REPUBLIC OF TÜRKİYE
YILDIZ TECHNICAL UNIVERSITY
GRADUATE SCHOOL OF SCIENCE AND ENGINEERING

EXPLORING MIDDLE SCHOOL SCIENCE TEACHERS' PROFESSIONAL DEVELOPMENT ON SOCIOSCIENTIFIC ISSUE AND MODEL-BASED LEARNING: A MULTIPLE-CASE STUDY

Benzegül DURAK

DOCTOR OF PHILOSOPHY THESIS

Department of Mathematics and Science Education

Science Education Program

Supervisor

Prof. Dr. Mustafa Sami TOPÇU

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A thesis submitted by Benzegül DURAK in partial fulfillment of the requirements for the degree of **DOCTOR OF PHILOSOPHY** is approved by the committee on 29.11.2024 in Department of Mathematics and Science Education, Science Education Program.

Prof. Dr. Mustafa Sami TOPÇU
Yildiz Technical University
Supervisor

Approved By the Examining Committee

Prof. Dr. Mustafa Sami TOPÇU, Supervisor
Yildiz Technical University ____________________

Prof. Dr. Hasan ÜNAL, Member
Yildiz Technical University ____________________

Assoc. Prof. Dr. Gülbin ÖZKAN, Member
Yildiz Technical University ____________________

Assoc. Prof. Dr. Kamil Arif KIRKIÇ, Member
İstanbul Sabahattin Zaim University ____________________

Prof. Dr. Gönül SAKIZ, Member
Marmara University ____________________

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Benzegül DURAK

Signature

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Dedicated to all the girls who chase their dreams and the teachers who light the path for them…

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LIST OF ABBREVIATIONS

CCC	Crosscutting Concepts
CoHE	Council of Higher Education
CRAP	Currency-Reliability-Authority-Purpose
DC	Domain of Consequence
DCIs	Disciplinary Core Ideas
DP	Domain of Practice
ED	External Domain
I#1	Interview 1
I#2	Interview 2
I#3	Interview 3
ICT	Information and Communication Technologies
IMPG	Interconnected Model of Professional Growth
MbL	Model-based Learning
MoNE	Ministry of National Education
NGSS	Next Generation Science Standards
NOS	Nature of Science
NRC	National Research Council
OECD	Organisation for Economic Cooperation and Development
PD	Professional Development
PeD	Personal Domain
SBK-MTÖ	Sosyobilimsel Konu ve Model-Tabanlı Öğrenme
SIMBL	Socioscientific Issue and Model-Based Learning
SPs	Scientific Practices
SSI	Socioscientific Issue
SSR	Socioscientific Reasoning
SSI-TL	The Socioscientific Issue Teaching and Learning
STSE	Science-Technology-Environment and Society

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ABSTRACT

Exploring Middle School Science Teachers' Professional Development on Socioscientific Issue and Model-Based Learning: A Multiple-Case Study

Benzegül DURAK

Department of Mathematics and Science Education
Doctor of Philosophy Thesis

Supervisor: Prof. Dr. Mustafa Sami TOPÇU

This study investigates the professional development (PD) of middle school science teachers in the design and implementation of the Socioscientific Issue and Model-Based Learning (SIMBL) framework. A comprehensive three-phase PD program was designed to support teachers in developing and implementing SIMBL units in their classrooms. Using a multiple case study design, the research provides an in-depth exploration of the experiences and practices of three middle school science teachers who participated in the program. The participants in the study are three middle school science teachers who completed the PD program and classroom implementations of the SIMBL units. Primary data sources include semi-structured interviews conducted before and after the PD program and post-implementation interviews. Secondary data sources include the developed SIMBL units, field notes of the PD program, classroom observations, and transcripts of unstructured phone calls and messages. Data analysis is guided by the Interconnected Model of Professional Growth framework. Findings indicate that the PD program significantly increased teachers' knowledge and competence in designing SIMBL units. The success of the program is closely linked to teachers' frequent interactions and reflective discussions regarding feedback on their unit plans and classroom practices. The results of classroom implementation show that the SIMBL framework is effective in improving students' content knowledge, media literacy skills and their ability to negotiate complex socioscientific issues. The study emphasises the importance of student-centred approaches that encourage active student participation for effective SIMBL teaching. It also highlights the need for ongoing PD and institutional support to facilitate the successful integration of the SIMBL framework into broader educational contexts. Overall, this research provides valuable insights into improving science education through the effective implementation of f the SIMBL framework.

Keywords: Socioscientific issue, scientific modeling, professional development, science teacher, teacher education.

ÖZET

Ortaokul Fen Bilimleri Öğretmenlerinin Sosyobilimsel Konular Ve Model Tabanlı Öğrenme Üzerine Mesleki Gelişimlerinin İncelenmesi: Çoklu Durum Çalışması

Benzegül DURAK

Matematik ve Fen Bilimleri Eğitimi Anabilim Dalı
Doktora Tezi

Danışman: Prof. Dr. Mustafa Sami TOPÇU

Bu çalışma, ortaokul fen öğretmenlerinin Sosyobilimsel Konu ve Model-Tabanlı Öğrenme (SBK-MTÖ) çerçevesini tasarlama ve uygulamada mesleki gelişimini (MG) araştırmaktadır. Öğretmenlerin sınıflarında SBK-MTÖ üniteleri geliştirmelerini ve uygulamalarını desteklemek için kapsamlı üç aşamalı bir MG programı tasarlanmıştır. Çoklu vaka çalışması tasarımını kullanan araştırma, programa katılan üç ortaokul fen öğretmeninin deneyimlerini ve uygulamalarını derinlemesine incelemektedir. Çalışmanın katılımcıları, MG programını ve SBK-MTÖ ünitelerinin sınıf uygulamalarını tamamlayan üç ortaokul fen öğretmenidir. Birincil veri kaynakları, MG programından önce ve sonra gerçekleştirilen yarı yapılandırılmış görüşmeler ile uygulama sonrası görüşmeleri içermektedir. İkincil veri kaynakları, geliştirilen SBK-MTÖ üniteleri, MG programından alınan saha notları, sınıf gözlemleri ve yapılandırılmamış telefon görüşmeleri ve mesaj kayıtlarını içermektedir. Veri analizi, Bağlantılı Mesleki Olgınlaşma Modeli rehberliğinde yapılmıştır. Bulgular, MG programının öğretmenlerin SBK-MTÖ üniteleri tasarlama konusundaki bilgi ve yeterliliğini önemli ölçüde artırdığını göstermektedir. Programın başarısı, öğretmenlerin sık etkileşimleri ve ünite planları ve sınıf uygulamalarıyla ilgili geri bildirimler hakkında tartışmalarla yakından bağlantılıdır. Sınıf uygulama sonuçları, SBK-MTÖ çerçevesinin öğrencilerin içerik bilgisini, medya okuryazarlığı becerilerini ve karmaşık SBK'yı müzakere etme yeteneklerini etkili bir şekilde geliştirdiğini ortaya koymaktadır. Çalışma, etkili SBK-MTÖ öğretimi için aktif öğrenci katılımını teşvik eden öğrenci merkezli yaklaşımları benimsemenin önemini vurgulamaktadır. Ek olarak, SBK-MTÖ çerçevesinin daha geniş eğitim bağlamlarına başarılı bir şekilde entegre edilmesini kolaylaştırmak için devam eden MG ve kurumsal desteğin gerekliliğini vurgulamaktadır. Genel olarak, bu araştırma SBK-MTÖ çerçevesinin etkili bir şekilde uygulanması yoluyla fen eğitimini geliştirmeye yönelik değerli içgörüler sunmaktadır.

Anahtar Kelimeler: Sosyobilimsel konular, bilimsel modelleme, model tabanlı öğrenme, mesleki gelişim, fen öğretmeni, öğretmen eğitimi.

1
INTRODUCTION

1.1 Literature Review

In today's modern society, scientific and technological advancements necessitate individuals who are scientifically literate. These citizens should possess the capability to make informed decisions, seek solutions, and take action based on knowledge and practices. Educating students to be scientifically literate stands as a fundamental objective in science education (Bossér et al., 2015). Although "scientific literacy" is widely used in the context of science education, there exists no unanimous agreement on its definition (Roberts, 2007). While it's commonly defined as the "public understanding of science," there is ambiguity regarding what the public should comprehend and who constitutes the public in this definition (Laugksch, 2000). As a result, multiple attempts have been made to define scientific literacy in various dimensions (Sjöström & Eilks, 2018). Roberts (2007) divides scientific literacy into Vision I and Vision II. Vision I concentrates on learning scientific content and processes, while Vision II emphasizes the practicality of scientific knowledge in real-life contexts (Roberts, 2007). The tension between Vision I and II stems from the divergence between "preparing future scientists" and promoting "science for all" (Sjöström & Eilks, 2018).

Scientific literacy is a crucial goal in science education, offering direct benefits to individuals. Being scientifically literate is essential for understanding and critically evaluating sources such as newspaper articles or television commentaries (Ogunkola, 2013). It aids in personal decision-making, such as choices related to diet or vaccination (Ogunkola, 2013). In the context of societal impact, scientific literacy is vital. Personal decisions not only affect individual health but also have repercussions for public health. Socioscientific issues (SSIs) exemplify these complex and contentious societal concerns related to science, which necessitate scientific, political, economic, and social understanding and action (Friedrichsen et al., 2020; Sadler, 2004).

Teaching science through SSI serves as an approach to foster scientific literacy aligned with Vision I and Vision II (Ke, Zangori, et al., 2021). SSI-based teaching involves engaging learners directly in exploring these issues, understanding science content relevant to the problem, and considering social dimensions, including political, economic, and ethical factors (Friedrichsen et al., 2016; Sadler, 2011). However, implementing SSI teaching presents several challenges for teachers. These challenges include limited teaching time, scarce resources, and an emphasis on science content over social dimensions (Friedrichsen et al., 2020). Many teachers believe that effectively teaching SSIs requires sacrificing students' acquisition of scientific knowledge and practices (Ke, Zangori, et al., 2021). This belief may stem from Zangori et al.'s (2017) observation that, apart from the practice of argumentation, the SSI approach has not been widely associated with promoting student engagement in scientific practices. To address this issue, efforts have emerged and one promising approach is to integrate scientific modeling into SSI instruction (Durak & Topçu, 2021; Ke, Zangori, et al., 2021).

Scientific modeling is one of the more complex scientific practices and provides an opportunity for students to engage in related activities such as data analysis and explanation construction (Duschl et al., 2016; Louca & Zacharia, 2012; Sadler et al., 2019). Additionally, scientific modeling supports essential skills like informal reasoning and decision-making (Demir & Namdar, 2019). Through scientific modeling, students gather data to support their arguments, laying the foundation for developing critical skills necessary for scientific literacy. There are significant parallels between modeling and the negotiation of complex societal issues (i.e., socio-scientific reasoning) (Ke, Zangori, et al., 2021). Both practices require systems thinking, which may help students transfer their scientific understanding and practices to reasoning about SSIs, thus promoting scientific literacy (Ke, Zangori, et al., 2021). Model-based learning (MbL) further involves students in the learning process as they develop, test, and revise their models, reflecting the practices of scientists (Shen et al., 2014). MbL encourages the use of various representations and alternative models (e.g., physical models, graphs, or mathematical formulas), catering to different learning styles (Shen et al., 2014). It also enhances peer learning opportunities as students collaborate on models, present them to the class, and evaluate each other's work (Shen et al., 2014).

Given the benefits of integrating scientific modeling in science classrooms, incorporating it into SSI-based learning environments will enhance learning opportunities. This integration supports the development of students' scientific practices and aligns with the objectives of scientific literacy and science education, thereby improving the effectiveness of SSI-based instruction. A growing body of research supports the integration of modeling into SSI-based instruction (Durak & Topçu, 2023; Ke, Sadler, et al., 2021; Ke, Zangori, et al., 2021; Lin et al., 2023; Sadler et al., 2019). Empirical evidence indicates that incorporating modeling/MbL into SSI-based instruction positively impacts students' ability to negotiate complex issues (Peel et al., 2019; Zangori et al., 2017), enhances students' content knowledge (Durak & Topçu, 2023; Zangori et al., 2017), and improves the decision quality of pre-service teachers (Lin et al., 2023).

Regarding the implementation of the integration of scientific modeling into SSI teaching, the Socio-Scientific Issue and Model-Based Learning (SIMBL) framework was developed based on a research study that synthesized findings from three distinct case studies, as detailed in the work of Friedrichsen et al. (2020) and Sadler et al. (2019). Design Case 1, titled "Collaborating with an Exemplary Biology Teacher," involved the research team working closely with a biology teacher and his honors class. They chose antibiotic resistance as the issue and aimed to teach the concept of natural selection. Together with the teacher, they co-designed an SSI unit focusing on modeling as a Next Generation Science Standards [NGSS] practice. The implementation of this unit resulted in students achieving a better understanding of generalized natural selection, although they faced challenges in comprehending how natural selection applies specifically to bacteria. This case illustrates that teaching SSI with modeling practice can lead to desired student learning outcomes, though these findings are based on the enactment by a single successful teacher. Design Case 2, "Secondary Teachers Co-Designing Curriculum," involved the research team designing PD where small teams of teachers co-designed SSI units for their classes. Teachers were given the flexibility to choose NGSS practices such as modeling, argumentation, or computational thinking that best suited their units and student needs. The results indicated that tools like the SSI Teaching Framework and the Issue Selection Guide supported teachers in planning and implementing SSI effectively. Additionally, culminating activities proved effective in synthesizing student ideas and practices. Design Case 3, "Implementing SSI Teaching in an Elementary School," focused on exploring how elementary teachers implemented and navigated issues-based learning. It also investigated how an SSI context could support teachers in understanding and utilizing model-based teaching and learning. Elementary classrooms, being interdisciplinary by nature, are suitable for SSI-based instruction. However, elementary teachers face challenges in grasping the purpose and utility of scientific modeling, as highlighted by previous studies (Justi & Gilbert, 2002; Vo et al., 2015). The research team theorized that embedding modeling within SSI would demonstrate the utility and purpose of scientific modeling to teachers, enabling students to develop and utilize scientific models to understand phenomena and address complex societal issues. Results indicated that elementary teachers perceived SSI as a means to foster social responsibility and make real-world issues relevant to students. They integrated their understanding of modeling within the context of SSI, viewing them as interconnected.

SIMBL emphasizes the role of SSI at the core of the approach and advocates for continuous connections with the issue throughout the curriculum unit. The framework delineates six key features, including exploring scientific phenomena, engaging in scientific modeling, considering issue system dynamics, employing information literacy strategies, contrasting multiple perspectives, and elucidating personal positions or solutions.

1.2 Objective of the Thesis

Despite the existing literature providing examples and highlighting the outcomes of integrating modeling and SSI, there is a lack of guidance on assisting teachers in achieving this integration. Therefore, considering the effectiveness of integrating modeling into SSI-based instruction (Durak & Topçu, 2021, 2023; Friedrichsen et al., 2020; Sadler et al., 2019; Zangori et al., 2017), it is essential to develop professional development (PD) programs that prioritize this integration. Furthermore, it is necessary to closely examine teachers' engagement and professional growth through these programs. Therefore, the aim of this thesis is to:

- Develop a professional development program for unit design of the Socioscientific Issue and Model-Based Learning (SIMBL) approach.
- Implement the developed profeSonal development program for middle school science teachers.
- Enact the units developed by the teachers in the professional development program in their classrooms.
- Examine the professional development processes of teachers who participated in the program and practiced it in their classrooms.

1.3 Research Questions

This study aims to address the need for PD programs prioritize SSI and MbL integration, and also need to explore teachers' engagement and professional growth closely through this PD program by developing a PD program designed to support middle school science teachers in both the curriculum unit development and implementation of SSI and MbL. The Interconnected Model of Professional Growth (IMPG) (Clarke & Hollingsworth, 2002) framework guides this study to analyze science teachers' engagement and growth through the PD program. Accordingly, the research questions aligned with the IMPG domains are:

1. What is the nature of the middle school science teachers' beliefs, attitudes, and knowledge about science teaching and learning? (Personal Domain)
2. Which elements of SIMBL do the middle school science teachers implement in their classrooms? (Domain of Practice)
3. What do the middle school science teachers perceive as salient outcomes when they implement their SIMBL units? (Domain of Consequence)
4. How are the middle school science teachers' interactions with each other and the researcher in the PD program? (External Domain)

1.4 Original Contributions

One of the main needs of today's society is scientifically literate individuals who can make conscious decisions, seek solutions to problems, use their knowledge and reasoning skills in solving problems, and raising these individuals is among the common goals of science education programs (Bossér et al., 2015). For approximately a decade, the integration of SSI in science education has been emphasized as a means to foster scientific literacy (Ministry of National Education [MoNE], 2013, 2018, 2024; National Research Council [NRC], 2012). The current Science Curriculum aims for students "to be curious about socioscientific issues, to conduct research, to question, and to develop innovative solutions with an interdisciplinary perspective" (MoNE, 2024, p. 5). Similarly, one of the main objectives of the 2018 Science Curriculum, which was in effect during the years the study was conducted, is explicitly stated as the "development of reasoning, scientific thinking, and decision-making skills using socioscientific issues" (MoNE, 2018, p. 9). Teaching science through SSI serves as an approach to develop these competencies (Zeidler et al., 2005).

Despite being a primary objective in science education, the incorporation of SSI in science lessons remains inadequate (Arslan & Çiğdemoğlu, 2020; Friedrichsen et al., 2020; Ke, Zangori, et al., 2021; Topçu, 2019; Topçu et al., 2022). This deficiency is largely due to insufficient teacher training, with a focus on directly imparting scientific knowledge while neglecting SSI integration (Dawson & Taylor, 2000; Ekborg et al., 2013; Lee et al., 2006). Additional challenges, such as limited resources, time constraints, and the absence of effective curriculum materials, further contribute to the underutilization of SSI (Ekborg et al., 2013; Lee et al., 2006; Lee & Yang, 2019). In Türkiye, teacher education programs are designed by universities according to specific standards, and until 2018, there was no specific course at the undergraduate level that directly addressed the teaching of SSI. Although some courses partially included SSI, it was not a focused objective. In 2018, a Teacher Training Undergraduate Program was introduced by the Council of Higher Education (CoHE) as a model for all universities (CoHE, 2018). The

'Interdisciplinary Science Teaching' course within this program marked the first formal inclusion of SSI teaching in Türkiye’s teacher education curriculum. However, despite the integration of SSI into the science curricula, these materials still fail to adequately support teachers in effectively incorporating SSI into their instruction (Arslan & Çiğdemoğlu, 2020; Friedrichsen et al., 2020; Ke, Zangori, et al., 2021; Topçu, 2019; Topçu et al., 2022).

Teachers are expected to incorporate SSI in classrooms, but neither undergraduate education nor available teaching materials provide enough guidance on how to achieve this. Consequently, the need to support teachers in using and teaching SSI is evident (Arslan & Çiğdemoğlu, 2020). This study's primary contribution is the development of a PD program that emphasizes the integration of SSI and scientific modeling. Through this program, teachers will learn how to develop teaching materials and effectively integrate SSI into their classrooms. The study aims to enhance teachers' capacity to adopt these approaches, ultimately improving scientific literacy and student engagement. Moreover, the PD program is designed to aid teachers in the creation and implementation of curriculum units that integrate SSI and MbL with the Socioscientific Issues and Model-Based Learning (SIMBL) (Sadler et al., 2019) framework. This addresses a recognized gap in the literature regarding practical guidance for teachers to effectively insert SSI instructional approaches (Friedrichsen et al., 2020; Öztürk & Irmak, 2020; Topçu, 2019).

Additionally, this study builds on previous research that demonstrates the benefits of integrating scientific modeling with SSI. It seeks to provide empirical evidence and practical examples of how such integration can be achieved in classroom settings, offering a model for other educators and researchers to follow.

Overall, the study addresses the crucial need for enhanced teacher preparation and support in integrating SSI into science education. By focusing on the development and application of a comprehensive PD program, employing a robust theoretical framework, and providing empirical evidence, the study aims to significantly contribute to the field of science education. Through these efforts, it seeks to empower teachers, enrich classroom practices, and ultimately foster a more scientifically literate and engaged student population.

1.5 Assumptions and Limitations of the Study

By acknowledging assumptions and limitations, this study provides a transparent account of its scope and potential constraints.

Assumptions of the study are:

1. It is assumed that all participating teachers were genuinely engaged with the PD program and implemented the SIMBL units to the best of their abilities. Their participation and feedback were considered to be honest and reflective of their true experiences.
2. The study assumed that the self-reported data provided by the teachers during interviews and unstructured communications were accurate and truthful. It is also assumed that their recollections and descriptions of their experiences are reliable.
3. It is assumed that any external factors, such as earthquakes or other disruptions, did not disproportionately affect the study’s outcomes, despite their acknowledged impact.

Limitations of the study are:

1. The selection of participants was limited to in-service middle school science teachers attending the voluntary PD program in Düzce.
2. The study period was limited to the academic year 2022-2023 in which the PD program was conducted.

2
THEORETICAL FRAMEWORK

2.1 Scientific Literacy

The concept of scientific literacy first appeared in academic literature in 1958, highlighting the need for public understanding of science (Hurd, 1958). Today, scientific literacy is crucial in modern education, civic engagement, and cultural dynamics (Li & Guo, 2021). Early literature often did not differentiate between scientific literacy and science literacy (Hurd, 1958; Shen, 1975). However, as these concepts have evolved, their distinctions have become crucial in understanding their roles within school science education research and practice. While both are closely connected to the curriculum, they are not synonymous, and recognizing their differences is essential for grasping the current educational landscape (Roberts & Bybee, 2014). As cited by Roberts (2007), “while "science literacy" refers to literacy related to science, "scientific literacy" refers to the characteristics of literacy that are scientifically sound, regardless of the content area being focused on”. Although most institutions do not make this distinction strictly, the word 'science' is not an adjective, so the terms are not exactly parallel (Roberts, 2007).

Scientific literacy has long been considered a key objective of science education. However, defining what it means to be scientifically literate remains a complex and multifaceted challenge. Roberts (2007) suggested two visions to define scientific literacy based on an earlier review.

Vision I of scientific literacy focuses on what it means to be literate within the domain of science. This perspective is primarily concerned with the competencies and knowledge necessary for individuals to function as insiders within the scientific community. Osborne (2023) highlights that this view aligns with the "fundamental sense" of scientific literacy, as articulated by Norris and Phillips (2003). In this context, being scientifically literate involves the ability to read, write, and engage in scientific discourse using the specialized language and concepts of the discipline. It is essential for the development of disciplinary literacy, where students learn to think, communicate, and understand the world through the lens of science. Vision I is critical because it underscores the importance of teaching science as a unique form of literacy. As Osborne (2023) argues, literacy is not merely an adjunct to science; it is constitutive of the scientific enterprise itself. Scientists spend a significant portion of their time engaged in literate activities, such as reading, writing, and discussing scientific concepts. Therefore, science education must prioritize the development of these literate practices to equip students with the tools they need to engage meaningfully with scientific knowledge (Osborne, 2023).

Vision II shifts the focus from the insider to the outsider's perspective, addressing what it means to be literate for those not directly involved in the scientific community. This vision aligns with the "derived sense" of scientific literacy described by Norris and Phillips (2003). Here, the emphasis is on the knowledge, understanding, and competencies needed to engage with science-related issues as informed citizens. Roberts (2007) and Feinstein (2011) characterize this view as essential for navigating the increasingly complex and science-driven world. Vision II considers the competencies required to make informed decisions on issues with a scientific component, such as climate change, healthcare, and technological advancements. The PISA framework (Organisation for Economic Cooperation and Development [OECD], 2006, 2017) reflects this perspective by defining scientific literacy as the ability to engage with science-related issues and reasoned discourse as a reflective citizen. Osborne (2023) emphasizes that Vision II is particularly relevant in today's context, where individuals are often epistemically dependent on the expertise of others (Hardwig, 1985; Nichols, 2017). In a society where no one person can possess all the knowledge required to make informed decisions, scientific literacy becomes a collective property of communities rather than an individual attribute (Snow & Dibner, 2016). This collective understanding is crucial for addressing complex, science-related challenges that transcend individual knowledge and expertise.

