.
18	E	I think this statement is true. Because the moon orbits the earth and the earth orbits the sun. When the moon is at the back of the earth, earth's shadow can sometimes block the sunlight from reaching the moon. As for when it is on the sides of earth, it will show half a moon or full.

Table 8. Mala' s students' written argument in the Phases of the Moon activity in year one

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Students' group response / Students' response for each explanation	A	E	A	D	D	D
A	We know this because the moon orbits the earth so in certain months of the year parts of the moon are not lit up by the moon.	You need a flat surface to have a shadow… so the shadow cannot reach the moon.	It's logically correct because the sun's light does reflect of the side that gives out light.		The light bounces on the moon because it is facing us	
B	It cannot be this because if the moon shrinks and bigger.	If the moon shrinks, we will see it go up and down in size because on clear nights we still certain moon furthermore you cannot have clouds in the sky	It is illogically wrong, because they would change as well as the weather the moon's orbit would also change.	We would have discovered if the moon shrinks or gets larger, but it stays the same size.	The moon doesn't change size.	
C	Because on clear nights you still get caesent			There aren't always clouds in the sky, so the clouds cannot block of the moon.	The clouds don't cover the shine of the moon	If it is a clear night and there is not clouds in the sky, but the moon is still blocked.
D					The light of the sun bounces on the moon on different sides which makes the moon have different faces.	
E	There's not shadow in space because there is no flat surface.	Clouds cannot be found in space. Every time we see the moon it doesn't go down in size and if the moon was spinning then we would see it moving.			Doesn't move in and out of the shadow but it orbits the light still reaches the moon.	

Table 9. Mala' s students' written argument in the Phases of the Moon activity in year two

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9	Group 10
Students' group response / Students' response for each explanation	E	B	D	D	E	E	E (Later D)	E	E	D
A				The moon cannot spin because we can always see the same …	Because the moon is not in half also it doesn't spin half, it spins in one.		A is a strong point but it isn't as strong as E because of the information isn't too clear.	The moon doesn't spin around, it rotates around the earth.		The moon doesn't spin around, it rotates around the earth.
B		Because the moon is a shape and the moon orbit the earth.		The moon cannot shrink then get bigger, because if it did, we would start off as very small and then it becomes bigger but it happens only with the shadow.		This cannot be true because you cannot really change size as it is, it is just a rock.	It's big because there isn't enough evidence and information to support the point.	The moon doesn't suddenly shrink so that cannot be right.	The moon cannot shrink, the earth is tilted. In summer the earth is tilted towards the moon so that looks bigger. In winter, the moon tilted towards the sun and the moon looks smaller.	The moon doesn't shrink, it's always staying the same size but some parts of it doesn't get reached by the sun's light so it isn't showing.
C	It is impossible.			The clouds cannot block the moon 24 hours for 7		This cannot be because there is a bit of	C has no evidence, it's only the point, this makes the		We know that the moon is blocked	It's not always cloudy every day

				days, it cannot be cloudy in everywhere.		clouds at night but if you move an angle the moon is still in one of its faces.	point very weak.		out by the fact that it orbits the earth and the clouds are far away from each other. Therefore, there is no relevance.	and clouds and the moon are far away from each other and not next to each other.
D				The moon could be behind the earth and the sun rise goes on it and the shadow of the earth falls on the moon.			D is a strong point, but it has not got more information and evidence than E.			Yes we cannot always see sides of the moon.
E				The moon cannot get...from the earth because it doesn't produce anything.	The moon moves in and out of the earth's shadow, and so light from the sun cannot always reach the moon.	The moon orbits the earth so the earth is blocking the light.	It has been…truthfully and fully it's clear what their point was and used relevant evidence to support their points so E is the best explanation due to the reasons.	As we all know the moon rotates and the sun also so that means that it's good to the southern…and we can only see a bit of it.	When the moon orbits the sun some of the earth's shadow will cover some of the moon.	The earth doesn't have a shadow.

<u>Note:</u> Group 7 changed their response to D during joint-pair discussion.

Appendix 12: An analytical framework for the pedagogy of scientific argumentation

Codes for Teacher Instructions that Reflect Goals for Argumentation	Categories of Argumentation Processes as Reflected in Teacher Instructions	Statements / affirmations / requests from teachers to scaffold argumentation processes
Encourages discussion Encourages listening	Talking and listening	Encourages discussion among students Encourages students to work as a group Encourages students to listen to others' opinions
Defines argument Exemplifies argument	Knowing the meaning of argument	Define argument Presents examples of arguments Questions about the dynamics involved in the argumentation process??
Encourages ideas Encourages positioning Values different positions	Positioning yourself in the construction of arguments	Encourages the presentation of students' ideas Encourages students to position themselves in the presentation of their ideas Values different points of view of students (usually in the application of more effective teaching strategies elaborated)
Checks evidence Provides evidence Prompts justification Emphasises justification Encourages further justification Plays devil's advocate	Justifying with evidence	Evaluates or checks whether justifications are supported by evidence Provides evidence to support students' ideas Asks justifications for students' conclusions Emphasises the importance of presenting justifications Encourages the presentation of new justifications in addition to those initially presented To argue against or reject an idea, argument, or proposition
Uses writing frame or written work/prepares presentations/gives roles	Constructing arguments	Elaborates teaching-learning strategies (e.g., debates, solving socio-scientific problems, etc.) that allow students to be asked to construct their arguments in written and oral form
Encourages evaluation Evaluates arguments process – using evidence content – nature of evidence	Evaluating arguments	Encourages students to evaluate their arguments Encourages reflection on what is necessary to build a good argument, considering the evidence that supports it
Encourages anticipating counterargument Encourages debate (through role play)	Counter-arguing/debating	Encourages counterarguments against arguments made by colleagues Encourages counter-argumentation during debates and role-playing

Encouranges reflection Asks about mind-change	Reflecting on the argument process	Stimulates reflection on the processes adopted by students for the construction of the argument Questions students about the changes in their opinions resulting from the processes adopted for the argument construction Encourages students to reach a consensus