Recently, a more advanced iteration of Vision II, termed Vision III, has been proposed, which places a greater emphasis on scientific engagement (Liu, 2013; Yore, 2012) and the concept of "knowing-in-action" (Aikenhead, 2007). While Hodson (2003, 2009, 2011) did not explicitly use the term Vision III, he introduced the concept of "critical scientific literacy," adding a fourth dimension—engagement in socio-political action—to the existing framework (Sjöström & Eilks, 2018). Vision III presents a more radical perspective on scientific literacy, viewing it as a tool for social action and justice. This vision is particularly concerned with how scientific knowledge can be used to address pressing global issues, such as climate change, social inequality, and environmental degradation. Scholars like Bencze et al. (2020) and Hodson (2009) argue that traditional notions of scientific literacy are inadequate for preparing students to confront the challenges of the modern world. Osborne (2023) suggests that Vision III represents a significant departure from conventional science education. It pushes the boundaries of what it means to be scientifically literate by integrating moral, economic, and political considerations into the curriculum. In this view, scientific literacy is not just about understanding the natural world; it is about using that understanding to effect change and promote justice.

The evolution of scientific literacy, from its inception in the late 1950s to the present, highlights a shift in focus from merely acquiring scientific knowledge to understanding the broader implications of science in society. This progression underscores the importance of a nuanced approach to science education that goes beyond rote memorization of facts to fostering a deep, critical engagement with scientific concepts and their applications. Scientific literacy now encompasses not only the knowledge of core scientific concepts but also the ability to think critically about scientific issues, apply scientific reasoning to real-world problems, and participate in informed civic discourse. This broadened scope reflects the increasing complexity of the world we live in, where science and technology play pivotal roles in addressing global challenges such as climate change, public health, and technological innovation.

Understanding the evolution of scientific literacy provides a foundation for the present study's focus on integrating SSI into science education. By addressing the broader and more nuanced definitions of scientific literacy, this study aims to contribute to educational practices that prepare students to be informed, engaged citizens. The development of a PD program centered on SSI-modeling integration may be a response to the need for educational approaches that reflect this expanded understanding of scientific literacy.

2.2 Socioscientific Issues (SSIs)

Socioscientific Issues (SSIs) represent a dynamic and multifaceted intersection between science and society, emerging from the complex and often contentious relationship between the two. SSIs are characterized by their factual and ethical complexity, lack of definitive solutions, and ongoing inquiry supported by evidence that is often uncertain and conflicting (Sadler, 2004). Unlike Science, Technology, Society, and Environment [STSE] education, which focuses broadly on the interconnections between these domains, SSI education places particular emphasis on the ethical dimensions of social issues that have scientific underpinnings (Zeidler et al., 2005). According to Ratcliffe and Grace (2003), SSIs possess several defining characteristics: they are grounded in cutting-edge scientific knowledge, require opinion formation and decision-making at both personal and societal levels, are frequently covered in the media with varying degrees of accuracy, involve incomplete and conflicting information, address issues with local, national, and global implications, require cost-benefit analyses where risk and values intersect, and often involve considerations of sustainable development and ethical reasoning.

The pedagogical value of SSI-based instruction has been extensively documented, with numerous studies highlighting its potential to foster critical thinking, decision-making, argumentation, reflective judgment, and moral development among students (Sadler, 2004; Zeidler et al., 2011). Moreover, SSI instruction is seen as a vital component in the development of students' scientific literacy, which, as Zeidler et al. (2005) argue, is essential for making informed decisions about complex socio-scientific issues. Roberts (2007) provided a comprehensive overview of the different perspectives on scientific literacy, categorizing them into two main streams: Vision I and Vision II. Vision I focuses on the intrinsic understanding of science, emphasizing the products and processes of science itself, while Vision II adopts an outward approach, focusing on how science interacts with other human affairs and the real-world situations that students are likely to encounter as citizens. Hodson (2003) critiqued traditional science education for its focus on established and secure knowledge while excluding contested knowledge, multiple solutions, controversy, and ethics, which are integral to understanding SSIs. This critique aligns with the broader argument that addressing only Vision I in science instruction is insufficient for helping students engage with the complex, open-ended, and value-laden nature of SSIs. Incorporating SSI into science education aligns with Roberts' (2007) Vision II of scientific literacy, which promotes the understanding of the relevance of scientific knowledge in meaningful contexts. More recently, SSI approach is also related to what Sjöström and Eilks (2018) define as Vision III scientific literacy, which includes socio-political action and moral-philosophical perspectives. Therefore, integrating SSI into the curriculum expands both the content and instructional practices commonly experienced in science classrooms, sometimes extending to taking action on societal issues.

SSIs are inherently contentious, socially alive issues that are deeply connected to science but also involve other disciplines such as politics and economics, as well as moral and ethical considerations (Albe, 2008; Evagorou et al., 2012; Kolstø, 2001). Typical examples of SSIs include genetically modified organisms, nanotechnology, and climate change, which are widely researched and debated topics. For younger students, SSIs may be more localized and community-based, such as the reconstruction of a school garden, or invasive species (Durak & Topçu, 2023; Zangori, 2023). Engaging with SSIs enables students to understand the importance of science in everyday life and develop the ability to critically evaluate scientific information (Kolstø, 2001). Moreover, SSI-based instruction has been shown to improve conceptual understanding, spark interest in science, encourage participation in discussion and debate, provide a framework for understanding the nature of science (NOS), and develop higher-order thinking skills, such as critical thinking and argumentation (Evagorou et al., 2012; Zeidler & Nichols, 2009).

The integration of SSIs into science education marks a significant shift towards a more holistic approach to teaching, one that prioritizes relevance and real-world application alongside conceptual understanding. By engaging with SSIs, students enhance their scientific literacy necessary to navigate and address the complex challenges of the modern world. This study contributes to this educational transformation by developing a PD program designed to empower teachers to effectively incorporate SSIs into their instruction. Through this program, teachers are equipped to prepare students to become scientifically literate individuals who can engage thoughtfully with the pressing issues of their time, participate in meaningful discourse, and make informed decisions that impact their communities and society at large.

2.2.1 Socioscientific Issue Teaching and Learning (SSI-TL) Model

Socioscientific Issue Teaching and Learning (SSI-TL) model (Sadler et al., 2017) offers a structured framework for integrating real-world issues into science education, promoting the development of scientific literacy that is deeply connected to societal and ethical considerations. In this study, SSI-TL model serves as the foundational framework for SIMBL framework, which is the practical framework used in the PD program to equip teachers with the skills and knowledge needed to effectively integrate SSI and modeling into their science classrooms.

SSI-TL model (Sadler et al., 2017) has evolved from various models and frameworks, representing the culmination of extensive research.

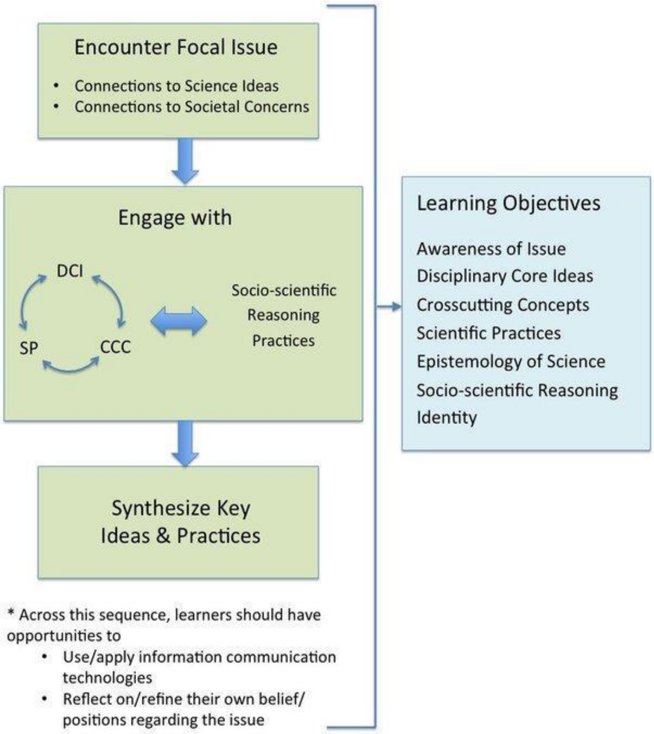

Figure 2.1 SSI teaching and learning model (Sadler et al., 2017, p. 80) (DCI: Disciplinary Core Ideas, CCC: Crosscutting Concepts, SP: Scientific Practices)

The model developed by Sadler et al. (2017) shares a theoretical background with previous models. However, it emphasizes gaps within these models and aims to address these deficiencies through the new Socio-Scientific Issues Teaching and Learning (SSI-TL) model. Figure 2.1 presents a graphical representation of the model, illustrating two sections. The left side delineates the learning experiences necessary for a successful SSI-TL, while the right side identifies the learning objectives that the SSI-TL process should reinforce. Notably, this inclusion of learning objectives represents a novelty in comparison to previous models. Another unique aspect of this model is its alignment with the Next Generation Science Standards (NGSS).

Similar to previous models, SSI-TL sequence commences by introducing the focal issue at the unit's outset. Understanding the science behind the issue and its social dimensions constitutes the initial phase. The subsequent phase involves constructing primary teaching and learning experiences. In accordance with the NGSS, this phase engages students in three-dimensional science learning alongside socio-scientific reasoning practices. This three-dimensional approach emphasizes disciplinary core ideas (DCIs), crosscutting concepts (CCCs), and science practices (SPs). DCIs encompass four main disciplinary areas: physical science, life science, earth and space sciences, and engineering, technology, and applications of science. CCCs involve patterns that link diverse scientific domains, such as cause and effect, scale and proportion, systems, energy and matter, structure and function, and stability and change. SPs encompass various scientific skills, including asking questions, developing models, planning investigations, analyzing data, using mathematics, constructing explanations, engaging in argumentation, and obtaining and communicating information (NGSS).

In the three-dimensional science learning, DCIs, CCCs, and SPs intersect while interacting with socioscientific reasoning (SSR) practices. SSR practices encompass: 1) acknowledging the complexity of SSIs, 2) analyzing issues from multiple perspectives, 3) determining ongoing inquiry aspects, 4) exercising skepticism towards potentially biased information, and 5) exploring how science contributes to and is limited by these issues. SSR practices take precedence in the model over social dimensions as they necessitate in-depth learning experiences.

The third and final phase involves synthesizing key ideas and practices, akin to the culminating experience in previous models (Presley et al., 2013). Here, students reflect on the issue through their perspectives, integrating science ideas (including DCIs and CCCs) and SSR practices, without proposing definitive solutions. SSI issues are open-ended problems, making definite solutions inappropriate.

Furthermore, the SSI-TL model introduces two additional elements not in sequential order. These elements cut across the three phases. First, akin to previous models, students should have opportunities to use information and communication technologies (ICT). Second, students should reflect on their ideas and positions regarding the focal issue. While similar to the culminating activity in other models, this element isn't considered a core aspect in this SSI-TL model, as some studies (e.g., Friedrichsen et al., 2016) show consistent refinement of student ideas toward the issue, eliminating the need for a culminating activity. Hence, the second element is a recommendation, not a core aspect.

The model's second section (the right side of Figure 2.1) delineates the learning objectives, a novel inclusion in comparison to previous models. The learning objectives comprise seven categories: awareness of the issue, disciplinary core ideas, crosscutting concepts, scientific practices, epistemology of science, socio-scientific reasoning, and identity. While the former categories have been elaborated on previously, stating them as learning objectives implies their achievement. Epistemology of science primarily refers to the nature of science (NOS). Although the SSI-TL model doesn't cover the entirety of NOS, students learn about it during the process. Finally, 'identity' refers to how students position themselves in light of new ideas in a conversation.

As outlined earlier, SSI-TL model serves as the foundation for the SIMBL framework, which integrates SSI and modeling/model-based learning. The following sections will first explore the concepts of scientific modeling, MbL, and the background of integrating SSI with modeling. This will provide the basis for a detailed explanation of SIMBL framework and its practical application in science education.

2.3 Scientific Modeling

The production and use of models are crucial to advancing scientific understanding. While there is consensus on their importance, there is no unique definition for models. In essence, a model is a partial representation of a target that focuses on specific aspects of it (Gilbert et al., 2000). This emphasis on 'partial' is crucial because “if a model were exactly like its target, it would not be a model but a copy” (Van Der Valk et al., 2007, p. 471). The target may be real objects, processes, systems, or events such as a model of the human skeletal system, or objects, processes, systems, or events like an atom model (Gilbert, 2004; Gobert & Buckley, 2000; Harrison & Treagust, 1998; Treagust et al., 2002). Also, the models can be in different forms, for example, in the form of a gesture, material, visual, verbal, symbolic, or virtual (Gilbert & Justi, 2016).

Models are unique and contingent upon the modeler's understanding of the subject and their intent in creating the model (Van Der Valk et al., 2007). For this reason, there may be several models that coexist for the same target. Scientists share their models, and by comparing and testing the models, they aim to reach agreement on consensus models, which are the main products of science (Gilbert et al., 1998). Therefore, models are used to grow scientific knowledge as a communication tool besides describing, explaining, and predicting natural phenomena (Buckley & Boulter, 2000; Gilbert et al., 1998, 2000).

Models and modeling serve in various ways in science education. Hodson (1992) summarized the purposes of science education as learning of science, which covers the conceptual understanding of scientific knowledge; learning about science, which means understanding issues in the philosophy, history, and methodology of science; and learning to do science, which involves becoming able to participate in activities aimed at the acquisition of scientific knowledge. In that sense, to learn science, previous literature (e. g. Gilbert et al., 1998; Harrison & Treagust, 2000; Justi & Gilbert, 2002; Justi & van Driel, 2006) suggests that (i) to learn science, students should know about the major scientific and historical models, understanding their scope and limitations; (ii) to learn about science, students should have an understanding of the nature of models and awareness of their importance in validating and disseminating scientific research results; and (iii) to learn how to do science, students should have the capacity to develop, explain, and test their own models (Justi & Gilbert, 2002; Justi & van Driel, 2006). Moreover, modeling itself is the process through which students generate representations of their learning (Clement, 2000). Therefore, students' models are valuable for teachers to monitor students' progress in changing from their initial mental models to an understanding of established scientific or historical models (Chittleborough et al., 2005). Besides this, the use of models and modeling activities provides support to students for the structuring and reasoning of external representations of visual representations with internal representations (mental models) (Buckley, 2000; Clement et al., 2005; Nersessian, 1999). Moreover, studies show that the external presentation of models fosters effective learning and guides students to understand and interpret the target systems and to develop their own mental models (Oh & Oh, 2011). Schwarz et al. (2009) suggest that modeling activities should involve constructing and using models, as well as evaluating and revising them. This cyclic process of modeling leads to a more meaningful involvement with the scientific inquiry and modeling process (Khan, 2007; Schwarz et al., 2009).

In summary, scientific modeling not only provides a powerful means for representing and exploring scientific concepts but also offers invaluable pedagogical benefits by actively involving students in the processes of scientific inquiry. Recognizing and leveraging the multifaceted functions of models is pivotal for designing educational experiences that foster critical thinking, enhance scientific literacy, and prepare learners to navigate and address complex real-world issues—core aims that underpin this thesis.

2.4 Model-Based Learning (MbL)

Model-based learning (MbL) is a pedagogical approach that centers on the use of models as fundamental tools for teaching and learning in science education. This approach involves engaging students in the processes of model construction, validation, and refinement, thereby deepening their understanding of scientific concepts and enhancing their problem-solving abilities.

MbL is grounded in the recognition that scientific knowledge is often organized around models, which serve as frameworks for explaining and predicting phenomena. As Clement (2000) notes, MbL facilitates conceptual change by encouraging students to replace their initial, often incorrect, conceptions with more accurate scientific models. This process is iterative, involving the continuous modification of models as students gain new insights and encounter new evidence (Clement, 2000).

One of the key benefits of MbL is its potential to promote deep learning by requiring students to actively engage in the construction and testing of models. This hands-on, inquiry-based approach not only helps students develop a more sophisticated understanding of scientific concepts but also fosters critical thinking skills. According to Nersessian (1999), MbL supports the development of "model-based reasoning," a cognitive process that involves the use of models to simulate, predict, and explain phenomena. This type of reasoning is central to scientific inquiry and is crucial for developing a robust understanding of the natural world

Furthermore, MbL aligns with the goals of science education by promoting the development of scientific literacy. As Zangori et al. (2017) suggest, MbL helps students understand the nature of scientific models—not as exact replicas of reality but as tools that scientists use to explore and explain the world. This understanding is critical for developing a nuanced view of science, where students recognize the limitations and strengths of different models and the importance of evidence in shaping scientific knowledge.

Ultimately, MbL is one of the effective pedagogical strategies that aligns seamlessly with contemporary educational goals of fostering active, inquiry-driven learning environments. By centering instruction around the development and refinement of models, MbL empowers students to construct meaningful knowledge, engage critically with scientific content, and develop competencies essential for lifelong learning and problem-solving—objectives that are integral to the advancement of science education and central to this research.

2.5 Integration of Socioscientific Issues and Modeling

Socioscientific issues offer students a meaningful context to engage in scientific modeling, enabling them to explain and predict scientific phenomena in ways directly relevant to their lives (Durak & Topçu, 2021, 2023; Ke, Sadler, et al., 2021, 2021; Sadler et al., 2019). SSI supports modeling practice as the significance of the issue allows students to connect their personal objectives (e.g., making decisions about a matter of concern) with the scientific objectives (e.g., understanding the mechanisms underlying the issue) (Ke, Zangori, et al., 2021). For instance, a student aiming to persuade their parents to quit e-cigarette use may employ this goal as motivation to investigate the impact of nicotine on the human body through modeling. Moreover, for students who might not have a pre-existing interest in science or science-related careers, SSI can serve as a compelling context that engages them in exploring the scientific aspects of the issue (Ke, Zangori, et al., 2021).

There are some examples from the previous literature that combine the modeling/ MbL and SSIs. Zangori et al. (2017) introduce a curriculum unit in their study that combines modeling-centered SSI instruction, aiming to enhance students' understanding of carbon cycling and its relationship with climate change. The findings suggest that a robust understanding of carbon mechanisms is crucial for grasping this connection, and as students' understanding improves, so does their reasoning about the interplay between carbon cycling and climate change (Zangori et al., 2017). In another study, Peel et al. (2019) focus on teaching students about antibiotic resistance (ABR) through a unit that combines an issues-based approach with model-based reasoning. The study assesses students' understanding of natural selection, a crucial concept in comprehending ABR. It reveals that students' model-based explanations about ABR significantly improved after the unit. However, students' explanations of generalized natural selection differed from those of ABR. Some students struggled to integrate mutation as the initial cause of variation in their explanations (Peel et al., 2019).

For middle school students, a study introduces a unit centered around the white butterfly, a local pest (Durak & Topçu, 2023). The unit spans four weeks and aims to investigate how changes in the white butterfly population interact with local ecosystems. The evaluation of the unit relies on students' models and explanations, assessed using specialized rubrics. The results indicate that students initially had limited knowledge about the white butterfly and its relationship with the ecosystem. Through the unit, they gained a deeper understanding of this relationship. However, some students struggled with visually representing the effects of control methods, highlighting the importance of considering students' drawing abilities when evaluating models (Durak & Topçu, 2023).

Another local issue stressed by Lin et al. (2023) focuses on the Dongfeng Highway in Taiwan, which is designed to address a disaster-related demand for improved transportation and medical access. The study employs SSI and modeling tools to create a teaching module for preservice teachers. The module involves two modeling cycles to guide decision-making. The results demonstrate that the module improved the quality of decision-making among participants. Initially, participants focused primarily on the relevance of factors, but after completing the module, they paid more attention to comparability, measurement, and evidence justification. While there is still room for improvement in considering the relationships among factors, the study highlights the effectiveness of the Modelling-based SSI (M-SSI) teaching module in enhancing decision quality (Lin et al., 2023).

2.6 Socioscientific Issue and Model-Based Learning (SIMBL) Framework

The Socioscientific Issues and Model-Based Learning (SIMBL) framework, introduced by Sadler et al. (2019), offers a practical, adaptable approach to designing curriculum units that integrate SSI and MbL. The SIMBL framework was developed from the results of three PD programs designed and implemented by Sadler et al. (2019) with secondary and elementary teachers. SIMBL aims to make SSI teaching more accessible and effective for both teachers and students. Throughout these PD iterations, Sadler et al. (2019) identified key challenges and areas for improvement in SSI-based instruction, particularly in integrating scientific practices, such as modeling, which led to the development of the SIMBL framework.

One critical insight from Sadler et al.'s (2019) PD programs was the difficulty teachers faced in effectively incorporating complex scientific practices like argumentation and modeling into their SSI instruction. While teachers managed simpler practices such as planning investigations, they struggled with the more epistemically demanding practices central to sense-making in science. Recognizing this, Sadler et al. (2019) decided to focus primarily on modeling, which they viewed as essential for student sense-making around complex phenomena, as well as for connecting with other scientific practices, such as data analysis and constructing explanations. This emphasis on modeling formed a core component of the SIMBL framework (Friedrichsen et al., 2020; Sadler et al., 2019).

Another key insight from Sadler et al.'s (2019) PD programs was related to the challenge of incorporating Socioscientific Reasoning (SSR) into classroom activities. Many teachers found it difficult to grasp and integrate SSR, a critical aspect of SSI instruction. To address this, Sadler et al. (2019) reframed SSR through the lens of systems thinking, a concept more familiar to educators. Systems thinking enables students to analyze both the scientific and social dimensions of SSIs, offering a more comprehensive understanding of complex issues. In this way, the SIMBL framework balances scientific modeling, which focuses on phenomena like climate change, with systems thinking, which helps students evaluate the broader social, political, and ethical implications of such issues.

The SIMBL framework (Figure 2.2) consists of six interconnected components: 1) explore underlying scientific phenomena, 2) engage in scientific modeling, 3) consider issue system dynamics, 4) employ information and media literacy strategies, 5) compare and contrast multiple perspectives, and 6) elucidate own position/solution.

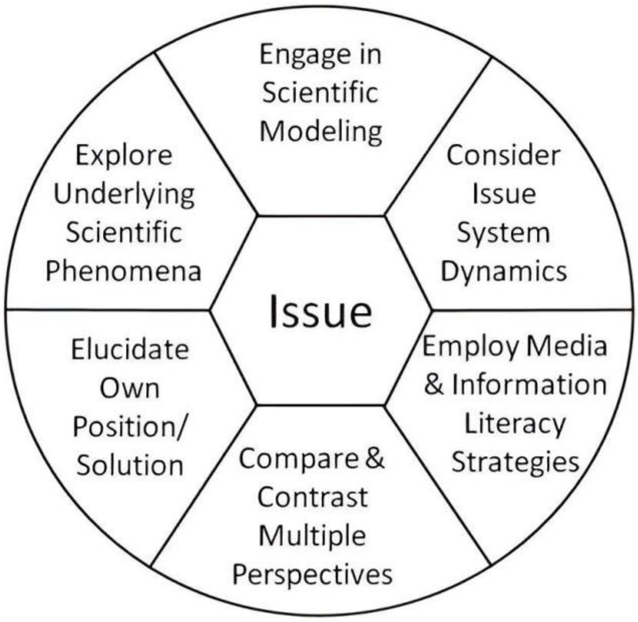

Figure 2.2 The socio-scientific issue and model-based learning (SIMBL) framework (Sadler et al., 2019, p. 17)

Exploring the underlying scientific phenomena emphasizes the science content behind the focal SSI. This feature is essential for science teachers to incorporate into teaching practices and create opportunities for students to explore the issue with anchor phenomena related to students' everyday experiences, observable, complex, have associated data, text, and images, and have a stakeholder community or audience interested in the results. Teachers often use anchor phenomena to connect science concepts to phenomena and to engage students in inquiry, as recommended by the NGSS (Sadler et al., 2019).

The SIMBL framework advocates the use of many forms of modeling and models and always includes a modeling package in which students develop their own models in response to a question or problem targeting scientific phenomena. Students develop initial models in the first drawing session; then, they may rate their models and explain why they gave the score to their model. Or, they may evaluate their models through the learning process and revise them more than once. In order to effectively use models, evaluation, and revision are crucial steps. Students understand that their ideas are dynamic rather than static entities (Sadler et al., 2019).

Considering issue system dynamics is a skill that students should develop through their education. Therefore, the SIMBL framework offers to encourage students to evaluate a system in light of the focal SSI and take into account scientific, human, and social factors, such as political, economic, ethical, and religious considerations (Sadler et al., 2019).

Employing information and media literacy strategies refers to the need to use media tools effectively to follow ongoing research, new ideas, and new perspectives. It is because SSI are contemporary issues and so open to change with developments. There are some strategies for media literacy for SSI teaching by Sadler et al. (2019), such as the "Know Your Sources" worksheet (see Sadler et al., 2019).

Comparing and contrasting multiple perspectives is a feature of socio-scientific reasoning. The definition of SSI refers to multiple perspectives, so SSI-based instruction should provide opportunities for students to acquire different perspectives and compare them.

Elucidating own position/solution also depends on the nature of SSI. In this critical feature, students are asked to defend their position on the focal issue and/or propose a solution. Generally, the students first generate their position at the beginning of the unit and finalize their position at the end of the unit in a culminating activity. Sadler et al. (2019) emphasize that this step should take place after students' experience multiple perspectives. Students clarifying their perspectives is very important, as it is in line with the aim of promoting scientific literacy. This approach offers students the opportunity to generate solutions, defend their ideas in the face of complex challenges, and learn science in a real-world context similar to what they will encounter as active citizens (Sadler, 2011; Sadler et al., 2019).

The present study utilizes the SIMBL framework as a guide for teachers participating in curriculum design, providing clear design elements that align with the overarching goal of promoting scientific literacy in real-world contexts. By integrating modeling and systems thinking, SIMBL offers a powerful approach to SSI teaching, fostering meaningful learning experiences that help students navigate complex SSIs.

2.7 Teachers' Professional Development (PD)

The integration of socioscientific issues (SSIs) and model-based learning has been recognized as a powerful approach to fostering scientific literacy among students. Despite growing evidence on the educational benefits of this integration, many teachers struggle to implement these complex instructional strategies in their classrooms effectively. This challenge underscores the need for PD programs that not only introduce teachers to SSI and modeling but also support them in designing and enacting lessons that align with these pedagogical approaches. The goal of the present study is to address this critical need by developing a PD program focused on the SIMBL framework. Through an in-depth exploration of teachers' learning experiences and classroom practices, this study aims to provide insights into how such PD programs can enhance teaching effectiveness and promote meaningful student engagement with real-world scientific issues.

PD for teachers is an ongoing process that plays a critical role in promoting educational reform and improving teaching practices (Ball & Cohen, 1999; Borko, 2004; Darling-Hammond & McLaughlin, 1999). Just as students need guidance to learn better, teachers need professional support to improve their teaching methods and adapt to changing educational demands (Putnam & Borko, 1997). Effective PD programs aim to enhance both the personal and PD of teachers, which ultimately benefits students by promoting a more enriching learning environment (Desimone, 2009; Garet et al., 2001; Loucks-Horsley et al., 2009).

Many studies investigated how PD programs could be designed for teachers and how these programs could be made more effective (Borko, 2004; Desimone, 2009; Garet et al., 2001; Loucks-Horsley et al., 2009; Putnam & Borko, 1997, 2000). Fundamentally, effective PD programs should be content-oriented, allowing participants to develop their professional knowledge and skills (Darling-Hammond et al., 2017; Desimone et al., 2002; Desimone, 2009; Garet et al., 2001; Guskey, 2003). In addition, active learning opportunities should be provided so that teachers can be an active part of the learning process (Garet et al., 2001; Desimone, 2009; Loucks-Horsley et al., 2009). Teachers' beliefs should be consistent with their classroom experiences and needs (Desimone, 2009; van Driel et al., 2012; Garet et al., 2001; Penuel et al., 2007). Otherwise, PD programs may remain superficial. In addition, sufficient time should be allocated for participants to internalize what they have learned and to apply it in their classrooms (van Driel et al., 2012; Garet et al., 2001; Loucks-Horsley et al., 2009; Wayne et al., 2008). In this way, teachers have the opportunity to discuss their experiences with PD instructors and colleagues. This feature also refers to the last effective PD feature known as collective participation (Borko, 2004; Desimone, 2009; Garet et al., 2001; Guskey, 2003; Little, 1993; Loucks-Horsley et al., 2009). It has been emphasized that PD programs in which teachers working in the same school, teaching the same grade level or the same course participate together provide more valuable discussions because they share common ground.

One of the primary goals of PD is to change instructional practices in ways that enhance student learning. Research highlights the importance of PD in preparing teachers to implement reform-based practices such as inquiry-based learning and the integration of SSIs into the curriculum (Capps et al., 2012; van Driel et al., 2012). Teachers are primary agents of change in classrooms, and without appropriate training and support, large-scale educational reforms may not achieve their full potential (Darling-Hammond & McLaughlin, 1999). Therefore, PD programs are designed to help teachers integrate new instructional strategies, enhance their content knowledge, and encourage reflective practices that enhance their classroom experiences.

As a result, an effective PD program allows teachers to develop their knowledge, skills and pedagogical approaches, thus providing improvements in student learning. These programs should lead to permanent changes by taking into account teachers' beliefs, motivations and cognitive processes (Guskey, 2002; Evans, 2014).

2.7.1 Importance of Professional Development Programs for Science Teachers

Science education changes over time and reflects the changing demands of society, educational standards, and pedagogical innovations. Over the years, science education has transitioned from a focus on purely academic content to a more balanced approach that prepares students both for scientific careers and informed citizenship. Since the 1980s, this shift has been influenced by a range of stakeholders, including policymakers and educators, moving beyond the sole influence of academic scientists (Fensham, 2013). In recent decades, accountability measures and standards like the Next Generation Science Standards (NGSS) have driven a move toward inquiry-based learning, which promotes critical thinking and practical application of scientific knowledge (Ediger, 2014). Countries have also integrated SSI into the curriculum in response to declining student engagement, aiming to make science more relevant and engaging (Viehmann et al., 2024).

Teachers are central to these educational reforms, particularly in science education, where curricula and teaching methods are constantly evolving to meet new standards (van Driel et al., 2001; Guskey, 2002). Adapting to these changes can be difficult, especially when they involve complex pedagogical shifts. These shifts require teachers to not only understand the new content but also implement innovative instructional strategies. To effectively navigate these transitions and ensure that students benefit from modern science education approaches, teachers need continuous PD programs (Darling-Hammond & McLaughlin, 1999). These programs equip them with the skills and knowledge necessary to keep pace with curricular reforms and enhance their classroom practices. Without continuous, high-quality PD programs, challenges in student learning and reform implementation are inevitable (Aksit, 2007; Guskey, 2002; Fishman et al., 2003; van Driel et al., 2001). Before implementing reforms, it is crucial to analyze the conditions and contexts of teachers, students, and society. High-quality PD programs that are accessible to all teachers and account for factors motivating teacher participation and the process of teacher change are essential for successful reform (Guskey, 2002). Effective PD programs allow teachers to reflect on their practices, learn how to implement new strategies, and refine their classroom methods (Harrison et al., 2008).

In summary, continuous PD, both pre-service and in-service, is crucial for developing effective science teaching practices and improving the educational system. Successful reforms in science education hinge on the ongoing professional growth of teachers, supported by well-designed, content-focused PD programs.

2.7.2 Pre-service and In-service Science Teachers' Professional Development Processes in Türkiye

The PD of the pre-service science teachers in Türkiye depends on the graduate education. After passing the university entrance exams, prospective teachers are placed into these faculties by the Council of Higher Education (CoHE), based on their preferences and exam results. To qualify as a science teacher, a four-year undergraduate degree and/or teaching certificate is required.

During their undergraduate program, prospective science teachers take subject-specific courses (biology, physics, chemistry, mathematics, environmental science, and earth sciences), pedagogical courses (focus on teaching methods, educational psychology, classroom management, assessment techniques, curriculum development, etc.), and science teaching courses. The graduates of this program work as science teachers in middle schools, and teach students from 5th to 8th grades. In addition to theoretical courses, the training is supported with observations, school experiences, and internships. After completing university education, candidates may work in either public or private schools in Türkiye.

Another way to qualify as a science teacher is by studying a four-year undergraduate program in fields such as physics, chemistry, or biology. After completing the program, or during the final year, students can obtain a teaching certificate from faculties of education. This teaching certificate is awarded after completing a pedagogical formation program. The program lasts one year, divided into two semesters, and requires teacher candidates to take pedagogical courses (focusing on teaching methods, educational psychology, classroom management, assessment techniques, curriculum development, etc.), as well as science teaching courses. In addition, they must complete training in schools, which includes observations, school experiences, and internships. After earning both their major degree and teaching certificate, they are eligible to work as science teachers in either public or private schools in Türkiye.

Since 2002, candidate teachers seeking public school positions must pass the Public Personnel Selection Examination, which assesses general culture, general skills, and educational sciences (Güven, 2010). This centralized selection process is often criticized for its reliability and efficacy (Eraslan, 2006, cited in Güven, 2010). In contrast, private schools have their own recruitment processes, often involving interviews, demo lessons, and evaluations by school administrators and department heads.

The MoNE also introduced a probationary training program for intern teachers in state schools. This includes basic training on civil services, preparatory training on the organization of MoNE, and practical professional training. Each candidate is mentored by an experienced teacher, although this mentoring program in Türkiye is not comprehensive. After a year, intern teachers are assessed through written and oral exams by a MoNE-assigned committee, evaluating their comprehension, communication skills, openness to scientific and technological developments, and public speaking abilities.

One of the major challenges in the PD of pre-service science teachers in Türkiye is the frequent changes in the K-12 science curriculum, which are not synchronized with the timing or structure of the teacher education curriculum. While the K-12 curriculum undergoes regular updates to reflect advancements in science and technology, teacher education programs often lag behind, unable to adapt at the same pace (Özergun et al., 2022). For instance, the K-12 science curriculum was revised three times in the past two decades (MoNE, 2013; 2018; 2024), but the science teacher education curriculum underwent only one centralized change (CoHE, 2018), with further updates left to individual universities. This misalignment creates a gap between the training pre-service teachers receive at universities and the realities they face in schools. Consequently, these teachers may enter the workforce without the necessary skills to effectively teach the latest curriculum. The CoHE attempted to address this issue through its 2018 reforms, which aimed to align teacher education more closely with K-12 curricular changes. However, challenges persist in ensuring that teacher education programs remain agile and responsive to ongoing reforms. For pre-service teachers, it is crucial that their training encompasses up-to-date content knowledge, pedagogical strategies, and discipline-specific teaching methods that reflect the latest developments in science education. Without cohesive collaboration between teacher education institutions and the MoNE, necessary adjustments can be delayed, hindering the preparation of future science teachers.

For in-service teachers, the PD programs are planned and organized by MoNE's In-service Training Office. These are typically short-term courses or seminars held at the beginning or end of the academic year. In recent years, recognizing the limitations and challenges in PD, initiatives such as School-Centered Professional Development have been introduced in some pilot schools through a project between MoNE and the European Union Commission (Bümen et al., 2012). Additionally, various non-governmental organizations like ORAV, ERG, and Intel have been developing PD programs for teachers. Since 2008, the Teachers Academy Foundation has been the first NGO in Türkiye to focus on teachers' personal and PD (Bümen et al., 2012).

In Turkey, one of the key challenges in the education system is the insufficient quantity and quality of in-service training programs (Bümen et al., 2012; Elçiçek & Yaşar, 2016). These programs, often delivered as courses or seminars, frequently fail to meet teachers' evolving needs, as they tend to recycle the same content without addressing the changing demands of the profession. The lack of qualitative depth in these programs is attributed to their design and delivery methods, which do not actively engage teachers or offer opportunities for practical application (Bümen et al., 2012). Another critical issue is the disconnect between the training content and the real-world classroom environments teachers face. Often, these sessions are led by external experts who may not consider the specific challenges teachers encounter in their unique educational contexts (Uştu et al., 2016). Additionally, collaboration among teachers—a key factor in enhancing PD—is seldom emphasized in these programs (Bayrakçı, 2009). Many teacher express dissatisfaction, citing an overemphasis on theory with insufficient focus on practical skills (Akdemir, 2012). Consequently, teachers' motivation for PD may decline, and they may perceive significant barriers to their professional growth (Kulbak, 2019). To address these concerns, research suggests that PD should be tailored to teachers' specific needs, emphasize active learning, and provide continuous, accessible opportunities that foster collaboration and practical application (Akdemir, 2012; Bayrakçı, 2020).

One example of the misalignment between the science education curriculum and the science teacher education curriculum is the absence of SSI as a focus in teacher preparation programs, despite it being a priority in K-12 science curricula (MoNE, 2013; 2018; 2024). While the 2013, 2018 and 2024 Science Curricula emphasize the importance of SSI in fostering students' scientific literacy, reasoning, and decision-making skills, teacher education programs in Türkiye have historically not provided sufficient training on how to teach SSI. Although SSI has been an explicit objective in K-12 science education for several years, it was only in 2018 that the "Interdisciplinary Science Teaching" course, which includes SSI, was introduced into the teacher education curriculum (CoHE, 2018). This gap further highlights the need for PD programs focusing SSI instruction for both preservice and in-service teachers.

2.8 The Interconnected Model of Professional Growth (IMPG)

In educational research, there is a consensus on the crucial role of teachers' PD in enhancing education. However, consensus is lacking on how this process occurs and can be effectively analyzed and promoted (Justi & van Driel, 2006). Clarke and Hollingsworth (2002) point out that teacher change should result from reflection on teaching practices, with consultation with colleagues being a crucial element and proposes an interconnected non-linear model for teachers' professional growth (Figure 2.3). This model facilitates the identification of particular ''change sequences'' and ''growth networks'', giving recognition to the distinctive and individual nature of teacher professional growth. In this thesis, the IMPG is used as a guiding framework to analyze and interpret teachers' PD within the context of SIMBL.

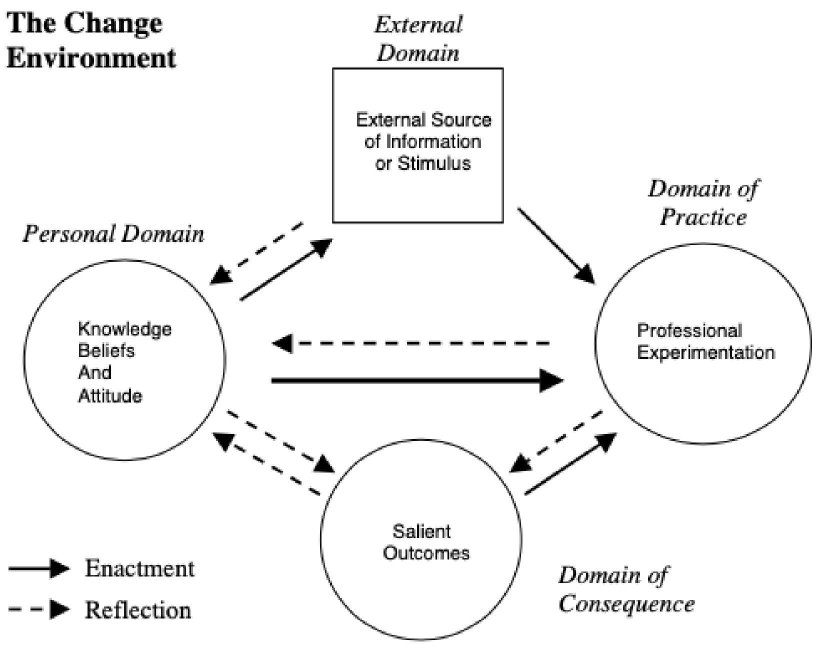

Figure 2.3 The Interconnected Model of Professional Growth (IMPG) (Clarke & Hollingsworth, 2002, p. 951)

The IMPG includes two types of domains: external domain and internal domains (domain of practice, personal domain, and domain of consequence). While the external domain exists outside the teacher's personal world, the internal domain together represents the teacher's professional world and include teachers' actions, the consequences of these actions, and the knowledge and beliefs guiding them (Clarke & Hollingsworth, 2002). The external domain exists outside the teacher's personal world, while the internal domains together represent the teacher's professional world, encompassing their actions, consequences of those actions, and the knowledge and beliefs driving them. Change can occur in any of the four domains, reflecting the unique nature of each. For example, adopting a new teaching strategy relates to the domain of practice, acquiring new knowledge or beliefs falls within the personal domain, and changing perceptions of outcomes relates to the domain of outcomes. Changes in one domain affect others through ‘reflection’ and ‘enactment.’ While ‘reflection’ involves considering changes and their effects, ‘enactment’ refers to turning beliefs or pedagogical models into practice and distinguishing it from mere action. In the model, reflection is represented by a dashed arrow, while enactment is represented by a solid arrow. According to the IMPG, teachers' growth involves four domains undergoing transformation through 'reflection' and 'enactment' (Clarke & Hollingsworth, 2002).

For the use of the Interconnected Model of Professional Growth (IMPG), Justi and van Driel (2006) suggest that researchers should properly define the four domains in relation to their study and also specify the criteria for enactment and reflection between the domains.

- Personal domain is commonly defined in most studies (e.g., Friedrichsen et al., 2020) as teachers' knowledge, skills, perspectives, and attitudes. When teachers acquire new knowledge, skills, attitudes, or perspectives, this domain undergoes a change. In this study, the personal domain refers to the teachers' knowledge, beliefs, and attitudes about SSI and modeling in teaching and learning, but it does not include skills, as no change in skills was anticipated within the scope of the research.
- Domain of practice encompasses all forms of professional experiences. Clarke and Hollingsworth (2002) mention that the domain of practice is generally limited to teachers' classroom experiences; however, they add that activities where teachers engage in design within teacher communities, professional associations, and subject committees can also be considered a natural part of the teaching profession and included in the domain of practice (e.g. Yazıcılar Nalbantoğlu, 2021; Zwart et al., 2007) On the other hand, Coenders and Terlouw (2015) suggested that developed teaching materials should constitute an additional fifth domain, the Developed Material Domain, in the IMPG. This study follows the original IMPG and defines the domain of practice as teachers' implementation of the SIMBL units in their classrooms.
- Domain of consequence represents the significant outcomes of the new practice (i.e., SIMBL unit implementation) that teachers and their students experience. Changes in this domain occur when teachers perceive the results that emerge (Clarke & Hollingsworth, 2002).

- External domain includes sources of information for teachers and provides support for developing new practices (Clarke & Hollingsworth, 2002). In this study, the external domain encompasses not only the PD program from which teachers gain knowledge but also their interactions with each other and with the researcher. This is because teachers also learn from feedback during the process. Some studies advocate for including books, articles, teacher forums, or peer discussions as sources of information and support within the external domain (Zwart et al., 2007). Additionally, in this study, the unit development process is considered a learning process and is therefore evaluated within the external domain.

The criteria for enactment and reflection across domains, according to Justi and van Driel's (2006) proposal, are presented in Table 2.1. These criteria are important to define the "change sequences" and "growth networks" that the participating teachers went through and to derive their PD models.

Table 2.1 Criteria for establishing relationships in the IMPG (Justi & van Driel, 2006)

Relationship	Criteria for establishment
From PeD to ED	When a specific aspect of teachers' initial knowledge, belief, or attitude influenced what they did or said during PD or during communication with the researcher.
From ED to PeD	When something that was done or discussed during PD or during communication with the researcher modified teachers' initial knowledge, belief, or attitude.
From ED to DP	When something that was done or discussed during PD or during communication with the researcher influenced something that occurred in teaching practice/ class implementation.

Table 2.1 Criteria establishing relationships in the IMPG (Justi & van Driel, 2006) (continued)

From PeD to DP	When a specific aspect of teachers' knowledge, belief, or attitude influenced something that occurred in teaching practice/ class implementation.
From DP to PeD	When something that teachers did in teaching practice/ class implementation modified their knowledge, belief, or attitude.
From DP to DC	When something that teachers or their students did in their teaching practice/ class implementation caused specific outcomes.
From DC to DP	When a specific outcome made teachers state how they would modify the associated teaching practice/ class implementation in the future.
From DC to PD	When teachers reflected on a specific outcome, thus changing a specific aspect of their previous knowledge, belief, or attitude.
From PD to DC	When a specific aspect of teachers' knowledge, belief, or attitude helped them in reflecting on/analyzing a specific outcome of their teaching practice/ class implementation.

PeD: Personal Domain; ED: External Domain; DP: Domain of Practice; DC: Domain of Consequence.

3
METHOD

3.1 Research Design

This study is designed as a multiple case study aimed at exploring teacher learning in the design and enactment of Socioscientific Issue and Model-Based Learning (SIMBL). The cases are bounded by the timeframe of the professional development (PD) program and the subsequent enactment of SIMBL units by the participants. Each teacher who participated in the PD program is treated as an individual case, providing a rich context for analyzing their beliefs, practices, and experiences.

According to Yin (2015), case studies can take different forms, including single or multiple case studies. In this study, a holistic multiple-case design is employed, where each teacher represents an individual case. Multiple case studies offer both benefits and challenges. While they can be expensive and time-consuming, they also provide higher representativeness, enabling a deeper understanding of variations across different contexts (Yin, 2015). As Stake (2006) explains, multiple case studies allow researchers to compare and contrast cases, drawing insights from the similarities and differences that emerge.

The decision to implement a multiple case study design is based on several factors. First, it aligns with the research questions that investigate various domains of teacher knowledge and practice, including: **Personal Domain** (teachers' beliefs, attitudes, and knowledge about science teaching and learning), **Domain of Practice** (how teachers implement SIMBL in their classrooms), **Domain of Consequence** (the perceived outcomes of implementing SIMBL), and **External Domain** (the interactions between teachers and the researcher within the PD program).

By examining each teacher's experience individually, this design allows for a deep exploration of how different factors influence their teaching practice and the enactment of SIMBL. Furthermore, this approach enables the collection of rich, context-specific data from multiple sources, which enhances the validity and depth of the findings.

The comparative aspect of the multiple-case design is crucial for identifying patterns and themes that may not be evident in a single case. By comparing the experiences and outcomes of different teachers, the study can generate findings that have the potential to be generalized to broader contexts. For example, variations in teachers' backgrounds, classroom settings, and interactions with the PD program provide unique insights into the factors that influence the implementation of SIMBL. These insights are valuable for the development of more tailored and effective PD programs in the future.

In conclusion, the multiple case study design offers a comprehensive approach to understanding the design and enactment of SIMBL. It allows for an in-depth examination of individual cases while also facilitating cross-case comparisons that can inform broader educational practices. By focusing on both commonalities and differences among teachers, this study contributes to the literature on SIMBL and teacher PD, offering practical implications for enhancing SSI-based teaching and learning.

3.2 Participants

The participants were selected through criterion sampling. In this method, the researcher defines specific characteristics or conditions proper to the interest of the study, and participants or cases that meet these pre-determined criteria involve the study (Patton, 2014). Participants of the study are in two groups as pilot study participants and main study participants.

3.2.1 Pilot Study Participants

For the pilot study, the criteria were first, working as a science teacher in a middle school in Düzce, Türkiye, this criterion was set to achieve face-to-face interaction, and second, the teachers' working together because the pilot study period open to changes in progress and managing this would be easier when teachers were together.

Pilot study participants are two science teachers from the same private school. The selected private school is one of the schools involved in the educational collaboration protocol of the researcher's institution. Within the protocol, teachers receive professional training from university faculty members. Prior to the study, all information about the study was clearly presented to the school administration and teachers, and after obtaining their approval, they were included in the study.

In the study, the abbreviations PST-1 and PST-2 were used as pilot study teacher 1 and 2 to encode the names of the teachers.

PST-1 and PST-2 graduated from the same university. PST-1 graduated from the physics department in 2010, and in the same year she received a teaching certificate. She has been working as a science teacher in the private schools since 2011. She has been teaching at the same institution for the last 5 years. She has not attended any training workshops before. PST-2 graduated from the science teaching program in 2016. She has been working in a private school for 2 years, before she worked as a paid teacher in public schools. Despite attending various conferences, she has never participated in a PD program before.

3.2.2 Main Study Participants

For the main study, the criteria were first, working as a science teacher in a middle school in Düzce, Türkiye, this criterion was set to achieve face-to-face interaction, and second, committing to implement the developed SIMBL units in class because previous studies (e.g. (Friedrichsen et al., 2020)) showed that all of the participants may not complete the whole process (PD program and implementation). After the ethical and approvals for the study, a brochure (Figure 3.1) and an application form were designed and shared with middle school principals to announce the teachers.

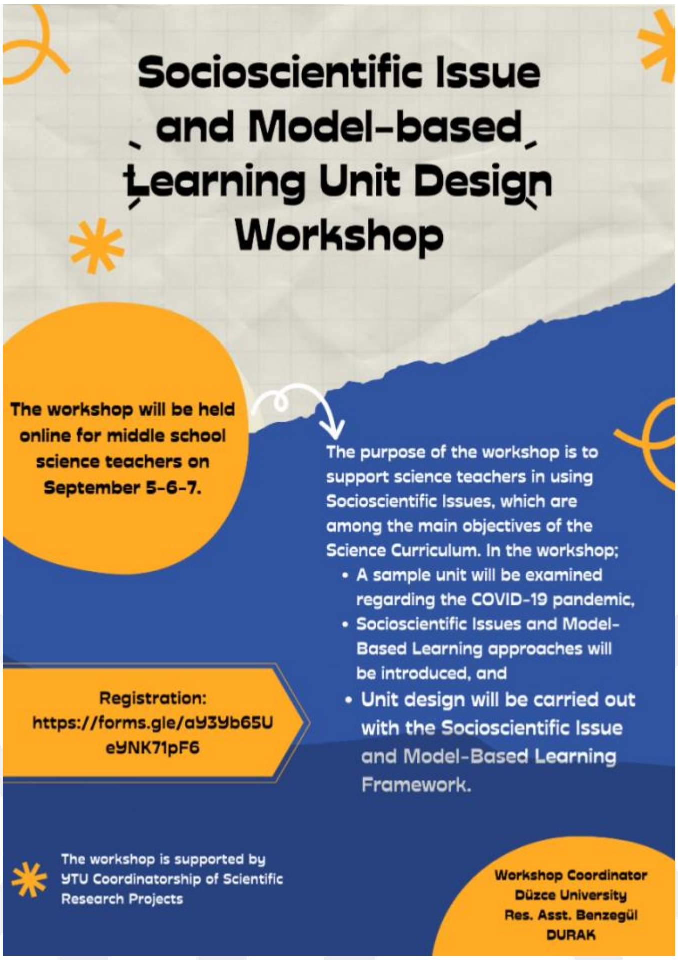

Figure 3.1 Study invitation brochure (translated to English)

Eight teachers working in Düzce expressed their interest in participating in the study by filling out the form and committing to implementing the unit they would develop in their classrooms. One teacher, who learned she was pregnant before the PD program started, withdrew from the study as she would be unable to implement the unit within the designated academic year. After the program began, two teachers left the study during Phase I, and one teacher left at the end of Phase II. One of the teachers who left during Phase I cited an inability to allocate time for the study, while the other provided no reason. The teacher who left at the end of the Phase II stated that her objective was to gain knowledge about the topics, and since she worked in a private school, she could not devote much time to implementation. Consequently, she did not see the need to participate in Phase III. Another teacher, one of the designers of the space research unit, explained that after beginning classroom implementation, he was unable to prepare for a lesson in time and resorted to direct instruction. Subsequently, he did not continue with the implementation and withdrew from the study.

The study involved a total of three participants who met the participation criteria: two teachers from two different public schools and one teacher from a private school. All participants were female. All participants volunteered to participate in the study. Informed consent forms were obtained. While presenting the research results the abbreviations T-1 to T-3 were used to encode the teachers' names.

All participants graduated from 4-years science teaching program. This program includes subject-specific courses (biology, physics, chemistry, mathematics, environmental science, and earth sciences), pedagogical courses (focus on teaching methods, educational psychology, classroom management, assessment techniques, curriculum development, etc.), and science teaching courses. The graduates of this program work as science teachers in middle schools, and teach students from 5th to 8th grades. Information about the participants and their practices was presented in Table 3.1.

Table 3.1 Participant information

Participants	**Years of Teaching Experience**	**Graduate Education**	**Topic of the Master's Thesis**	**The SIMBL Unit**
T-1	12	has a master's degree in education	teacher roles in SSI-based instruction	Climate Change Unit
T-2	7	has a master's degree in education	career awareness of teachers	Space Research Unit
T-3	4	-	-	Recycling Unit

3.2.3 Participant Management

Participant attrition is a common challenge in studies (e.g. 8 of the 18 teachers completed the study by Friedrichsen et al., 2020), and has a potential impact on the robustness and reliability of research. Several strategies were implemented in the present study to mitigate these risks. These included a comprehensive onboarding process to set clear expectations, regular check-ins and support, incentives for participation, and flexible scheduling.

After the ethical approvals for the study, a brochure (Figure 3.1) and an application form were designed and shared with middle school principals to announce the teachers. The brochure featured the study's main objectives, target audience, and a link to the application form. The form included an informational text detailing the study's purpose, rationale, and data collection methods, along with various questions. It asked teachers for demographic information (names, the schools they are working, the grades they will be teaching in the semester, their experience years, the previous education programs they attended, their education status, communication preferences, etc), their intention to implement the developed units in their classrooms, their preferred participation week, and preferred time slots on the selected days.

The participation options were within the first two weeks of September—the period designated by the Ministry of National Education for term preparations and teacher seminars before the academic term began. The study schedule was then planned based on the commonly selected days and times. Prior to the interviews, phone calls were made to the teachers to check-in also provide detailed information about the process. This information covered the study's content as well as the ethical principles were adhered to. These ethical principles were ensuring voluntary participation with the right to withdraw at any time without negative consequences, obtaining informed consent, maintaining confidentiality and anonymity, and offering exit interviews to understand withdrawal reasons to improve the study experience.

Throughout the study, phone calls and messages were maintained to check in with and support the teachers. Furthermore, reminder meetings were held with two teachers whose classroom implementations were scheduled for a later date, and the units were reviewed again. By implementing these strategies, it was aimed to maintain the study's integrity and reliability, proactively addressing participant attrition while ensuring our research remained robust and ethical.

3.3 The Professional Development (PD) Program

This section outlines the design, development, and implementation of the PD program central to this study. The PD program was specifically designed to enhance middle school science teachers' ability to integrate SIMBL approach into their classroom practices. The development process involved several key stages, beginning with the initial design. Expert opinions were solicited to refine and validate the program's content and structure. Following this, a pilot study was conducted to test the feasibility of the program, leading to further refinements. Finally, the PD program was implemented in the main study with the participating teachers, and its impact was assessed based on the study's research objectives. This section provides a detailed description of each phase, from development to implementation. The design process of the PD program is iterative because it involved refining the program from the pilot study results to its final version; it involves revising the PD program based on findings from the pilot study and then proceeding with further implementation. This iterative process is illustrated in Figure 3.2.

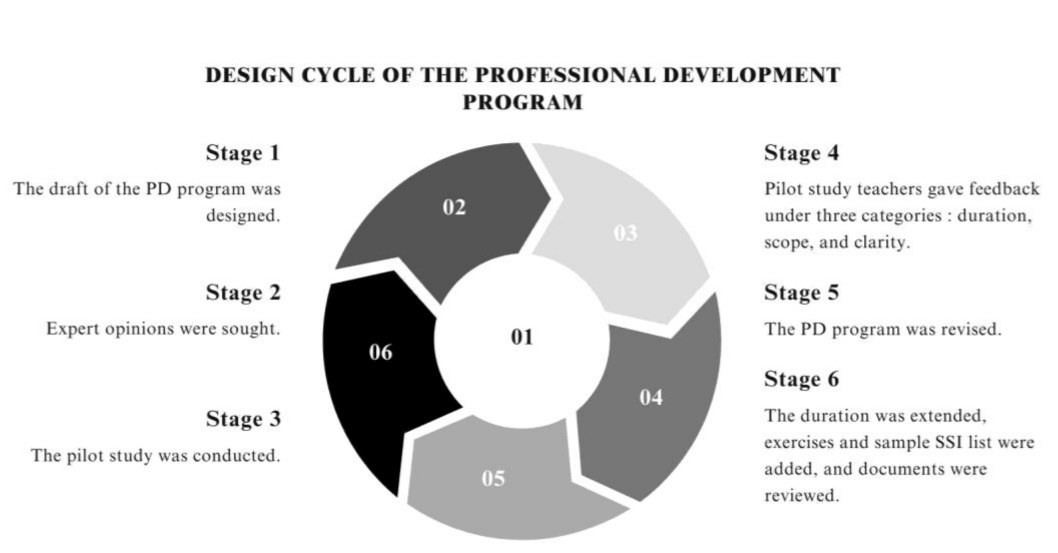

Figure 3.2 Design cycle of the professional development program

3.3.1 Design Process of the PD Program

This section details the development process of the PD program, including the strategies that informed its design. The development process aimed to create a program that would effectively support teachers in incorporating SIMBL framework into their instructional practices.

A draft of the PD program in this study was designed by utilizing the three-phase PD plan followed by Foulk et al. (2020) (Table 3.2). The PD module developed by Foulk et al. (2020) aims to support pre-service secondary teachers design SSI-based curriculum units using the SSI-TL Framework (Sadler et al., 2017). The module was later used in a study involving in-service science teachers (Topçu et al., 2022). Due to its relevance and efficiency, this study followed this three-phase plan to create a PD program draft (Table 3.2), which consists of three phases where participants take on the roles of a student, a teacher, and a curriculum designer. While in the role of a student, participants are exposed to a sample SIMBL unit as if they were students themselves; in the role of a teacher, they learn the teaching details of the SIMBL framework; and in the role of a curriculum designer, they prepare a curriculum unit using the SIMBL framework.

Table 3.2 Professional development program plan

Time Period	Focus	Activities
Phase I	Learning Science with the SIMBL	Implementation of sample unit (the COVID-19 unit, Sadler et al., 2020; EPIC Learning, 2023)
Phase II	Teaching Science with the SIMBL	Introduction to SIMBL framework -the SSI and SSI-based teaching framework -scientific models, modeling, and MbL -the SIMBL framework
Phase III	Curriculum Unit Design with the SIMBL framework	Co-creation of SIMBL units: -SSI Selection Guide (Peel et al., 2018) -Planning Heuristic (Peel et al., 2018)

Phase I of the PD program focused on the participants' engagement in a sample unit, the COVID-19 unit (see COVID-19 unit at the website: https://epiclearning.web.unc.edu/covid/). It was chosen as a sample unit because COVID-19 is a shared experience, and the unit includes various modeling techniques (such as system mapping, mathematical models, drawing, simulation, graphics) as part of its instructional practices. The aim was for participants to experience learning science with the SIMBL curriculum unit as if they were students themselves. In phase II, the focus was on teaching science using the SIMBL framework, and it was planned to provide participants with training on SSI and SSI-based teaching frameworks, scientific models, modeling, MbL, and the SIMBL framework. In phase III, the teachers would ask to think about an SSI that they wanted to work on by using the SSI Selection Guide (Peel et al., 2018). Then, they were expected to develop their units by following the Planning Heuristic (Peel et al., 2018). In the following sessions, time was allocated for discussing each developed unit, providing feedback from researchers and teachers, and revising the units based on the feedback.

3.3.2 Expert Opinions for the PD Program Design

To ensure the PD program's rigor and relevance, expert opinions were sought from specialists in curriculum development and science teacher education. Their feedback played a critical role in refining the content and structure of the program, ensuring it aligned with both theory and practical need. Feedback from the experts primarily focused on the scope of the theoretical content presented in the PD program. The feedback from the experts emphasized several important aspects:

- Three-Phase Structure: Both experts praised the program’s three-phase structure, noting that it was well-organized and beneficial for teachers' development (Table 3.2). They also highlighted the value of collaborative work, where they could review and provide feedback on each other's units, which was seen as a key factor in enhancing the effectiveness of the PD program.
- Pilot Study Suggestion: For Phase I (Table 3.2), since the unit being worked on by the teachers was a translated version, one expert recommended conducting a pilot study or a preliminary trial with pre-service science teachers. This was suggested to test the unit's applicability and effectiveness before its full implementation.
- Excessive Theoretical Content: In Phase II (Table 3.2), both experts pointed out that the theoretical content presented to the teachers was overly detailed and extensive. They advised that teachers would benefit more from active engagement rather than remaining in a passive listening role for extended periods.
- Content Focus: To address the issue of content overload, one expert specializing in science teacher education proposed narrowing the focus of the materials. He suggested a simplified flow from the appendices to narrow the theoretical content.
- PD Program Duration: Both experts raised concerns about the overall duration of the program, which they felt was too long.

In response to these feedbacks, adjustments were made to shorten the program by incorporating the suggested content narrowing from science teacher education expert. Additionally, a pilot study was planned to test the revised program with in-service science teachers, ensuring that the content and structure were both practical and effective before full implementation in the main study.

3.3.3 Pilot Study

Before full-scale implementation, a pilot study was conducted to test the PD program's feasibility. This section presents participants and findings of the pilot study, which led to valuable insights and necessary adjustments in the program design. Pilot study was necessary because the subjects (SSI and MbL) within the PD program have a long and detailed history in science education, and it was essential to determine the scope of these subjects and how much time was required for them. Additionally, the sample curriculum unit and materials used in the PD program were originally in English and had been translated into Turkish, and the pilot study tested the clarity of these translations.

The participants of the pilot study were two middle school science teachers working at a private school in Düzce. For participant selection, a call was made to private schools through the research and development protocol of the institution where the researcher is employed. A school was chosen where the teachers had never participated in a similar program before, the teachers voluntarily wanted to participate to the PD program, and both the school's and the researcher's schedules were suitable.

The abbreviations PST-1 and PST-2 were used to encode the names of the teachers as Pilot Study Teacher 1 and 2. PST-1 and PST-2 graduated from the same university. PST-1 graduated from the physics department received a teaching certificate. She has been working as a science teacher in private schools since 2011. PST-2 graduated from the science teaching program and has been working for two years.

The PD program in the pilot study was conducted from November 1, 2022, to January 7, 2023. Over eight weeks of this 10-week period, the PD program was implemented for a total of 16 hours, with sessions held once a week for two hours each day (due to a 6.0 magnitude earthquake in Düzce on November 23, 2022, there was a two-week delay in the program). As a result of the PD program, the teachers collaboratively designed a SIMBL unit on environmental pollution. One of the teachers, PST-2, who was teaching sixth grade, implemented the unit. The implementation and teacher interviews were completed by the end of April 2023.

The pilot study was led by the researcher of this thesis who had experience in science teacher education for about 6 years and also experience in leading a PD program about SSI teaching. During the pilot study, the researcher conducting the PD program maintained a reflective journal. This journal captured teachers' comments before sessions, their interactions with the researcher and among themselves during sessions, their reactions to session content, the time spent on activities, and their evaluations at the end of each session. To ensure objectivity, the researcher also included self-assessments in the journal.

At the conclusion of the pilot study, the teachers provided feedback in three categories: duration, scope, and clarity. The teachers provided the following feedback:

- There were translation-related problems, especially in the worksheets.
- We had difficulties with simulation or graphic activities.
- We struggled with finding socioscientific issues.
- Phases I and II should be swapped: socioscientific issues, model-based learning, and the SIMBL framework should be presented first, followed by the sample unit demonstration. This would make unit design easier for us.
- High-level activities in the sample unit should be removed. For example, the "infection curve simulation" activity is not something we can implement in the classroom and was difficult for us to do.
- The unit plans developed during the study should be shared and open for use.

The first three pieces of feedback from the teachers revealed common themes identified by the researcher. According to the researcher's notes, detailing the MOIB framework (Zangori et al., 2018) was found to overlap with the SIMBL framework in many areas; therefore, it is recommended to explain the MOIB framework using a figure. Moreover, In the pilot study, teachers were assigned tasks such as identifying an SSI topic for the next session and using the SSI Selection Guide (Peel et al., 2018) to review this topic. Teachers reported difficulties with these tasks.

Based on this feedbac and after further expert consultation, the researchers implemented the following adjustments.

- All documents were reviewed with the assistance of expert translators to ensure clarity in the worksheets.
- A list of example SSI topics compatible with the local curriculum was created. Before teachers selected an SSI topic for unit development, an exercise was added to follow the SSI Selection Guide using an example SSI with the teachers. Since the difficulty of finding SSI topics related to the local curriculum, as noted by both teachers and the researcher, was thought to be due to assigning these tasks to the teachers, these assignments were integrated into the PD process.
- The request from teachers to switch phases I and II was evaluated along with the researcher's notes, revealing that teachers wanted to use the example unit during their unit development processes. Instead of changing the structure of the PD program, the example unit (the COVID-19 unit), the carbon cycle unit by Zangori et al. (2017), the white butterfly unit by Durak and Topçu (2023), and the Dongfeng Highway unit by Lin et al. (2023) were shared with the teachers.
- The design components of the COVID-19 unit were examined, and unit layouts were extracted and matched with SIMBL to give teachers the opportunity to analyze the unit and similar units from a teacher's perspective.
- In response to the teachers' suggestion to remove high-level activities from the sample unit, no changes were made to preserve the unit's integrity. The fact that the pilot study teachers might not use a similar activity in their classrooms does not imply that other teachers will avoid it. Additionally, even if some teachers choose not to use it, they will still benefit from being exposed to a simulation graph as part of the modeling activity.

- Finally, the teachers requested that the units developed during the main study be made available for their use. A cloud storage was created to share the units with other teachers with the permission of the teachers who developed them.

3.3.4 Implementation of the Main Study

After refining the PD program based on expert feedback and the pilot study results, the program was implemented in the main study. This section describes the implementation process. The implementation details have been explained according to phases (Table 3.2). The main study, conducted by the researcher who led the pilot study, was completed over 5 days between September 5-9, 2022, totaling 20 hours. The program was administered during the period allocated by the Ministry of National Education for term preparations before the 2022-2023 term started. The sessions were conducted online and recorded.

As explained before the PD program was designed in three phases (Table 3.2). Phase I of the PD program focused on engaging participants in a sample unit (the COVID-19 unit). This unit was selected because COVID-19 is a universally shared experience, and the unit employs various modeling techniques such as system mapping, mathematical models, drawing, simulations, and graphics. The goal was for participants to experience learning science through the SIMBL curriculum as if they were students themselves. In Phase II, the focus shifted to teaching science using the SIMBL framework, where participants received training on SSI, SSI-based teaching frameworks, scientific models, modeling, MbL, and the SIMBL approach. Phase III tasked the participants with selecting an SSI to develop their own units, guided by the SSI Selection Guide (Peel et al., 2018) and the Planning Heuristic (Peel et al., 2018). Subsequent sessions were dedicated to discussing each unit, receiving feedback from researchers and peers, and revising the units accordingly.

3.3.4.1 Phase I of the PD Program

In Phase I, teachers experienced the COVID-19 unit developed by Sadler et al. (2020) as if they were students. The unit plan summarizing the focuses of the lessons is provided in Table 3.3. Through this unit, it was anticipated that teachers would experience the integration of SSI into science lessons, the guidance provided to students in exploring the scientific phenomena underlying the topic, and how various modeling techniques support science teaching, student learning, and the understanding of SSI. Teachers were expected to realize the dynamic nature of students' models and ideas, delve into how media literacy strategies can enrich and broaden students' knowledge, recognize the enhancement of students' reasoning skills through the integration of SSI into teaching, and acknowledge that this experience empowers students to articulate and defend their own perspectives amidst complex issues.

Table 3.3 Summary of the COVID-19-unit plan (EPIC Learning, 2023)

Lesson	Focus
Lesson 1: System Map Activity	The purpose of this activity is to highlight the inherent complexity of the COVID-19 pandemic.
Lesson 2: Model of Viral Spread	In this activity, students use a mathematical model, programmed within a spreadsheet (Google Sheets), to explore viral transmission and exponential growth.
Lesson 3: Handwashing and Face Masks	The handwashing activity asks students to use and analyze models, as well as engage in argumentation. The face masks activity asks students to analyze data and engage in augmentation.

Table 3.3 Summary of the COVID-19-unit plan (EPIC Learning, 2023) (continued)

Lesson 4: Infection Curve Simulation	The purpose of this assignment is to introduce students to modeling the spread of viruses using an infection curve simulation. For this exercise, students use a computational model developed within Netlogo.
Lesson 5: Comparing National Responses to COVID-19	In this activity, students interpret COVID-19 data from the United States, Italy, and Switzerland, analyze the data in relation to government policies, and draw conclusions about policy implementation and COVID-19 cases.
Revisiting Lesson 1: System Maps	At this point, students should be able to make significant changes and reflections on their original system map.
Lesson 6: Media Literacy Activities	The purpose of this set of activities is to help teachers and students develop better media and information skills particularly in the context of Socio-scientific Issues.
Lesson 7: Social Vulnerabilities & COVID-19	COVID-19 has disproportionately impacted people of color, women, and people experiencing poverty. This assignment asks students to explore how and why these public- health disparities occur.
Lesson 8: Culminating Activity	This assignment asks students to create a presentation that synthesizes what they have learned throughout the learning experience. Students will propose a policy with appropriate evidence aimed at lowering the spread of COVID-19. This assessment aims to highlight not only the biology and epidemiology of the pandemic, but the complex social issues that have arisen as well.

In this phase, the unit was implemented in a regular classroom setting without discussing whether teachers explored these expectations or not.

Implementation of this phase started with that the instructor asked the driving question and, after a small discussion, continued with the system mapping presentation (the COVID-19 unit, Sadler et al., 2020; EPIC Learning, 2023). This presentation explained how to construct a system map step by step. At the end of this presentation, there were questions that directed students to think about the factors affected by COVID-19 and the factors affecting it. Then, teachers started to construct their own system maps. Figure 3.3 shows the system map of one of the teachers.

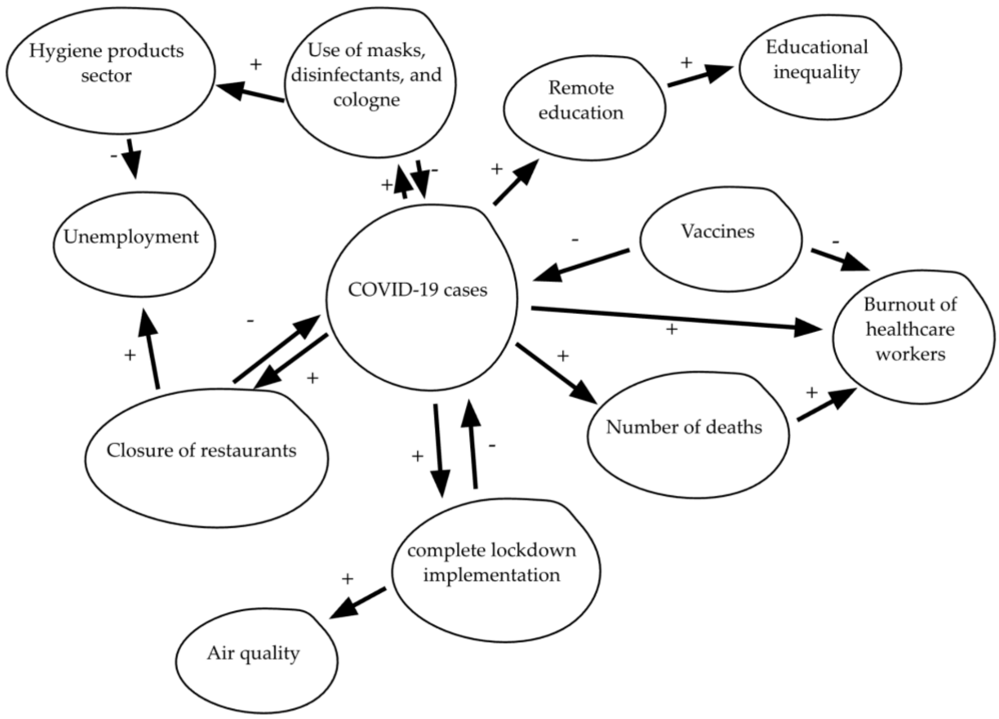

Figure 3.3 System map constructed by a teacher during the PD program (translated into English)

Following this, teachers guided by the instructions and questions provided in the worksheet, utilized a mathematical model programmed within a spreadsheet (Google Sheets) to delve into viral transmission and exponential growth. The activity aimed to stimulate critical thinking among learners by exploring various implications of the model and contemplating strategies for reducing the R0 for a virus and its associated impacts on transmission. However, similar to the pilot study, teachers found this activity challenging to complete. Subsequently, they engaged in an activity incorporating videos, animations, and model drawings to investigate how handwashing and the use of face masks influence the spread of COVID-19. Many teachers noted the applicability of this activity to their own students.

Following a brief interlude, they attempted to grasp the effect of social distancing using a computational model designed in NetLogo to mitigate the spread of viruses. This lesson, reinforced by worksheets, also analyzed COVID-19 graphs from different continents (Asia, Europe, and North America) and deliberated on how the policies of various governments regarding social distancing influenced the spread of COVID-19, as outlined in the worksheet questions.

In the next lesson, teachers interpreted COVID-19 data from the United States, Italy, and Switzerland, analyzing it in relation to government policies and drawing conclusions about policy implementation and COVID-19 cases. This exercise prompted teachers to critically reflect on the government's role in responding to the pandemic and its resulting consequences. It urged teachers to contemplate the implications for public safety, economic repercussions, and political factors involved in implementing COVID-19 precautions and policies among the general public.

Teachers commenced revisiting their system maps with guidance from worksheets. The objective of this lesson was to revise their system maps based on improved understandings and additional evidence collected related to COVID-19, justify their system maps with evidence, and employ their system maps to reason about the system dynamics of key factors related to COVID-19. Teachers' feedback on the utility and evident progress of the system map and its application was overwhelmingly positive.

Later, the instructor delivered a presentation on media literacy, and teachers examined sample news stories through worksheets. All teachers stated that they found media literacy tools beneficial for their classrooms.

In the subsequent lesson, teachers delved into how and why public health disparities occur. COVID-19 has disproportionately impacted people of color, women, and individuals experiencing poverty. As this lesson veered slightly from the core content, teachers displayed less enthusiasm about completing the worksheets.

In the unit's final lesson, teachers received information about the culminating activity and began individual work using the provided worksheets. Teachers were not required to design posters to ensure efficient use of time. Instead, they were tasked with proposing a policy with appropriate evidence aimed at reducing the spread of COVID-19 and elucidating how other components on the system maps could be affected using their system maps. Through this activity, teachers explored COVID-19 as both a scientific and social system, comprehending how any proposal could impact various segments of society or different events. Additionally, the worksheet contains references to media literacy activities and other lessons (the COVID-19 unit, Sadler et al., 2020; EPIC Learning, 2023).

3.3.4.2 Phase II of the PD Program

In Phase II, the aim was to introduce teachers to science teaching with the SIMBL framework. The initial part of this phase primarily centered on theoretical knowledge, with presentations and booklets prepared to convey the information effectively.

The definition of socio-scientific issues (SSIs) was discussed. Before diving into SSI-based frameworks, examples were shared to illustrate how activities could integrate SSI topics into lessons. Subsequently, SSI-based instruction drew from established frameworks such as "An Emergent Framework for SSI-Based Education" (Sadler, 2011), "Design of a Socio-Scientific Issue Curriculum Unit" (Friedrichsen et al., 2016), and "The Current Socio-Scientific Issue Teaching and Learning (SSI-TL) Model" (Sadler et al., 2017). While many teachers were familiar with the concept of SSIs and recognized SSI examples, the instructional frameworks and sample designs were new to many participants.

As the session shifted to modeling, various definitions, classifications, and examples were reviewed based on studies by Harrison and Treagust (2000) and Justi and Gilbert (2002). The concept of MbL was further elaborated using Clement (2000)'s theoretical framework, emphasizing a cyclic modeling process recommended for MbL. This approach, rooted in a constructivist perspective, encourages learners to develop, use, evaluate, and revise their models.

Furthermore, the model-oriented issue-based (MOIB) framework (Zangori et al., 2018) was introduced as a precursor to transitioning to the SIMBL framework, which was comprehensively explained through Sadler et al. (2019)'s study. Following this, teachers collaboratively mapped out the lesson flow of the COVID-19 unit, aligning it with SIMBL components to gain insights from a teacher's perspective. Working in groups, Table 3.4 illustrates how one group outlined the COVID-19 unit according to the SIMBL components.

Table 3.4 Teachers' alignment of the COVID-19 Unit plan with SIMBL framework components

Lesson	SIMBL Components
Lesson 1: System Map Activity	Engage in scientific modeling
Lesson 2: Model of Viral Spread	Engage in scientific modeling, Explore underlying scientific phenomena
Lesson 3: Handwashing and Face Masks	Engage in scientific modeling, Explore underlying scientific phenomena
Lesson 4: Infection Curve Simulation	Engage in scientific modeling, Explore underlying scientific phenomena, Consider issue system dynamics, Compare & contrast multiple perspectives,

Table 3.4 Teachers' alignment of the COVID-19 Unit plan with SIMBL framework components (continued)

Lesson 5: Comparing National Responses to COVID-19	Compare & contrast multiple perspectives, Engage in scientific modeling, Explore underlying scientific phenomena, Consider issue system dynamics
Revisiting Lesson 1: System Maps	Engage in scientific modeling, Consider issue system dynamics
Lesson 6: Media Literacy Activities	Employ media & information literacy strategies
Lesson 7: Social Vulnerabilities & COVID-19	Consider issue system dynamics, Compare & contrast multiple perspectives
Lesson 8: Culminating Activity	Elucidate own position/solution, Engage in scientific modeling, Employ media & information literacy strategies

The teachers were provided with studies integrating modeling and SSI-based instruction for their examination (the carbon cycle unit by Zangori et al. (2017), the white butterfly unit by Durak and Topçu (2023), and the Dongfeng Highway unit by Lin et al. (Lin et al., 2023)).

3.3.4.3 Phase III of the PD Program

During Phase III, participants were tasked with developing a SIMBL curriculum unit suitable for implementation in their classrooms. To aid them in this process, two supportive tools were shared with the teachers: the SSI Selection Guide (Peel et al., 2018) to assist in selecting the socio-scientific issue to concentrate on, and the Planning Heuristic (Peel et al., 2018) to provide step-by-step guidance during development (Appendix A). Some adjustments were made, such as substituting NGSS objectives with those from the national science education program. These tools were derived from a PD study where teachers developed SSI-based units and were proven effective (Peel et al., 2018), hence their inclusion as supportive aids in this program.

Teachers were introduced to the SSI Selection Guide along with an explanation of its use. They were tasked with reviewing it to find a socio-scientific issue for unit development. Prior to starting unit development, following the pilot study results, teachers were provided with a list of SSIs compatible with the local curriculum. An exemplary topic selected from this list was examined using the SSI Selection Guide. Genetic engineering studies related to Spinal Muscular Atrophy (SMA) disease, a prominent subject for donation campaigns in Türkiye, were discussed as a sample dilemma. The dilemma presented was as follows:

> *Genetic engineering interventions can address diseases like Spinal Muscular Atrophy (SMA) through genetic studies, potentially preventing these diseases at a lower cost than treatment expenses. However, this may initiate a pursuit for creating 'perfect' humans via genetic engineering (including selecting children's gender, hair color, and eye color), disrupting the natural balance and raising ethical concerns, thereby suggesting that genetic engineering studies should not be permitted.*

One teacher opted for climate change, another for recycling, and two chose space research. These topics were not found on the exemplary list. Subsequently, the Planning Heuristic (Peel et al., 2018) (Appendix A) was shared with the teachers. The two teachers who selected space research collaborated on developing their unit, while the others embarked on individual unit development.

Teachers presented the unit outlines and activities they had developed. They all began their units with constructing a system map and concluded with a culminating activity prompting students to propose a policy in response to the driving questions. This approach seemed to stem from the teachers' recognition of the effectiveness and comprehensiveness of these two activities when used together, as noted during Phase 1. Additionally, teachers incorporated various forms of modeling, such as graphs, simulations, and drawing activities into their units. Notably, one unit, space research unit, involved building a model, telescope. Following the presentations, teachers engaged in discussions and provided feedback to each other. For example, one teacher questioned the necessity of a telescope activity due to students' lack of prior knowledge about lenses. However, another teacher shared previous positive experiences and argued for its inclusion *"In previous years, I conducted a telescope activity before covering the topic of lenses, and the students enjoyed it. When they learned about lenses, they remembered the telescope activity on their own. Therefore, I think it can be used."*. Table 3.5 presents examples of the presented, revised, and implemented versions of the space research unit. This unit received criticism mainly regarding timing. Teachers had included lengthy videos to engage students, but this exceeded the allocated time according to the curriculum. Thus, Table 3.5 illustrates presented, revised, and implemented versions of the space research unit.

Table 3.5 Presented, revised, and implemented versions of the space research unit

Lesson (time)	**Focus**	**Presented**	**Revised**	**Implemented**
1	Preliminary information about space exploration, discussion of guiding questions	Brainstorming System map activity	Brainstorming System map activity	Brainstorming System map activity

Table 3.5 Presented, revised, and implemented versions of the space research unit (continued)

2	Technologies used in space exploration (telescope, satellite, rocket, etc.) and prominent scientists	Journey to the End of Space and the Universe (documentary) How did we discover space? (video) - Who discovered space? Worksheet	Journey to the End of Space and the Universe documentary - Who discovered space? Worksheet	Journey to the End of Space and the Universe documentary (partially watched due to time restriction) - Who discovered space? Worksheet
3	Telescope, which is a turning point for space research, types of telescopes and working principles of the telescope	Telescope model design-making Why is the Webb space telescope so important? (video)	Telescope model design-making	Telescope model design-making

Table 3.5 Presented, revised, and implemented versions of the space research unit (continued)

4	Observatories, which are the center of space research, the factors affecting the choice of location for the establishment of observatories and the effect of light pollution on space research	Brainstorming -Examining the examining similarities and differences between the observatories from the world-using the Internet and Media Literacy Tools	Brainstorming -Examining the examining similarities and differences between the observatories from the world-using the Internet and Media Literacy Tools	Discussion with the invited space researcher
5	Space exploration discussions	Research guided with worksheet Argumentation Back to the system map	Research guided with worksheet Back to the system map	Research articles/ newspapers on space exploration - Media Literacy Tools Back to the system map
6	Culminating activity	Students' presentations	Argumentation	Students' presentations

The details about developed SIMBL units are presented in Table 3.6.

Table 3.6 Developed SIMBL units in the professional development program

The SIMBL Unit	Grade Level	Duration (lesson hour)	Driving Questions	Implementation Dates
Climate Change Unit	8th	8	*"Should individuals or governments take measures against global warming?"*	June 5-13, 2023
Space Research Unit	7th	7	*"Should the budgets allocated by governments for space exploration be transferred to more urgent needs (diseases, natural disaster preparation, etc)?"*	September 14-28, 2022
Recycling Unit	5th	6	*Should we recycle, or not consume?*	June 5-14, 2023

The implementation dates were arranged according to the sequence of topics outlined in the annual plan provided by the Ministry of National Education (MoNE, 2022). As per the annual plan, the space unit was designated as the initial topic for the fall term and thus was implemented immediately following the PD program. The remaining topics were scheduled for the spring term. However, before the commencement of the spring term, on February 6, 2023, southeastern Türkiye was struck by two consecutive earthquakes measuring 7.7 and 7.6 in magnitude. These earthquakes caused extensive devastation across 10 provinces, resulting in approximately 55,000 fatalities and numerous injuries.

While Düzce itself was not directly impacted by the earthquakes, the start of the school term was delayed due to relief efforts. Consequently, the Ministry of National Education made adjustments to the spring term program, and the units were implemented as per the revised schedule. Due to the significant delay, reminder meetings, each lasting approximately two hours, were conducted separately with the two teachers on May 27 and 28, 2023 to review the unit plans. During these meetings, the teachers revisited their units and discussed whether any modifications were necessary or if they had any queries regarding the implementation process. No changes were deemed necessary to the unit plans.

3.4 Data Sources

The present study follows the multiple case study design, so collecting in-depth data is the basis of the study. The main data sources of the study were semi-structured interviews, and the secondary data sources were developed SIMBL units, field notes of the PD program, classroom observations of the lessons, and unstructured phone calls/messages. Considering the case study design, data was generated within the bounded case, rather than to a point of saturation. It means the data of the study was bounded within the time frame of the PD program and the participants' implementation of their SIMBL units. By employing a diverse range of qualitative data collection methods, a thorough understanding of the PD process undertaken by the participating teachers was achieved.

3.4.1 Semi-structured Interviews

Three detailed interviews were conducted with the teachers in order to fully reflect their PD process. These interviews comprised a pre-PD program interview (I#1), an end-of-PD program interview (I#2), and a post-implementation interview (I#3). The interview questions were categorized according to the IMPG domains (Clarke & Hollingsworth, 2002), ensuring a systematic exploration of teachers' experiences and perceptions. Furthermore, some questions were asked iteratively to delve into the teachers' evolving knowledge, beliefs, and attitudes regarding the SSI, MbL, and SIMBL approach. A semi-structured interview protocol was employed and each interview lasted approximately one hour, allowing for personal reflection and discussion of individual perspectives (Creswell, 2014). Some examples of interview questions were provided in Table 3.7 (all interview questions on the Appendix B. The researcher conducted these interviews individually via a conference app, resulting in a total of 505 minutes of audio/video recording for the three teachers.

Table 3.7 Example interview questions baded on IMPG domains and interview numbers (I#1, I#2, I#3)

Interview Questions	**Content**			**IMPG Domains**				**Interview#**		
	SSI	MbL	SIMBL	PeD	ED	DP	DC	1	2	3
What do you think about engaging students in the social aspects of a topic?	✓			✓				✓		✓
How can models and modeling be useful for your students?		✓		✓				✓		✓
When you attended the SIMBL workshop, what were some of your “ah-ha” learning moments?			✓		✓				✓	

During the preparation of the interview questions, the interview form developed by Friedrichsen et al. (2021) was considered, containing specific questions tailored for each of the four IMPG domains. Subsequently, essential refinements were made by two experts in science education and the IMPG to enhance the validity and relevance of the interview questions.

3.4.2 SIMBL Units Developed by the Teachers

During the PD program, the teachers developed SIMBL units using the SIMBL framework (Sadler et al., 2019). These units served as valuable artifacts of teachers' instructional practices and provided insights into how they applied the framework to design science units.

3.4.3 Field Notes of the PD Program

The PD program was conducted online with open cameras and audio and lasted for 5 days, 20 hours in total. Field notes were created by the researcher by watching the records. These field notes provided contextual information about the PD sessions, including discussions, activities, and reflections. This documentation enhanced understanding of the PD process, capturing the dynamics of teacher engagement, the nature of their participation, and the evolution of their instructional practices.

3.4.4 Classroom Observations of the Lessons

Some of the lessons, suitable for both the researcher and the class, were observed to gain firsthand insights into the implementation of SIMBL units in the classroom. These observations provided a direct view of teachers' instructional practices, student engagement, and the integration of SIMBL practices into the curriculum. 9 out of 21 lessons were observed by the researcher. Several visuals from the classroom observation are included in the Appendix C.

3.4.5 Unstructured Phone Calls/Messages

In order to maintain communication with the teachers throughout the implementation process and ensure participant continuity, teachers were encouraged to provide feedback in written, verbal, or visual forms regarding the lessons. Although this feedback was not structured in terms of content, these conversations with the teachers were documented. These unstructured communications offered valuable insights into teachers' experiences, challenges, and reflections on the implementation of SIMBL units, enriching the understanding of how the framework was applied and adapted in practice.

3.5 Data Analysis

Deductive and inductive approaches for data analysis were used together.

3.5.1 Deductive Analysis

For the deductive analysis, the concept-driven coding approach (Gibbs, 2018) was employed. This method begins with predefined concepts, theories, or frameworks, and data is analyzed in relation to these established categories. In this study, the deductive approach was applied in three distinct ways.

First, data from multiple sources—three interviews, field notes from the PD program, classroom observations, and phone calls—were coded according to the four domains of the IMPG (see examples in Table 3.8):

a. Personal Domain
b. Domain of Practice
c. External Domain
d. Domain of Consequence

Table 3.8 Examples from the deductive analysis codebook

Categories	Description	Quotes	Sources
Personal Domain	the teacher's knowledge, beliefs, and attitudes about science teaching and learning	*Using the students' responses as a starting point, T-1 then asked, "How do you think we can calculate it?" This approach prompted students to consider their individual contributions to carbon emissions in their daily lives."*	classroom observation notes

Table 3.8 Examples from the deductive analysis codebook (continued)

Domain of Practice	teachers' implementation of the SIMBL units in their classrooms	*"The class participation is very low, so I am considering inviting a researcher working at the observatory to the class online in order to break away from the routine. In this case, would it be a problem if I don't use all the worksheets I have prepared in PD?"*	phone calls
External Domain	the PD program from which teachers gain knowledge and their interactions with each other and with the researcher	*"I believe that 5th-grade students will be active in the activities, but they will still ask what the correct answer is."*	[Comment on teacher attitude initiated]. field notes
Domain of Consequence	the significant outcomes of the new practice (i.e., SIMBL unit implementation) that teachers and their students experience	*"I used to define modeling as representing something abstract, such as modeling an atom. However, in the activity we did in class, we saw that even a problem could be modeled."*	interviews

According to the deductive analysis results, different proportions of data output were obtained from each data source for each domain. For instance, interviews provided data for all domains, whereas field notes analysis only provided data for the personal domain and the external domain. The detailed visualization of the analysis results from the data sources for the IMPG domains is depicted in Figure 3.4.

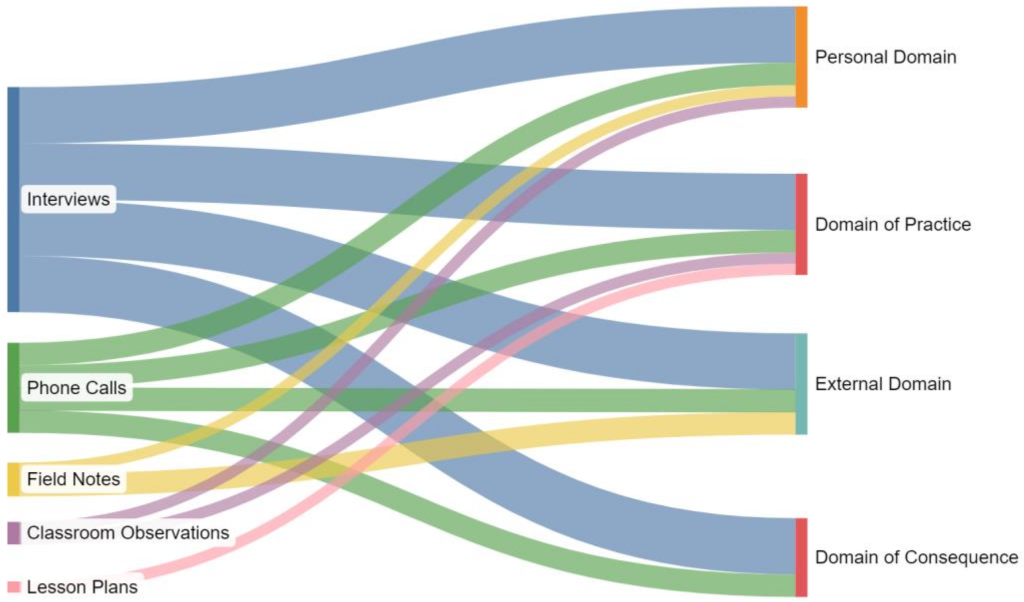

Figure 3.4 Analysis results from data sources for IMPG domains

Second, the data coded according to the IMPG domains were analyzed using the criteria set (Table 2.1). The criteria for enactment and reflection across the domains, as proposed by Justi and van Driel (2006), are crucial for identifying the "change sequences" and "growth networks" the participating teachers experienced and for developing their PD models. Table 3.9 presents examples of the analysis according to the criteria set.

Table 3.9 Example analysis of teacher professional development model relationships

Relationship	**Criterion met/not met**	**Explanation**	**Excerpts**
From PeD to ED	✓	T-1's initial knowledge about SSI and modeling contributed significantly to the discussions during the PD workshop and she provided feedback on the units of other teachers, she actively communicated with the researcher.	*"To conduct effective SSI instruction, it is necessary for us as teachers to determine our position in advance. The decision should be based on the topic and the class's discussion skills, but in my own classes, I prefer 'Commited Impartiality'."* (from field notes)
From ED to PeD	✓	Her understanding of the SIMBL framework was enhanced, and she made connections between the SIMBL framework and constructivism.	*"I've never heard of the SIMBL framework, is it related to controversial models?"* (I#1) *"SIMBL framework via model-based learning; As in the constructivist approach, it seems to be a method in which we aim for the student's learning to progress on its own."* (I#2)

Table 3.9 Example analysis of teacher professional development model relationships (continued)

From ED to DP	✓	T-1 implemented the SIMBL unit that was developed during the PD workshop, and in the process, influenced interactions with researchers.	*"While introducing the system map to the students, we all created a system map example regarding COVID-19 together and continued the unit. Instead of doing it this way, if I had done system mapping activities on appropriate topics several times during the semester, students could have been more productive with their first maps."* (from phone calls after the lessons)

Third, the developed SIMBL (Socioscientific Issue Modeling-Based Learning) units were analyzed using the SIMBL Framework (Figure 2.2) and SSI Selection Guide (Peel et al., 2018) (Appendixes A) as evaluation tools. These checklists were used to assess how many SIMBL components were included in the units, allowing for a systematic evaluation of their alignment with SSI integration strategies.

Evaluation of Climate Change Unit

- Evaluation of the climate change unit according to SSI Selection Guide (Peel et al., 2018): The climate change unit is structured around the guiding question, "Should individuals or governments take measures against global warming?" This question effectively frames the unit as an SSI and invites students to explore the scientific and social dimensions of climate change.

The following analysis evaluates the unit against the criteria set by the SSI Selection Guide (Peel et al., 2018).

Table 3.10 Evaluation of climate change unit according to SSI Selection Guide

Criteria	Analysis
1. Relevance of the Topic	Climate change is a pressing global issue that directly affects individuals and societies, making it highly relevant.
2. Interdisciplinary Nature	The unit effectively integrates scientific themes (carbon cycle, greenhouse effect) with social concerns (economic, political).
3. Engagement of Students	The guiding question encourages students to explore personal and governmental responsibilities, fostering engagement.
4. Opportunity for Critical Thinking	The argumentation and culminating activities provide opportunities for students to critically evaluate different perspectives.
5. Promotion of Civic Responsibility	The unit addresses civic responsibility by prompting discussions about the roles of individuals and governments in addressing climate change.
6. Connection to Students' Lives	The unit encourages students to calculate their ecological footprint and consider their impacts, connecting the topic to their lives.
7. Encouragement of Values and Attitudes	Discussions on environmental ethics and the role of science in policy-making promote values such as responsibility and activism.

The climate change unit aligns well with the SSI Selection Guide (Peel et al., 2018) criteria, making it a suitable SSI for students. It successfully integrates scientific concepts with social concerns, encouraging critical thinking, civic responsibility, and personal relevance.

- Evaluation of the climate change unit according to the SIMBL framework: The unit consists of six lessons, each focusing on different aspects of climate change, from basic concepts to individual and government impacts, culminating in discussions on policy making.

Table 3.11 Evaluation of the climate change unit according to the SIMBL framework

SIMBL Component	**Lesson Focus**	**Alignment with SIMBL framework**
Explore underlying scientific phenomena	1. Preliminary information about climate change	Effectively introduces the topic and engages students with a system map, helping them visualize connections.
Explore underlying scientific phenomena	2. Climate change, greenhouse effect, global warming	Uses experiments and simulations to connect students with the science behind climate change.
Engage in scientific modeling	1. & 6. System map activities	Initial and final system map activities encourage modeling and representation of complex systems.
Consider issue system dynamics	4. Effects of governments; energy preferences	Engages students in understanding the system dynamics of climate change, including human factors.

Table 3.11 Evaluation of the climate change unit according to the SIMBL framework (continued)

Consider issue system dynamics	5. Climate Change and International Negotiations	Discusses the complexity of international negotiations, integrating social and political dimensions.
Employ information/media literacy strategies	3. Individual effects	Research activity promotes media literacy as students investigate the impacts of individual behaviors by using media literacy tools.
Compare and contrast multiple perspectives	5. Climate Change and International Negotiations	The argumentation activity allows students to consider multiple perspectives on climate change.
Elucidate own position/solution	6. Culminating activity	Students defend their positions and propose solutions, promoting engagement and ownership of learning.

The climate change unit begins effectively by introducing the topic through a system map, which helps students grasp the broader context of climate change. A strong aspect of the unit is the use of system maps, allowing students to visualize the relationships between various components of climate change. Lessons that focus on governmental impacts and international negotiations address the social dimensions of climate change. The research activity on individual effects supports the development of media literacy. The culminating activity effectively promotes student engagement through solution-oriented discussions. However, providing clear guidelines for articulating and defending positions can enhance the depth of student responses, allowing them to better articulate their perspectives.

3.5.2 Inductive Analysis

For the inductive analysis, a data-driven approach was employed, where the data from multiple sources—three interviews, field notes from the PD program, classroom observations, and phone calls—were coded without any pre-existing theoretical categories or frameworks in mind (Gibbs, 2018). This approach allows themes and patterns to emerge directly from the data rather than being shaped by predetermined concepts. The purpose of the analysis was to identify common themes related to teachers' perceptions of the PD program, challenges they encountered, and successes they achieved in implementing SIMBL framework.

The inductive analysis followed a systematic, six-step process (Clarke & Braun, 2013):

1. **Data Acknowledgement:** To gain a comprehensive understanding of each participant's reflections and experiences, the data transcripts were read several times.
2. **Initial Coding**: The data were coded line by line, with particular attention paid to any recurring statements, ideas, and patterns that emerged in relation to the teachers' experiences with SSI, scientific modeling, SIMBL framework and participation in the PD program.
3. **Theme Development:** The codes were then organised into broader categories, and preliminary themes were created by identifying recurring ideas across participants.
4. **Theme Review**: These emerging themes were then reviewed and refined to ensure that they accurately reflected the teachers' experiences and were consistent across the entire dataset.
5. **Theme Identification and Naming:** The final themes were then identified, contextualised and connected to the research questions so that they contributed to a coherent narrative of the findings.
6. **Writing Up:** Once the themes had been finalised, the findings were presented in a clear and structured manner. Each theme was supported by quotations from the participants, thus ensuring that their voices were central to the narrative.

The inductive analysis revealed seven key themes that summarise the teachers' PD journey. These included changes in knowledge, unit design, unit implementation, responses to feedback, self-evaluations, student evaluations, and communication. These themes were pivotal in understanding how the teachers engaged with the SIMBL framework and how their professional practices evolved throughout the study.

- **Change in knowledge:** One of the most prominent outcomes from the PD program was a notable increase in the teachers' knowledge of SSI, modeling, MbL, and SIMBL. This increase in knowledge was evident in teachers' responses to repeated knowledge questions during the interviews.

"I don't know model-based learning, but I think of it as teaching students, for instance, by demonstrating the systems through body models." (I#1)

"Model-based learning is an approach where students interact with various types of models, but most importantly, they construct what they have in their minds about the subject into a model and, as they learning progress, they question and update the model in parallel." (I#2)

- **Unit Design:** The PD program provided clear guidance, which helped teachers create units that aligned with the SIMBL framework, enabling them to design meaningful instructional materials.

"Before participating in the program, I used to incorporate SSI into my classes, and my goal was not concept teaching but rather enabling students to evaluate the issue from different perspectives. After the implementation, I learned that an entire unit can be planned around SSI, and teaching can be conducted based on it." (I#2)

- **Unit implementation:** The implementation phase revealed varying levels of success among teachers. Some felt confident executing their SIMBL units, while others faced challenges in adapting their teaching methods to incorporate SSI effectively.

"I believe that developing and implementing units without support won't be easy for me." (I#3).

- **Responses to feedback:** Responses to feedback were vital to the teachers' professional growth. Teachers engaged in a cycle of providing and receiving feedback, which helped them refine their teaching practices.

[While discussing whether there should be a telescope activity in the space unit] *"In previous years, I conducted a telescope activity before covering the topic of lenses, and the students enjoyed it. When they learned about lenses, they remembered the telescope activity on their own. Therefore, I think it can be used."* (from field notes)

- **Self-evaluations:** Self-evaluation emerged as a crucial theme in the reflective process. Teachers reported regularly assessing their own teaching practices and identifying areas for improvement based on their experiences with the PD program. However, engagement in self-evaluation varied across teachers.

"I completed the system mapping activity we planned for today. Students wrote more about recyclable and non-recyclable materials. I tried to encourage some thinking by asking why we should recycle." (from text messages after lessons)

- **Student evaluations:** A key theme that emerged from the inductive analysis was how teachers evaluated their students' learning outcomes after implementing the SSI-based and scientific modeling lessons. This evaluation process provided insight into both teachers' assessment strategies and their perception of students' engagement and understanding of the content. The results of these evaluations varied significantly across teachers.

"In the classroom, we didn't apply policy-making activities for the first time. However, utilizing the system map, regardless of which side of the dilemma students advocated for, allowed them to better comprehend the potential impacts of their decisions within the system. As a result, students' perspectives expanded, and the activity became more effective."(I#3)

- **Communication:** This theme encompasses both the interactions among teachers and the communication between teachers and researchers during the PD process. Effective communication was identified as essential for fostering collaboration, providing feedback, and supporting the successful implementation of SIMBL units. The degree and quality of communication varied across teachers, influencing their experiences and outcomes throughout the program.

“The class participation is very low, so I am considering inviting a researcher working at the observatory to the class online in order to break away from the routine. In this case, would it be a problem if I don't use all the worksheets I have prepared in PD?” (from phone calls before lesson)

Through the inductive analysis of teacher reflections, three distinct teacher profiles were identified based on changes in knowledge, unit design, unit implementation, responses to feedback, self-evaluations, student evaluations, and communication: Competent, Diligent, and Naïve. These profiles represent different levels of engagement with and mastery of the SIMBL framework, capturing the teachers' varying degrees of knowledge acquisition, pedagogical implementation, and responsiveness to feedback. The profiles demonstrate subtle variations in the manner in which teachers approached the integration of SSI and SIMBL into their pedagogical practices, as well as their interactions with both the PD program and their students. A comprehensive account of the distinctive characteristics and behavioural patterns associated with these profiles is presented in Table 3.12.

Table 3.12 Teacher profiles and characteristics

	Profiles		
	Competent	**Diligent**	**Naïve**
Changes in knowledge	Already knowledgable about SSI; increase in knowledge of MbL and SIMBL; built on prior expertise	Significant increase in knowledge of SSI, MbL, and SIMBL; but still working on deeper integration	Basic increase in knowledge of SSI, MbL, and SIMBL; lacking depth or practical application
Unit design	Successful	Successful	Successful
Unit implementation	successfully implemented all components of the SIMBL framework	implemented most of the SIMBL components, though some areas needed improvement	implemented moderately the SIMBL components, with evident gaps in practice
Responses to feedbacks	provided feedback to other teachers based on her experiences, promptly responded to received feedback	provided feedback, and responded to received feedback and made changes	provided feedback to other participants, and responded positively to received feedback but lacked thorough follow-through on implementing suggestions

Table 3.12 Teacher profiles and characteristics (continued)

Self-evaluations	Conducted detailed self-evaluations, reflecting critically on teaching practices	Self-evaluations were attempted but lacked depth and regularity	Limited self-evaluation or reflection, overlooking key areas for growth
Students evaluations	Effectively evaluated student learning outcomes	Effectively evaluated student learning outcomes	Limited ability to evaluate student outcomes, often missing key indicators of student understanding or gaps in learning
Communication	maintained effective communication with researchers and other participants during the PD program genuinely engaged in detailed pre- and post-lesson calls	maintained good communication with researchers and other participants during the PD program engaged in pre- and post-lesson calls	maintained good communication with researchers and other participants during the PD program communicated briefly with the researcher through messages, did not mention the problems faced

3.6 Trustworthiness

Trustworthiness was addressed in the following ways. The concepts of credibility, transferability, dependability, confirmability, and reflexivity were used as criteria (Shenton, 2004).

3.6.1 Credibility

To ensure credibility, both data triangulation and researcher triangulation were employed. Data triangulation involved collecting data from multiple sources, including interviews, field notes, and classroom observations, to verify the consistency of the findings. Researcher triangulation was achieved through independent analysis by two distinct researchers. The researcher and an experienced researcher familiar with the IMPG conducted separate analyses of the data. This process allowed for cross-verification of the results, ensuring that the findings were credible and grounded in diverse perspectives.

3.6.2 Transferability

For transferability, comprehensive descriptions of the research context, participants, and procedures were provided to allow readers to judge the applicability of the findings to other contexts. Detailed information on the teachers' backgrounds, the PD program, and the instructional settings was included. By offering this rich contextual data, the study enhances the potential for other researchers or educators to determine if the findings can be transferred to their own settings or experiences.

3.6.3 Dependability

Dependability was established through the consistent application of research methods and ensuring inter-coder reliability. Two independent researchers—one being the researcher of the current study and the other with expertise in IMPG—analyzed the data related to Teacher 1 (T-1). A 90% agreement was achieved between the coders. In the instances where a 10% discrepancy arose, the researchers held discussions until they reached a consensus. Furthermore, the process of naming the emerging teacher profiles also involved collaborative discussions between the researchers. This method ensured that the data coding was dependable and consistently applied throughout the analysis.

3.6.4 Confirmability

To address confirmability, the findings were supported through direct quotations extracted from interviews, allowing the teachers’ own words to substantiate the interpretations. Additionally, a reflexive journal maintained by the primary researcher was shared with the independent researcher.

3.6.5 Reflexivity

Reflexivity was a crucial element of this study, aimed at recognizing and mitigating potential biases introduced by the researcher. Throughout the data collection and analysis process, a reflexive journal was maintained, documenting not only the researcher’s decisions but also their thoughts, feelings, and potential biases. For instance, during the classroom observations, the researcher reflected on how personal beliefs about effective teaching practices might influence the focus of their attention. By acknowledging these reflections in real-time, the researcher consciously sought to minimize the impact of subjective interpretations.

One specific example of reflexivity occurred during the interviews. While analyzing the teacher responses, the researcher recognized a tendency to emphasize data that aligned with preconceived expectations regarding the PD outcomes. To counteract this, the researcher reviewed the data multiple times and sought alternative interpretations of the teachers' statements. These reflections were recorded in the reflexive journal and shared with the independent researcher. The second researcher then provided feedback on areas where personal bias might have emerged, and further adjustments were made to the analysis process.

Additionally, reflexivity was maintained during the coding process. For instance, after the initial coding of Teacher 1’s data, the researcher questioned whether certain codes reflected the participants' true experiences or the researcher’s assumptions about the PD model. This led to re-examining the data with a focus on separating the participants' perspectives from the researcher's expectations. These insights were also shared in the reflexive journal and discussed during the triangulation meetings with the second coder, ensuring the reliability of the analysis.

Through these measures, the study ensured that the findings were not only grounded in the data but also critically examined to reduce the influence of the researcher's personal views. By documenting these reflexive practices, the study aims to enhance transparency and strengthen the trustworthiness of the research outcomes.

3.7 Personal Stance

In qualitative research, the researcher's personal stance plays a crucial role in shaping the approach and results of the study. Recognizing and expressing this stance helps ensure transparency and increases the credibility of research findings. I am a researcher with one year of teaching experience and seven years of research assistant experience in the field of science education. My motivation for choosing this research topic stems from my master's thesis, in which I worked closely with a single teacher. During this project, I developed a unit based on SSI and modeling-based learning in collaboration with the teacher. The teacher then implemented this unit in his classroom, and the study focused on examining student development as a result of this intervention. Building on this experience, my doctoral thesis involves training teachers to develop units around SSI and MbL. Although there are numerous studies presenting positive outcomes for students using these frameworks or incorporating SSI in lessons, there is a lack of research on teachers integrating this framework into their teaching practices. Therefore, leveraging my experience from my master's thesis, I focused my doctoral research on the PD of teachers within the framework of SSI and MbL from a broader perspective.

In my previous study, I developed the unit in collaboration with the teacher. In my doctoral research, however, I provided training and feedback on improving the units and collected, analyzed, and interpreted the study's data as a researcher. Having developed units in the past positioned me as both an insider and an outsider to the study—familiar with the educational content and processes but different from the current study's participants.

Balancing the roles of educator and researcher was challenging, as my previous work with SSI and MbL could introduce biases. My positive experiences with these frameworks have led me to favor similar approaches, defining the boundaries of this study. I endeavored to remain open to findings that challenge my assumptions. The feedback from my thesis monitoring committee members and comments on my thesis article prompted me to critique my biased approach and maintain an open mind.

Throughout the research process, I documented my reflections alongside participants' statements. This practice helped me critically examine my impact on the study and ensure a balanced interpretation of the data. My personal stance influenced the choice of a case study approach, focusing on teachers' PD in the context of SSI and MbL. While my perspective may shape data interpretation, I used analysis/researcher triangulation to validate the findings and ensure they accurately represented participants' views.

By acknowledging and reflecting on my personal stance, I aimed to conduct a rigorous and ethically sound qualitative study that provides valuable insights into teachers' PD. Ethical Considerations: Protecting participants' privacy and autonomy is crucial. I had a brief acquaintance with only one of the participants, including those from the pilot study, before this research. This participant was a student who graduated from the master's program at the university where I worked. As part of my duties, I did not attend any of his classes nor participate in any official business or proceedings involving him. Since he was already a graduate during the study period, there was no conflict of interest.

4
RESULTS

The results section of this study is structured around the domains of the Interconnected Model of Professional Growth (IMPG) to address the research questions. Each teacher in the study is treated as an individual case—Case 1: Teacher-1, Case 2: Teacher-2, and Case 3: Teacher-3—allowing for a detailed examination of their distinct experiences and outcomes. Findings are presented for each case within each IMPG domain, showcasing how the professional growth of each teacher unfolded in relation to the unique contexts of their experiences. Data from interviews were labeled as I#1, I#2, and I#3, corresponding to a pre-PD program interview (I#1), an interview conducted at the end of the PD program (I#2), and a post-implementation interview (I#3). Then, PD models for each teacher are introduced, derived from the assessment conducted using the criteria outlined in Table 2.1. These criteria facilitate the identification of 'change sequences' and 'growth networks,' emphasizing the individualized nature of teacher development within the IMPG framework. Finally, the teacher profiles that emerged from the inductive analysis are presented, offering a comprehensive overview of the findings.

4.1 Teachers' Personal Domain

The personal domain encompasses the teachers' knowledge, beliefs, and attitudes about SSI and modeling in teaching and learning. Change in this domain reflects shifts in the teacher's conceptual understanding or pedagogical approaches, driven by their engagement in the PD program. As teachers incorporate new perspectives, their personal domain evolves, influencing their approach to practice and student interactions.

For the personal domain, which focuses on teachers' knowledge, beliefs, and attitudes about science teaching and learning, data was gathered through interviews, phone calls, field notes, and classroom observations. These sources provided insight into how teachers' understanding and perspectives evolved throughout the study, offering a comprehensive view of their internal growth.

Case 1: Teacher-1 (abbreviated as T-1) defined herself as an innovative teacher and thought that students learn better by experiencing the topic. Also, she indicated that her teaching approach was close to constructivism (I#1). She expressed her main aim for science teaching as *"students' recognition of science in every aspect of life"* (I#1). She was very knowledgeable about SSI and had been using SSI-based instruction in her classes. However, she had insufficient knowledge of modeling and defined models only as *"representations of concepts like the atomic model, which are not observable in reality"* (I#1). After the PD program, she became aware of the details of models, modeling, and MbL, she answered the model-related questions by referring to the PD program sessions (I#2). Also, with SIMBL unit development and implementation she stated *"I think using this framework will save me the loop of just using argumentation practice during SSI instruction, it has improved me in that aspect…"* (I#3). Lastly, she asked if the SIMBL instruction had any influence on her science teaching aim or teaching approach, she stated that the MbL practices and so the SIMBL instruction were also constructivist (I#3). Moreover, she thought that the SIMBL helped her aim for science education and developed students' thinking of complex issues in daily life (I#3).

Case 2: Teacher-2 (abbreviated as T-2) explained her teaching approach as constructivist and she explained her aim for science teaching *"I want students to be excited and curious about science, to explore everything"* (I#1). She had been introducing SSI in lessons, not in a structured way, but rather she had used examples and argumentation sessions (I#1). On the other hand, she had limited knowledge about models, modeling and had no idea about MbL (I#1). After the PD program and implementation, she stated more accurate definitions for these concepts (I#2 & I#3). *"This experience taught me how to develop a unit around an SSI, previously I used to only have SSI-focused argumentation sessions at the end of the lessons, but with the SIMBL framework and the guiding question, all the lessons in the unit* *focused on the SSI."* (I#3). Also, she stated that *"I noticed that MbL and the SIMBL framework are in harmony with the constructivist approach."* (I#3).

Case 3: Teacher-3 (abbreviated as T-3) defined herself as an innovative teacher but her main aim for science education was concept teaching and her teaching style was traditional (I#1). She mostly preferred direct instruction and included SSI just in GMO (Genetically Modified Organisms) issue as an example (I#1). She had limited knowledge about the models and cannot explain why there is more than one model of an object or concept (I#1). After the PD program, she answered SSI- and model-related questions moderately. And, she stated, *"The SSI Selection Guide will be very useful for me in determining which topics are suitable for students."* (I#2). Also, she learned about the types of models, the mean of modeling, and MbL. After class implementation, she said, *"I didn't feel as comfortable with implementation as I did with planning."* (I#3). Lastly, she asked if the SIMBL instruction had any influence on her science teaching aim or teaching approach, she could not make a relationship between teaching approaches and the framework but she said that *"I express myself as an innovative teacher and think that I learned new tools that are innovative and not easily foundable."* (I#3).

In conclusion, this study revealed significant changes in the personal domain, specifically in teachers' knowledge, beliefs, and attitudes about science teaching and learning, which were influenced by their participation in the PD program. Teachers such as T-1, who had already acquired knowledge of SSI but lacked a more profound comprehension of modeling, expanded their conceptual frameworks and integrated novel strategies into their pedagogical practices. T-2, who had previously demonstrated a limited understanding of models and modeling, exhibited a notable advancement in her conceptualization of these concepts and demonstrated a more systematic integration of them into her instructional practice. T-3, who initially demonstrated a proclivity for traditional pedagogical approaches, acquired new insights into SSI and models. However, she encountered difficulties in fully integrating these into her teaching style. These findings underscore the personalized nature of teacher growth within the personal domain, where changes in understanding, perspectives, and approaches are shaped by the unique challenges and opportunities encountered by each teacher. The evolution of their personal domain illustrates how PD, when targeted and structured, can facilitate meaningful transformations in teaching practices, even when starting from disparate levels of expertise.

4.2 Teachers' Domain of Practice

The domain of practice in this study refers to the implementation process of the Socioscientific Issue-based Modeling Learning (SIMBL) units in the teachers' classrooms. This domain involves the actual teaching experiences and classroom activities where the newly acquired strategies and knowledge are put into action. It reflects the transformation of beliefs into practical teaching methods. While Clarke and Hollingsworth (2002) suggest that the domain is often limited to classroom practices, this study also acknowledges the broader professional experiences that contribute to teachers' practice like SIMBL Unit design.

For the domain of practice, which involves the implementation of SIMBL units in the classroom, data was collected through interviews, phone calls, classroom observations, and lesson plans. These sources helped capture how teachers applied their newly acquired strategies and knowledge in practice, reflecting changes in their teaching methods and classroom engagement.

Case 1: T-1 developed an SIMBL unit namely the Climate Change Unit. Summary of the unit plan as follows.

<u>Themes of the Unit</u>

- Scientific Themes: Climate change
- Scientific Practices: Asking questions, developing and using models, planning and conducting research, analyzing and interpreting data, using mathematics and mathematical thinking, structuring explanations and designing solutions, participating in the evidence-based scientific argumentation process
- Socioscientific Issue: Climate change

<u>Guiding question:</u> *"Should individuals or governments take measures against global warming?"*

Concepts needed to explore the guiding question

- Scientific concepts: Carbon cycle, climate change, global warming, carbon emissions, greenhouse effect, recycling
- What social ideas and concerns influence the discussion of the problem? Environmental, economic, political, social

Unit objectives according to (MoNE, 2018)

F.8.1.2.1. Explains the difference between climate and weather events.

F.8.1.2.2. Express that climatology is a branch of climate science and experts working in this field are called climatologists.

F.8.6.3.3. Discusses the causes and possible consequences of global climate change.

a. Explains the greenhouse effect.
b. Questions how environmental issues in the context of global climate change could impact the future of the Earth and human life.
c. Expresses predictions about the potential impact of environmental issues on the future of the world through artistic means.
d. Calculates their ecological footprint (safe sites such as edu, org, and gov can be used as references).
e. Explains to the measures taken by world countries to prevent global climate change (e.g., the Kyoto Protocol).

Unit Evaluation

- Students' system maps

Lesson sequence of the unit is in Appendix D.

In the class enactment period, T-1 make applied all features of the SIMBL framework in her class successfully. She started the unit by asking the driving question to the class and after precisely discussing it, continued with system mapping. With the example of COVID-19, she supported the students and they made a system map together. Then, students made their system map on the climate change issue individually. The lessons continued with activities that focused on the reasons for climate change and precautions that could reduce the pace of climate change. For each lesson, she used videos that contains basic questions from children to a professor studying climate change. Videos were supported with Phet simulations. Moreover, students learned about the misconceptions related to climate change by using media literacy tools like "Know Your Sources" and "CRAP (Currency-Reliability-Authority-Purpose) Test". Afterward, students revisited their system maps, making changes or additions as needed. In the last lesson, the culminating activity was students' policy makings that addressed individuals or the national government. Then, they explained how the different groups on their system maps would be affected by these policies. Lastly, all students presented their policies in class and discussed them with others. From this experience, T-1 stated that *"I definitely continue to use this framework by adapting to the other topics. Furthermore, I plan to integrate and use the system mapping and media literacy activities that I learned during this process, in lessons where I can."* (I#3).

Case 2: T-2 developed an SIMBL unit namely the Space Research Unit. Summary of the unit plan as follows.

<u>Themes of the Unit</u>

- Scientific Themes: Space exploration, space technologies
- Scientific Practices: Asking questions, developing and using models, planning and conducting research, analyzing and interpreting data, using mathematics and mathematical thinking, structuring explanations and designing solutions, participating in the evidence-based scientific argumentation process
- Socioscientific Issue: Space exploration

<u>Guiding question:</u> *Should the budgets allocated by governments for space exploration be transferred to more urgent needs (diseases, natural disaster preparation, etc)?*

<u>Concepts needed to explore the guiding question</u>

- Scientific concepts: Satellite, space pollution, sky observation instruments

- What social ideas and concerns influence the discussion of the problem? Environmental, economic, political, social

Unit objectives according to (MoNE, 2018)

1. Explains space technologies.
    a. Artificial satellites are mentioned.
    b. Satellites sent by Turkey to space and their missions are mentioned.
2. Expresses the causes of space pollution and predicts the possible consequences of this pollution.
3. Explain the relationship between technology and space exploration.
4. Explain the structure of the telescope and what it does.
    a. Telescope types are mentioned.
    b. Light pollution is mentioned.
5. S/he makes inferences about the importance of the telescope in the development of astronomy.
    a. The selection of the observatory (observatory) establishment sites and the conditions of these places are mentioned.
    b. The contributions of Western astronomers and Turkish-Islamic astronomers are mentioned.
6. Prepares and presents a simple telescope model.

Unit Evaluation

- Students' system maps

Lesson sequence of the space research unit is presented in Appendix D.

T-2 started the unit with a debate about space research and asked students the driving question. This initial engagement was followed by guiding the students through the creation of system maps focused on space exploration. Before this unit, she had had her class practice before this unit to familiarize them with using the system map. The next lessons covered the history of space exploration with a documentary. Then, science concepts behind space research and include a telescope-making activity as a modeling activity. Even though this was not in the unit plan, to add some extra excitement, she invited a space researcher to the classroom virtually. During this session, students were given an opportunity to ask questions and discuss various aspects of space exploration and observatories. After this course, students were given research articles -newspapers on space explorations and what could be done with the developments provided by space exploration, and what can be done with the budget spent on space exploration. They were tasked with assessing the papers' currency, reliability, authority, and purpose (CRAP Test). Then, students revisited their system maps and improved them. However, for the following sessions, she had problems with the argumentation session and policy-making activity (the SIMBL's components 5 and 6) because few students wanted to share his/her idea (I#3). She stated that she definitely continues to use this framework and the system mapping for each social-related topic, and also media literacy tools (I#3). For the future use of the SIMBL, she stated that *"Even if it doesn't contribute to your study, I would like to stay in touch and try it again."* (I#3) and *"I will definitely follow this plan for this unit in the coming semesters. I will also try to adapt the SIMBL framework for the other classes I teach, or at least use the system map and other media literacy activities especially when I give homework including Internet search."* (I#3).

Case 3: T-3 developed an SIMBL unit namely the Recycling Unit. Summary of the unit plan as follows.

<u>Themes of the Unit</u>

- Scientific Themes: Recycling
- Scientific Practices: Asking questions, developing and using models, planning and conducting research, analyzing and interpreting data, using mathematics and mathematical thinking, structuring explanations and designing solutions, participating in the evidence-based scientific argumentation process
- Socioscientific Issue: Climate change

<u>Guiding question:</u> *"Should we recycle, or not consume?"*

<u>Concepts needed to explore the guiding question</u>

- Scientific concepts: Environmental pollution, conservation and beautification of the environment, human-environment interaction (human impact on the environment), local and global environmental issues, resource usage, conservation, frugality, recycling
- What social ideas and concerns influence the discussion of the problem? Environmental, economic, political, social

Unit objectives according to (MoNE, 2018)

F.5.6.2.1. Expresses the importance of interaction between humans and the environment.

F.5.6.2.2. Offers suggestions for solving an environmental issue in the local surroundings or within our country.

F.5.6.2.3. Makes inferences about potential future environmental issues resulting from human activities.

F.5.6.2.4. Discusses examples of benefits and harms in human-environment interaction situations.

Unit Evaluation

- Students' system maps

Lesson sequence of the recycling unit is Appendix D.

In order to make familiar her students, T-3 showed an example of system mapping before the unit on the biodiversity topic. In the first lesson, she asked her students the driving question, briefly discussed it, and then students started to develop system maps. T-3 indicated that *"Since the students think of only the examples they see in daily life, such as plastic, glass, household waste, and they mostly write them on the map, I intervene with questions such as whether recycling has an impact on the economy."* (I#3). This type of intervention caused non-linked concepts in the system maps of the students. It means that even though the students didn't grasp the connection between the concept presented by the teacher and recycling, they still embraced it. They believed that if the teacher mentioned it, it had to be accurate and represented on the map (I#3). Next lessons, watching videos about recycling process of different wastes, students learned about the facts of recycling like not every recyclable product actually will recycle. Then, students read some news about waste pollution by using CRAP test. After that, they returned their system maps and made improvements with colorful pencils, or some students made new maps. Lastly, as a culminating activity, each student prepared a poster defending recycling or not consuming plastic. The original SIMBL unit included different culminating activities like classroom discussions about recycling and a policy-making activity that defines the limits of using non-recyclable materials. T-3 explained this change *"I couldn't be sure whether the students would be able to make the inference about reducing consumption based on what they had learned about recycling. Therefore, during classroom discussions, I stated that it would be better to reduce plastic consumption instead of spending energy and money on recycling. Consequently, I decided to change the culminating activity as following the initial plan would be meaningless."* (I#3). For the future, she stated that *"I rushed and directed the students. Now, I believe that developing and implementing units without support won't be easy for me."* (I#3).

To sum up, the domain of practice in this study demonstrates how teachers implemented the SIMBL units in their classrooms, effectively translating their beliefs and newly acquired knowledge into practical teaching methods. The data collected from interviews, phone calls, classroom observations, and lesson plans provided a comprehensive view of the implementations in question. T-1 effectively developed and enacted a climate change unit, demonstrating a strong application of the SIMBL framework and its components, which ultimately enhanced her teaching practice. T-2 similarly demonstrated enthusiasm and commitment to integrating the framework into her Space Research Unit, engaging students through a variety of activities, including a virtual guest speaker. However, T-3's experience with the Recycling Unit demonstrated the significant challenges that can arise when adapting the SIMBL approach. Although she initially facilitated the effective introduction of system mapping, her subsequent intervention during discussions resulted in the emergence of misconceptions among students, leading to a lack of coherence in their conceptual understanding. Moreover, her decision to modify the culminating activities due to concerns about students' comprehension demonstrated a lack of confidence in implementing the SIMBL framework as intended. This adaptation process revealed the complexities that teachers encounter when applying new pedagogical frameworks, underscoring the necessity for continuous support and reflection in PD initiatives.

4.3 Teachers' Domain of Consequence

The domain of consequence captures the outcomes that result from implementing new teaching practices, such as the SIMBL units. It encompasses the perceived effects on both teachers and their students. This domain reflects the tangible and intangible impacts of the new strategies, including student engagement, learning outcomes, and teachers' professional growth. Changes here demonstrate how teachers assess and reflect on the effectiveness of their newly implemented methods and the lessons learned from these outcomes.

Data for the domain of consequence, which examines the outcomes experienced by both teachers and students as a result of the new practice, was obtained through interviews and phone calls. These data points provided evidence of how teachers perceived the impact of their teaching on student learning and their own PD.

Case 1: According to T-1, students experienced the SIMBL strategies (system mapping) for the first time and this helps them to understand the complexity of the issue and the social, economic, and political factors that affect climate change and are affected by climate change. Also, this unit expanded students' understanding of the science content (climate change in this context). She thought that *"media literacy strategies were new for students, and worksheets can be new habits for their research and content consumption on the Internet"* (I#3). Moreover, she stated *"Students' arguing the effects of their decisions as policymakers broaden their perspectives on the issue, and system maps were helpful to this process. I think they learned to think one step further."* (I#3).

Case 2: T-2 emphasized the contribution of the unit to students' content knowledge (space research in this case), negotiation of the issue, and the positive outcomes of the new tools (media literacy tools). Moreover, she stated that the results of SIMBL's components 5 and 6, were not fruitful because her students were not in the habit of presenting their own ideas and asking questions of opposing views. She stated that *“Students -who have been congratulated by their other teachers because they listened to lessons silently- would not have the willingness to discuss and present their own ideas.”* (I#3).

Case 3: T-3 did not present detailed student outcomes as much as other teachers. She frequently stated *“I guided the students in nearly all activities, and at points where I thought they wouldn't be able to make inferences, I provided direct answers or shared my opinions. I believe that the outcomes were influenced by my approach.”* (I#3). Also, for student learning, she said that *“I have doubts about what the students have learned on this subject (recycling). Since I intervened in almost all activities and didn't administer a content exam to them, it's not possible for me to assess this.”* (I#3).

In short, the domain of consequence in this study reveals the diverse outcomes resulting from the implementation of the SIMBL units, highlighting both positive and challenging experiences for teachers and students alike. The data collected through interviews and phone calls demonstrated that T-1 observed a notable advancement in her students' comprehension of climate change. This evidence substantiates the efficacy of system mapping and media literacy strategies in fostering engagement and critical thinking. T-2 also acknowledged the beneficial influence of the unit on students' content knowledge and negotiation abilities. However, she encountered challenges in facilitating open discussions among students, indicating a necessity for further enhancement of their communication competencies. In contrast, T-3's reflections highlighted the shortcomings of her approach, as her comprehensive guidance impeded students' capacity to independently investigate concepts pertaining to recycling.

4.4 Teachers’ External Domain

The external domain includes the sources of information and support that influence teachers' professional growth. In this study, it comprises the PD program, interactions between teachers, feedback from peers and researchers, and the unit development process. These external elements provide crucial input that fosters change in the internal domains of practice, knowledge, and outcomes. This domain highlights the role of external resources in shaping teachers' professional journeys and facilitating collaborative learning experiences.

For the external domain data was collected through interviews, phone calls, and field notes of the PD program. These data sources offered critical insights into how external support systems contributed to teachers' professional growth and the implementation of new practices.

Case 1: During the PD program, T-1 always asked her questions in an assertive way, worked sincerely to revise the feedback, and was open in communication throughout the implementation. A week before she started the implementation, a reminder meeting was held and she asked her questions about the unit and also shared her concerns about the implementation. Before and after each lesson, she summarized the lessons, asked some questions about the lesson or following lessons, and also made self-evaluations as a teacher.

Case 2: During the PD program, T-2’s communication with the researcher and other participants was high. During the unit development process, she collaboratively worked with another teacher from a different school (as a note, since he did not complete the implementation, he was not stated between participants). She frequently shared her experiences and contributed to discussions. During the implementation, she provided timely and comprehensive feedback. She made phone calls before and after the lessons and also received feedback from the researcher.

Case 3: T-3's communication with the researcher and other participants was good, but she often started a conversation to express her anxiety. She contributed to the discussions during the unit development process. However, although T-3 felt she had problems, she communicated through text messages with the researcher after the lessons and did not mention the problems.

In summary, the external domain of this study demonstrates the considerable influence of diverse support systems on teachers' professional growth and the implementation of novel practices. The data collected through interviews, phone calls, and field notes demonstrated the impact of the PD program, peer interactions, and feedback processes on teachers' internal domains of practice, knowledge, and outcomes. T-1's proactive approach to seeking feedback and reflecting on her lessons demonstrated an effective utilization of external resources to enhance her teaching practice. T-2's collaborative approach and open communication fostered a supportive network that enriched her professional experience, thereby facilitating the successful implementation of the SIMBL units. In contrast, T-3's experience demonstrated a deficiency in the effective utilization of external support. Despite her participation in discussions, her reluctance to voice her concerns impeded her professional growth. This variation among teachers highlights the importance of fostering an open and communicative environment where external support is not only available but actively engaged with.

4.5 Professional Development (PD) Models of the Teachers

4.5.1 PD Model of T-1

This section presents the PD model of the T-1 (Figure 4.1), which were assessed using the criteria outlined in Table 2.1. These assessments for the T-1 is showed in Table 4.1, ensuring a comprehensive understanding of T-1’s professional growth.

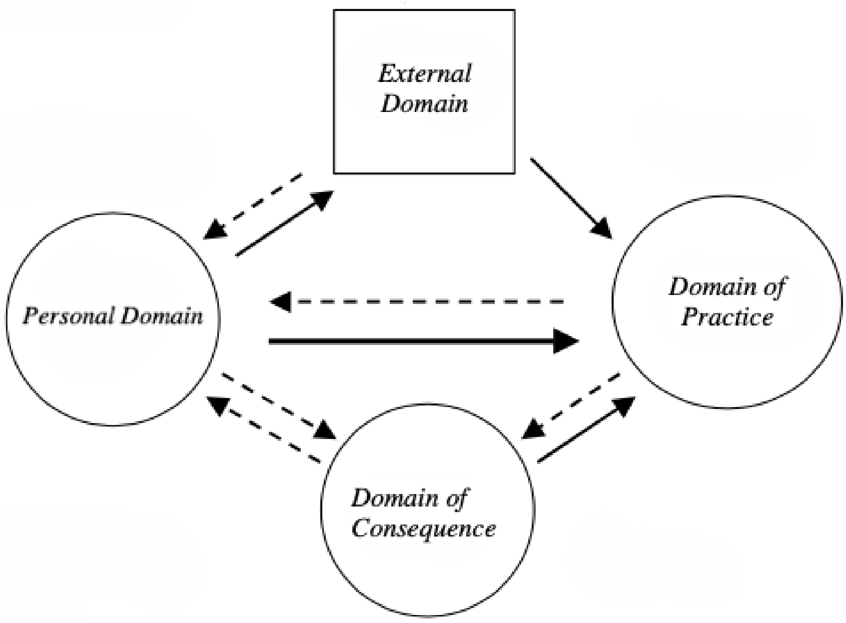

Figure 4.1 Professional development model of T-1

Table 4.1 Establishing relationships in the IMPG for T-1

Relationship	Criterion met/not met	Explanation	Excerpts
From PeD to ED	✓	T-1's initial knowledge about SSI and modeling contributed significantly to the discussions during the PD workshop and she provided feedback on the units of other teachers, she actively communicated with the researcher.	*"To conduct effective SSI instruction, it is necessary for us as teachers to determine our position in advance. The decision should be based on the topic and the class's discussion skills, but in my own classes, I prefer 'Commited Impartiality'."* (from field notes)
From ED to PeD	✓	Her understanding of the SIMBL framework was enhanced, and she made connections between the SIMBL framework and constructivism.	*"I've never heard of the SIMBL framework, is it related to controversial models?"* (I#1) *"SIMBL framework via model-based learning; As in the constructivist approach, it seems to be a method in which we aim for the student's learning to progress on its own."* (I#2)

Table 4.1 Establishing relationships in the IMPG for T-1 (continued)

From ED to DP	✓	T-1 implemented the SIMBL unit that was developed during the PD workshop, and in the process, influenced interactions with researchers.	*“While introducing the system map to the students, we all created a system map example regarding COVID-19 together and continued the unit. Instead of doing it this way, if I had done system mapping activities on appropriate topics several times during the semester, students could have been more productive with their first maps.”* (from phone calls after the lessons)
From PeD to DP	✓	Throughout the implementation, T-1 demonstrated her expertise in teaching and encouraged class discussions, her knowledge and attitude played a significant role in the implementation process.	*“After the greenhouse effect experiment, one student asked, "What is a carbon footprint?" Despite having a carbon footprint calculation activity planned for the next session, instead of directly guiding students to the activity, T-1 asked them, "What do you think it is?" Using the students' responses as a starting point, T-1 then asked, "How do you think we can calculate it?" This approach prompted students to consider their individual contributions to carbon emissions in their daily lives.”* (from classroom observation notes)

Table 4.1 Establishing relationships in the IMPG for T-1 (continued)

From DP to PeD	✓	Following the implementation, she noted that the SIMBL framework improved her instruction, particularly in terms of incorporating modeling rather than relying solely on argumentation.	*"I think using this framework will save me the loop of just using argumentation practice during SSI instruction, it has improved me in that aspect…"* (I#3)
From DP to DC	✓	T-1 identified student-centered outcomes, such as a deeper understanding of complex issues, improvements in content knowledge, and enhanced media literacy skills.	*"In the classroom, we didn't apply policy-making activities for the first time. However, utilizing the system map, regardless of which side of the dilemma students advocated for, allowed them to better comprehend the potential impacts of their decisions within the system. As a result, students' perspectives expanded, and the activity became more effective."*(I#3)

Table 4.1 Establishing relationships in the IMPG for T-1 (continued)

From DC to DP	✓	T-1 expressed her intention to continue using this framework due to its effectiveness, as observed in activities like media literacy tools.	*"Students actually possess fundamental skills such as categorizing media tools as reliable sources. However, the new tools help them notice the tone and direction in the presentation of news were very effective, so I will definitely continue to use them. I believe these tools will stay in students' minds not only during my classes but also when they navigate the internet." (from phone calls after the lessons)*
From DC to PeD	✓	T-1 stated some outcomes that changed her knowledge, attitude or beliefs.	*"I used to define modeling as representing something abstract, such as modeling an atom. However, in the activity we did in class, we saw that even a problem could be modeled."* (I#3) *"I believe that through this implementation, students understood that any everyday topic is connected to science and scientific advancements. For instance, whether we recycle or not affects global warming within the system. Therefore, I think I can demonstrate to them that science is everywhere* [her aim for science teaching]*."* (I#3)
From PeD to DC	✓	T-1's expertise in SSI teaching was evident in her detailed explanations of students' outcomes and self-evaluations.	*"While students were thinking and discussing an SSI, instead of merely advocating for either a positive or negative viewpoint, they were able to visualize through a system map how their advocated viewpoint interacted with the entire system. They achieved this both in written and verbal forms."* (I#3)

PeD: Personal Domain; ED: External Domain; DP: Domain of Practice; DC: Domain of Consequence and I#1-2-3 refers to the Interviews 1-2-3

4.5.2 PD Model of T-2

This section presents the PD model of the T-2 (Figure 4.2), which were assessed using the criteria outlined in Table 2.1. These assessments for the T-1 is showed in Table 4.2, ensuring a comprehensive understanding of T-2's professional growth.

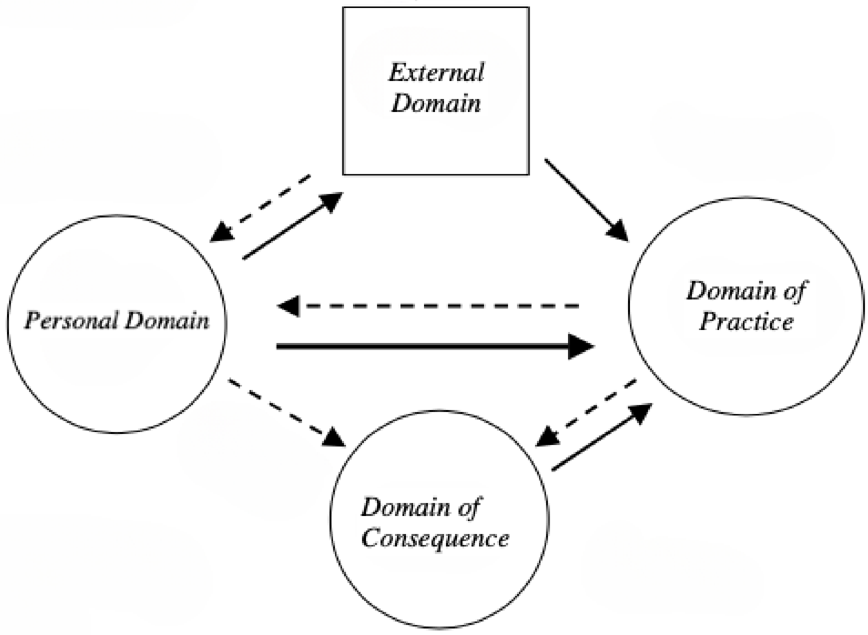

Figure 4.2 Professional development model of T-2

Table 4.2 Establishrelationships in the IMPG for T-2

Relationship	Criterion met/not met	Explanation	Excerpts
From PeD to ED	✓	T-2 actively contributed to the discussions during the PD workshop and also shared her experiences to enhance the unit plans.	[While discussing whether there should be a telescope activity in the space unit] *"In previous years, I conducted a telescope activity before covering the topic of lenses, and the students enjoyed it. When they learned about lenses, they remembered the telescope activity on their own. Therefore, I think it can be used."* (from field notes)
From ED to PeD	✓	Her responses regarding the SSI, modeling, and SIMBL indicated an improvement in her initial knowledge and she emphasized that the SIMBL framework was instrumental in attaining her goals in science education.	*"I don't know model-*based *learning, but I think of it as teaching students, for instance, by demonstrating the systems through body models."* (I#1) *Model-based learning is an approach where students interact with various types of models, but most importantly, they construct what they have in their minds about the subject into a model and, as they learning progress, they question and update the model in parallel."* (I#2)

Table 4.2 Establishing relationships in the IMPG for T-2 (continued)

From ED to DP	✓	T-2 implemented the SIMBL unit that was developed during the PD workshop, and in the process, received feedback from the researcher.	T-2: *"The class participation is very low, so I am considering inviting a researcher working at the observatory to the class online in order to break away from the routine. In this case, would it be a problem if I don't use all the worksheets I have prepared in PD?"* Researcher: *"No, it wouldn't be a problem, of course. However, to ensure that the topics emphasized in the worksheets are discussed in class, if students don't ask or if your guest doesn't mention them, you can ask or provide your guest with the main topics beforehand and ask them to talk about those. For instance, how does increasing light pollution affect space studies? The examples they provide could be more memorable for the students."* (from phone calls before lessons)
From PeD to DP	✓	Throughout the implementation, her knowledge and attitude played a significant role in the implementation process. For example, she invited a researcher to increase the students' attention.	*"The class participation is very low, so I am considering inviting a researcher working at the observatory to the class online in order to break away from the routine."*

Table 4.2 Establishing relationships in the IMPG for T-2 (continued)

From DP to PeD	✓	She noted that after implementing the SIMBL unit, she gained insight into how to structure lessons around an SSI.	*“Before participating in the program, I used to incorporate SSI into my classes, and my goal was not concept teaching but rather enabling students to evaluate the issue from different perspectives. After the implementation, I learned that an entire unit can be planned around SSI, and teaching can be conducted based on it.”* (I#2)
From DP to DC	✓	According to T-2’s evaluations, the implementation of the SIMBL unit enhanced students’ knowledge, their ability to engage with the issue, and their media literacy skills.	*“Comparing with previous years, I can say that students not only learned more but their learning was also more enduring. When we approached the subject from different angles, we covered more points than the information provided in the book. Additionally, I believe that the activities we conducted enhanced the students' learning retention.”* (I#3)

Table 4.2 Establishing relationships in the IMPG for T-2 (continued)

From DC to DP	✓	T-2 expressed a desire to continue utilizing the SIMBL framework, system mapping, and other media literacy activities after observing their positive outcomes.	*"Currently, I don't have a specific topic in mind, but in the classes I teach this semester, even if it's not within the SIMBL framework, I plan to start using media literacy tools and system mapping. Especially when assigning tasks based on searching to students from various age groups, I will encourage them to use media literacy tools."* (I#3)
From DC to PD	-	T-2 did not mention any changes in her knowledge, attitude, or beliefs specifically related to the outcomes.	-
From PeD to DC	✓	T-2 evaluated the outcomes of the students based on her expertise and the reasons of students' participation to the class discussions from her perspective. However, she did not make self-evaluations.	*"This semester, I've begun teaching this class. I believe that if I had conducted this unit with a class I've been teaching since the 5th grade, the results might have been different. Developing students' ability to express their own opinions and engage in discussions takes time. So far, the students in this class have been encouraged to silently listen to the teacher without fostering these skills."* (I#3)

PeD: Personal Domain; ED: External Domain; DP: Domain of Practice; DC: Domain of Consequence and I#1-2-3 refers to the Interviews 1-2-3

4.5.3 PD Model of T-3

This section presents the PD model of the T-3 (Figure 4.3), which were assessed using the criteria outlined in Table 2.1. These assessments for the T-1 is showed in Table 4.3, ensuring a comprehensive understanding of T-3's professional growth.

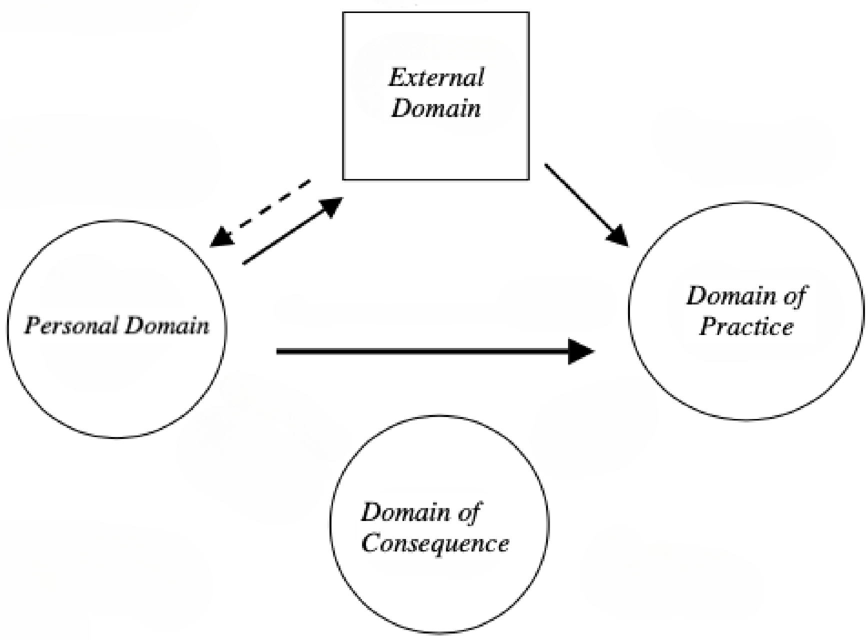

Figure 4.3 Professional development model of T-3

Table 4.3 Establishing relationships in the IMPG for T-3

Relationship	Criterion met/not met	Explanation	Excerpts
From PeD to ED	✓	During the PD workshop, T-3 actively contributed to discussions, sharing her experiences and expressing anxiety about implementation. She also provided feedback on the development of SIMBL units.	*"Students are familiar with the concept map, so when creating the system map, they may consider the constraint of writing concepts in the boxes; we need to prevent this."* (from field notes)

Table 4.3 Establishing relationships in the IMPG for T-3 (continued)

From ED to PeD	✓	While there was no apparent shift in her beliefs about teaching science, and there was notable growth in her knowledge about SSI and modeling.	[Regarding having multiple models for one target] *"I think this diversity is both good and bad. It's good because, on one hand, but when students see something different in differen books, they hesitate because it's not what we know. However, if there was only one model, a universally accepted, scientifically precise model, I would prefer that. But when there are different models, the shortcomings that are not present in others become apparent. Therefore, having a single model seems better to me."* (I#1) *"There can be multiple models for one goal, and this may be related to the purpose of the model, historical development, or it may vary depending on the person modeling it."* (I#2)
From ED to DP	✓	T-3 implemented the SIMBL unit she developed during the PD workshop in her class	*"I completed the system mapping activity we planned for today. Students wrote more about recyclable and non-recyclable materials. I tried to encourage some thinking by asking why we should recycle."* (from text messages after lessons)

Table 4.3 Establishing relationships in the IMPG for T-3 (continued)

From PeD to DP	✓	T-3 continued to employ a teacher-centered pedagogy, so her initial beliefs and attitude played a significant role in the implementation process.	*"I believe that 5th-grade students will be active in the activities, but they will still ask what the correct answer is.* [Comment on teacher attitude initiated by T-1]. (from field notes) *"I thought students wouldn't be able to make inferences, so I frequently guided them toward the correct answer."* (I#3)
From DP to PeD	-	After the implementation, T-3 raised concerns, expressing that it would be challenging for her to develop and implement units without support.	*"I believe that developing and implementing units without support won't be easy for me."* (I#3).
From DP to DC	-	T-3 did not provide specific student outcomes. Consequently, there is no discernible relationship to or from the domain of consequence.	*"I have implemented it, but I'm not sure about its contribution to the students, and I haven't applied any test or similar assessment to evaluate this."* (I#3)

Table 4.3 Establishing relationships in the IMPG for T-3 (continued)

<table>
<tr><td>From DC to DP</td><td>-</td><td rowspan="3">T-3 did not provide specific student outcomes. Consequently, there is no discernible relationship to or from the domain of consequence.</td><td rowspan="3">"I have implemented it, but I'm not sure about its contribution to the students, and I haven't applied any test or similar assessment to evaluate this." (I#3)</td></tr>
<tr><td>From DC to PeD</td><td>-</td></tr>
<tr><td>From PeD to DC</td><td>-</td></tr>
</table>

PeD: Personal Domain; ED: External Domain; DP: Domain of Practice; DC: Domain of Consequence and I#1-2-3 refers to the Interviews 1-2-3

4.6 Teacher Profiles

The findings were analyzed inductively, allowing patterns and categories to emerge from the data without relying on predefined frameworks (Table 3.12). This approach led to the classification of T-1 as "Competent", T-2 as "Diligent", and T-3 as "Naïve". Figure 4.4 shows the comparison of the teachers' profiles.

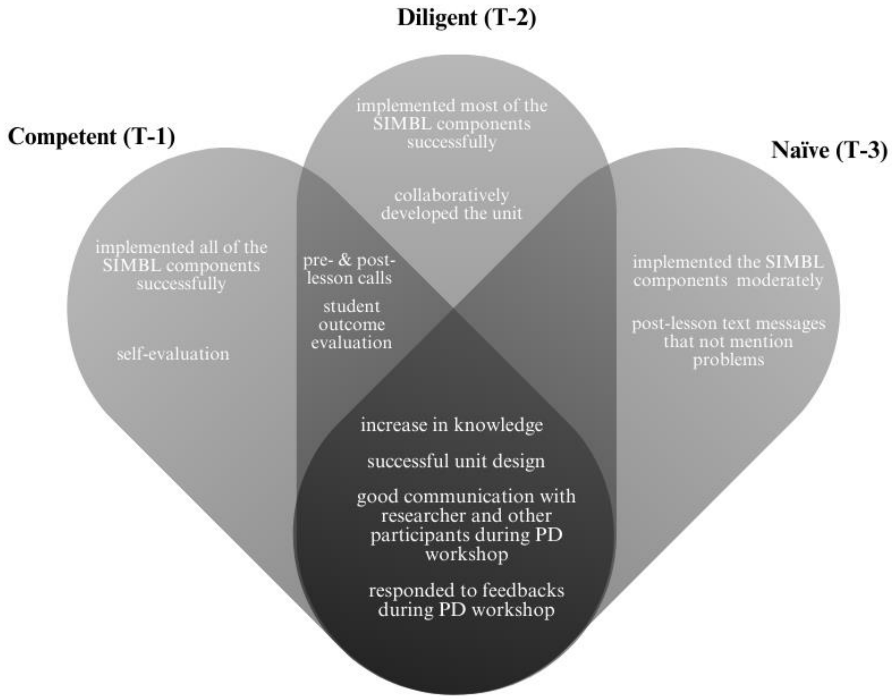

Figure 4.4 Comparison of teacher profiles

Competent was used for a teacher who had successfully implemented all components of the SIMBL framework in the classroom, maintained effective communication with researchers and other participants during the PD program, provided feedback to other teachers based on her experiences, promptly responded to received feedback, and genuinely engaged in detailed pre- and post-lesson calls, including self-evaluations and student outcome evaluations.

Diligent was used for a teacher who had implemented most of the SIMBL components in the classroom, was aware of the missing points, maintained good communication with researchers and other participants during the PD program, shared experiences, provided feedback, and responded to received feedback, and engaged in pre- and post-lesson calls including student performance evaluations.

Naïve was used for a teacher who did not fully comprehend the requirements of SSI teaching and directed students to her ideas about the issue, so implemented moderately the SIMBL components, had good communication with researchers and other teachers during PD program, often spoke up to share concerns, provided feedback to other participants, and responded positively to received feedback during the PD program, but nevertheless, during the implementation process, only communicated briefly with the researcher through messages, did not mention the problems faced, and expressed the need for assistance if she was to go through this process again, indicating she may not proceed without help.

5
DISCUSSION AND IMPLICATIONS

This section aims to synthesize the findings related to the research questions centered on the Interconnected Model of Professional Growth (IMPG) domains. Building upon the results presented, this section interpreted the teachers' PD models and teachers' profiles also.

5.1 Personal Domain

This section examines the specific characteristics of each teacher's approach, the impact of their backgrounds on their pedagogical decisions, and the implications for their PD and student outcomes.

T-1 identified herself as an innovative educator, emphasizing experiential learning and aligning closely with a constructivist teaching approach. Similarly, T-2 identified with a constructivist teaching approach and T-3 regarded herself as innovative teacher. The constructivist approach gained prominence alongside the introduction of the science education curriculum in 2005 in Turkey (MoNE, 2005). The subsequent major program overhaul occurred in 2018, introducing an integrated STEM education curriculum (MoNE, 2018). With this program, there was an increased emphasis on innovative teaching or innovative teaching skills The teachers' focus on constructivism can be linked to the continued implementation of the 2005 curriculum during their teacher education period, highlighting how systemic curricular changes shape educators' pedagogical beliefs (Ke et al., 2020). Additionally, the focus on innovation may be attributed to the emphasis placed on it in teacher education and ongoing PD programs since 2017. At this point, T-1 and T-2 correctly embraced the constructivist approach and recognized that the SIMBL framework supports this approach. In MbL, each individual constructs their own mental models by connecting new information to the existing knowledge they use to interpret experiences. Therefore, learning becomes the process of refining mental models to assimilate new experiences (Schwarz et al., 2009). However, T-3 employed a teaching approach predominantly focused on direct instruction, which is far from being innovative and encountered challenges in directly linking SIMBL to her teaching approach. The difficulties encountered by T-3 can be elucidated through an examination of the extant literature on teachers' beliefs and prior experiences. The extant literature indicates that teachers' beliefs about learning and teaching exert a significant influence on their engagement in PD activities. In particular, teachers who hold student-oriented beliefs are more likely to engage actively in continuing PD, whereas those with a subject matter focus demonstrate less engagement (de Vries et al., 2013). This indicates that T-3's preference for direct instruction may originate from a more traditional perspective on teaching, which could elucidate her constrained engagement with the SIMBL framework. Moreover, it is crucial that teachers' beliefs align with their classroom experiences and needs (Desimone, 2009; van Driel et al., 2012; Garet et al., 2001; Penuel et al., 2007). When there is a misalignment, PD programs may remain superficial, failing to influence teaching practices effectively. T-3's situation illustrates this dynamic, as her traditional approach may prevent her from fully embracing innovative methods, leaving her struggling to integrate the SIMBL framework into her teaching. In the personal domain, a crucial aspect of PD is enhancing teachers' knowledge, particularly regarding SSI, modeling, MbL, and SIMBL. Among the participating teachers, T-1 displays a notable depth of knowledge and demonstrates an ability to integrate SSI effectively into their lessons. Conversely, T-2 has the theoretical knowledge but lacks the practical experience to design a unit explicitly focused on SSI. T-3 shows a limited understanding of the SSI. Prior research has documented instances where teachers have demonstrated an understanding of SSI, yet have encountered difficulties integrating these concepts into their lessons or have chosen not to do so for various reasons (Ekborg et al., 2013; Friedrichsen et al., 2020). For example, Ekborg et al. (2013) found that while teachers acknowledged the relevance of SSI, they encountered difficulties in facilitating student inquiry and critical examination of arguments due to uncertainties regarding the management of group discussions and the encouragement of independent thinking. Furthermore, all three teachers exhibit a common gap in their grasp of modelling and MbL, and no prior exposure to the SIMBL framework. This situation is consistent with the findings of previous studies, which demonstrate that while many teachers recognise the importance of models in science education, their understanding and application in the classroom often falls short of the standards that would be expected (Justi & Gilbert, 2002; Nielsen & Nielsen, 2021). The findings of the study suggest that the PD program and classroom implementations were largely successful in enhancing the participating teachers' understanding of SSI, modeling, MbL, and the SIMBL framework.

The three-phase structure of the PD program appears to be a contributing factor to this progress. The participants were initially presented with an exemplary SIMBL unit, which provided a robust foundation for the comprehension of the underlying concepts. Subsequently, they received targeted instruction that facilitated a more profound understanding of the subject matter. Subsequently, the teachers collectively devised their own SIMBL units with the assistance of the researcher and their fellow participants. This structured approach not only facilitates teachers' learning but also empowers them to create effective curriculum units. The efficacy of this three-phase plan has been corroborated by studies conducted by Foulk et al. (2020) and Topçu et al. (2022), which underscore its beneficial influence on teachers' PD. The success of this three-phase PD program can be attributed to its design, which aligns with the key features identified in the literature as essential for effective PD. Desimone (2009) highlights five core characteristics that are crucial for effective PD: content focus, active learning, coherence, duration and collective participation. The content focus of the PD program emphasizes subject matter knowledge, directly linking teacher learning to student outcomes. This link has been shown to improve teachers' knowledge and skills (Garet et al., 2001; Hawley & Valli, 1999). By focusing on science content knowledge and discussing how to integrate activities into classroom practice, the program ensures that teachers acquire relevant, applicable skills. Active learning opportunities, such as working with a sample unit and collaborating on unit development, encourage deeper engagement and reflection among teachers (Borko, 2004; Loucks-Horsley et al., 2009). This hands-on approach not only enhances teachers' understanding of SSI, modeling, MbL, and SIMBL but also aligns with effective PD practices that promote SSI learning and teaching strategies (Garet et al., 2001). Coherence between PD activities and teachers' beliefs and classroom practices is essential for effective implementation (Penuel et al., 2007). Aligning the program with current educational reforms ensures that teachers not only acquire new knowledge, but also see its relevance to their teaching contexts (Darling-Hammond et al., 2017). Linking PD to teachers' existing experiences and encouraging professional communication among participants supports sustainable changes in teaching practice (Garet et al., 2001). The structure of the program spans multiple sessions, facilitating sustained engagement that supports intellectual and pedagogical change over time (Cohen & Hill, 2001; Fullan, 1993). Research suggests that longer, more intensive PD experiences are more likely to produce positive outcomes than shorter sessions (Garet et al., 2001). Collective participation is demonstrated through collaboration among teachers in developing their units, enhancing the learning experience through meaningful interactions and discourse (Guskey, 1994; Little, 1993). This supportive environment not only contributes to teachers' professional growth but also enhances their capacity to implement innovative practices effectively (Topçu et al., 2022; Foulk et al., 2020).

Lastly, in the personal domain just T-1 emphasized the point that using the SIMBL framework will remove herself from the cycle of using argumentation while conducting SSI-based instruction and will enable her use modeling as a scientific practice. It is crucial in terms of understanding the main contribution of the SIMBL framework to SSI-based instruction because as indicated by Zangori et al. (2017), "with the exception of the practice of argumentation, the SSI approach has generally not been associated with promoting student engagement in scientific practices" (p.4). The emergence of the SIMBL framework seeks to empower teachers to integrate various scientific practices, particularly modeling—which necessitates advanced epistemic skills—into their SSI-based instruction, alongside argumentation (Sadler et al., 2019). The fact that only T-1 emphasized this aspect of the SIMBL framework may be attributed to her prior experience with SSI-based instruction before the PD program. In contrast, T-2 may not have differentiated between previous SSI instructional frameworks and the SIMBL framework due to her lack of practical implementation of SSI-based units. T-1's alignment with the SIMBL framework highlights the importance of coherence between teacher beliefs and instructional innovations, as noted by Desimone (2009) and Luft & Hewson (2014). Furthermore, the findings reflect a continuum in teacher profiles as suggested by Friedrichsen et al. (2020). T-1 resembles the "Embracers," teachers who have a pre-existing understanding of SSI and align their personal goals with the framework's objectives, allowing them to refine their practices effectively. In contrast, T-2 may fit into the "Explorers" category, indicating a transitional phase in her understanding and application of SSI. Her eagerness to adopt the SIMBL framework suggests she recognizes the practical benefits of integrating modeling and SSI, even though she may not yet fully understand the framework's nuances.

This highlights the need for targeted PD that fosters coherence between teachers' existing beliefs and the innovative practices they are expected to adopt. Teachers like T-1, with strong alignment among the four IMPG domains, can significantly enhance their perceptions of the benefits and applicability of frameworks like SIMBL. Meanwhile, teachers like T-2, who are still navigating their beliefs and practices, require ongoing support and resources to develop a more profound understanding of the SIMBL framework.

In conclusion, this study reveals critical insights into the differing pedagogical approaches of T-1, T-2, and T-3, emphasizing the significant impact of teachers' backgrounds on their engagement with constructivist methodologies and the SIMBL framework. While T-1 and T-2 effectively leverage these approaches to enhance their instruction, T-3 struggles to integrate innovative concepts into her practice, highlighting the crucial need for comprehensive PD . The successful application of the SIMBL framework by T-1 and T-2 demonstrates its potential to enrich SSI-based instruction, fostering a deeper understanding of scientific practices beyond argumentation. Conversely, T-3's limited engagement underscores the necessity for targeted support aimed at bridging knowledge gaps and facilitating the adoption of constructivist methodologies. These findings collectively underscore the importance of sustained PD that not only enhances teachers' content knowledge but also transforms their pedagogical beliefs and practices. By aligning PD with teachers' existing beliefs and classroom experiences, educational programs can effectively empower educators to integrate innovative strategies into their teaching. Ultimately, such targeted PD not only benefits educators like T-1 and T-2, who have successfully embraced the SIMBL framework, but also supports those like T-3, ensuring that all educators are equipped to foster effective student engagement and learning in science education.

5.2 Domain of Practice

The domain of practice revealed distinct trajectories for each of the three teachers as they navigated the implementation of the SIMBL framework in their classrooms. T-1 demonstrated a proactive approach to education, demonstrating a comprehensive understanding of SSI and effectively utilizing the SIMBL framework to enhance instructional practices. Her dedication to engaging in regular discussions with the researcher before and after lessons is illustrative of her commitment to enhancing the quality of her lessons and the outcomes for her students. In contrast, T-2 demonstrated commendable efforts to apply the SIMBL framework comprehensively yet encountered difficulties in fostering student engagement during critical discussions. T-3, however, encountered considerable difficulties in implementing the framework, primarily due to a tendency to rely on teacher-centered pedagogy, which constrained students' opportunities to explore SSI concepts. This section examines the impact of these disparate approaches on their pedagogical practices, the incorporation of the SIMBL framework, and the overall efficacy of their instruction.

In the domain of practice, it is evident that all three teachers largely continued with their own teaching approaches. T-1, who had prior experience with SSI, demonstrated the most comprehensive understanding of the SIMBL framework following the PeD (Personal Domain), aligning her practice with the goals of SSI-based instruction. Consistent with Borko (2004) and Desimone (2009), her ability to implement the framework effectively can be attributed to her ongoing engagement with the researcher during the implementation process (External Domain), participating in both pre- and post-lesson discussions. This kind of sustained dialogue is critical for teacher development, as it offers continuous feedback that helps address potential challenges in real-time (Garet et al., 2001; Evans, 2014).

T-2, on the other hand, made substantial efforts to implement all steps of the SIMBL framework. However, her challenges during argumentation and policy-making sessions point to the complexity of facilitating student-centered activities in the classroom, a common difficulty noted in studies on SSI-based teaching (Friedrichsen et al., 2020; Zangori et al., 2017). This issue emphasizes the importance of repeated practice and reflection, as effective use of SSI frameworks like SIMBL often requires teachers to continuously build experience in adapting these methodologies to their specific classroom contexts (Topçu et al., 2022; Lebak, 2015). While T-2's efforts were promising, her struggles with fostering student engagement suggest that further development is necessary, particularly in facilitating meaningful argumentation (Justi & van Driel, 2006).

In contrast, T-3 faced the most difficulties during the implementation. Her continued reliance on teacher-centered pedagogy limited students' opportunities to engage in SSI-based activities, directing them toward predetermined "right answers." This aligns with findings from Friedrichsen et al. (2020), where teachers who experienced dissonance between their personal beliefs and the PD program struggled to adapt. T-3's reluctance to shift from traditional teaching methods underscores the challenge of transforming teaching practices, especially when teachers are not fully aligned with the innovative frameworks introduced in PD programs (Desimone, 2009; Ekborg et al., 2013; Ke, Sadler et al., 2021).

Although T-2 and T-3 designed their SIMBL units successfully, their difficulties in classroom practice suggest that theoretical knowledge alone is insufficient for effective implementation. As highlighted by Topçu and Çiftçi (2023), this situation points to the need for ongoing support and multiple cycles of enactment, where teachers can refine their practice over time (Ke et al., 2020). The experience of T-3 further reinforces the argument that successful implementation requires coherence between teachers' personal beliefs and the innovation being introduced, as well as alignment with the school context (Desimone, 2009; Louca & Zacharia, 2012).

In sum, while the PD program facilitated the design of SIMBL units, the teachers' varying levels of success in implementation reveal the importance of sustained practice and reflective engagement. This finding is consistent with broader research on teacher learning, which suggests that deep changes in practice require continuous professional growth, supported by iterative experiences and reflective feedback (Borko, 2004; Bümen et al., 2012; Bosser et al., 2015).

Following the implementation of the SIMBL framework in the classroom, T-1 indicated that it offered a structured approach that facilitated the process of creating argumentation-based unit plans as scientific practice. She observed that the framework mitigated the workload associated with planning, particularly by providing tools such as system mapping and media literacy activities, which she plans to continue employing. Similarly, T-2 confirmed the continued use of the SIMBL framework, indicating a preference for the same tools that assisted them in navigating the complexities of teaching SSI. The positive experiences reported by both teachers align with the findings of Borko (2004) and Desimone (2009), who emphasise that structured, coherent frameworks introduced in PD programs can significantly enhance teachers' instructional practices by providing clear pathways for integrating innovative methods.

However, T-3 conceded that additional assistance would be beneficial in order to develop and implement future units independently, suggesting that the PD program was not sufficient for her to feel fully prepared. This experience is consistent with the findings of Topçu et al. (2022) and Gray and Bryce (2006), which indicate that teachers who participate in PD programs on SSIs often still feel inadequately prepared to address controversial and rapidly evolving scientific topics in the classroom. The difficulties encountered by T-3 illustrate a crucial element of teacher learning: while PD programs offer valuable tools and frameworks, they must also address teachers' confidence and ability to independently apply these methods (Ke et al., 2020; Zangori et al., 2017).

The experiences of all three teachers reflect the broader need for ongoing, iterative PD, where teachers receive continuous support and opportunities to refine their practice (Garet et al., 2001; Friedrichsen et al., 2020). This is particularly important in the context of SSI instruction, which requires a balance between scientific content knowledge and the facilitation of student-centered argumentation (Justi & van Driel, 2006; Capps et al., 2012). As T-3's experience shows, even after PD, some teachers may struggle with this balance, reinforcing the need for PD programs to include long-term follow-up and collaborative reflection (Topçu et al., 2022; Louca & Zacharia, 2012). Furthermore, the differences in the teachers' responses can be explained by the role of teacher beliefs and prior experiences. T-1 and T-2's willingness to continue using the framework may be attributed to their openness to constructivist approaches, as noted by Friedrichsen et al. (2020) and Zangori et al. (2018), whereas T-3's continued reliance on traditional methods suggests a deeper misalignment between her instructional beliefs and the principles of SSI-based instruction (Gray & Bryce, 2006; Ekborg et al., 2013). These findings underscore the importance of considering teachers' beliefs and readiness when designing PD programs (Desimone, 2009; Evans, 2014).

While the SIMBL framework was positively received by T-1 and T-2, the experience of T-3 demonstrates the need for more comprehensive PD that not only introduces frameworks but also equips teachers to apply them confidently in diverse classroom contexts. Research supports the idea that PD must go beyond initial training and include sustained engagement, allowing teachers to continuously develop their skills and adapt to the demands of SSI-based instruction (Borko, 2004; Bümen et al., 2012; Bosser et al., 2015).

In conclusion, the domain of practice analysis revealed that while all three teachers engaged with the SIMBL framework to varying degrees, their distinct trajectories underscore the need for sustained, iterative PD. T-1's proactive engagement with both the framework and the researcher exemplifies how continuous reflection and feedback can lead to successful implementation, enhancing instructional quality and student outcomes. T-2's challenges with fostering student engagement highlight the complexities of SSI-based instruction, where repeated practice is necessary to fully integrate student-centered methodologies. Meanwhile, T-3's reliance on traditional teaching methods and her struggle to adapt to the SIMBL framework illustrate the importance of aligning PD programs with teachers' beliefs and pedagogical approaches. These findings emphasize that effective implementation of innovative frameworks like SIMBL requires not only initial training but also ongoing support, tailored feedback, and opportunities for teachers to refine their practices over time. Ultimately, successful integration of SSI into classroom practice hinges on a combination of teacher readiness, beliefs, and the availability of structured, reflective professional growth opportunities.

5.3 Domain of Consequence

This section examines the distinctive impact of each teacher's implementation of the SIMBL framework, highlighting how their varied approaches, as perceived by the teachers, shaped student learning, engagement, and the development of critical skills essential for navigating complex SSIs. By analyzing these diverse methodologies, this section reveals how differences in instructional strategies, based on the teachers' perspectives, influenced classroom dynamics and students' ability to engage deeply with SSI-related content.

T-1's implementation of SIMBL, particularly through system mapping, proved transformative for students. This approach enabled a more profound comprehension of climate change, encompassing its multifaceted socio-economic and political dimensions. The integration of media literacy strategies and research-based worksheets provided students with valuable tools for navigating online content. T-1 observed a notable expansion in students' perspectives, emphasizing their enhanced ability to think critically and consider the broader implications of their decisions as potential policymakers. Although studies by Durak and Topçu (2023) and Zangori et al. (2017) highlight improvements in students' content knowledge and discussion abilities through SSI instruction, they do not specifically address media literacy. However, the integration of real-world issues into science education, as T-1 implemented, underscores the importance of approaches like SIMBL in developing critical thinking and decision-making skills. T-1’s experience underscores the broader value of integrating real-world issues into science education, as also supported by Borko (2004) and Desimone (2009), who emphasize that structured PD programs can significantly enhance teacher practice and student outcomes. T-1’s experiences aligns with Friedrichsen et al.'s 'Embracers' profile and demonstrates strong alignment across the IMPG domains. Similar to Friedrichsen et al.’s description of the 'Embracers' profile, T-1 appeared primed to adopt the SSI framework, integrating it seamlessly into classroom practices. Like the Embracers, T-1 had a pre-existing alignment between personal beliefs and the goals of the PD, fostering a transformative learning experience for students. This alignment empowered students to engage critically with climate change and its socio-economic and political dimensions, much like the Embracers' ability to design coherent SSI units and foster informed decision-making in their classrooms (Friedrichsen et al., 2020).

In contrast, T-2 underscored the significant gains in students' content knowledge, specifically within the realm of space research. While recognizing the value of SIMBL components, T-2 faced a challenge in student participation during argumentation and policy-making sessions. This issue, as T-2 noted, stemmed from students' prior experiences with more passive learning environments. This observation reflects the findings of Ke et al. (2020) and Friedrichsen et al. (2020), who discuss the importance of fostering a classroom culture conducive to active student engagement, especially when transitioning from traditional, teacher-centered approaches to more inquiry-based, student-centered methods like those promoted by SIMBL. The reluctance of T-2's students to engage in argumentation highlights a broader challenge in shifting deeply ingrained classroom norms, a challenge also noted by Evans (2014) and Louca & Zacharia (2012). T-2's challenge in fostering student participation during argumentation and policy-making sessions can be compared to the 'Explorers' in Friedrichsen et al.'s study. These teachers, while seeing the value in SSI teaching, struggled to fully integrate the social aspects of SSI into their practice, often due to a lack of prior experience or discomfort in handling the nonscientific dimensions of SSI (Friedrichsen et al., 2020). Despite these difficulties, T-2 recognized the value of SIMBL in promoting deeper content learning, aligning with studies by Justi & van Driel (2006) and Zangori et al. (2018), which demonstrate how SSI-based instruction can enhance student comprehension of scientific content.

T-3, on the other hand, provided limited insights into specific student outcomes, but acknowledged a highly guided approach throughout the unit. This more controlled method of instruction may explain why T-3's students did not exhibit the same levels of critical engagement as those of T-1 or T-2. Research by Gray & Bryce

(2006) and Topçu et al. (2022) suggests that a heavily teacher-directed approach can limit students' opportunities for independent thinking and problem-solving, which are crucial in SSI-based instruction. While T-3’s approach may have ensured that students followed the structured path of the unit, it may have constrained their ability to fully engage with the open-ended nature of SIMBL. T-3’s highly guided approach and limited discussion of student outcomes reflect characteristics of the 'Dismissers' profile in Friedrichsen et al. (2020), where teachers demonstrate minimal engagement with SSI frameworks due to misalignment between their Personal and External Domains. In T-3’s case, this lack of coherence between beliefs, school context, and PD goals likely contributed to the more limited outcomes observed in the classroom. Friedrichsen et al. (2020) emphasize the importance of providing targeted support and ongoing feedback in such cases, suggesting that T-3 could benefit from further PD rounds and team collaboration to better integrate the SSI framework into practice.

Overall, this analysis suggests that each teacher’s approach to implementing SIMBL had different outcomes on student learning and engagement. T-1’s emphasis on systems mapping and media literacy encouraged critical thinking and broader social awareness, while T-2’s focus on content knowledge emphasized the importance of supporting active student participation in argumentation. T-3’s more directed approach, while structured, limited opportunities for students to fully engage in SSI-based learning. These findings are consistent with research by Garet et al. (2001) , which emphasizes the need for PD programs that not only provide new frameworks but also help teachers create learning environments that encourage student initiative and critical thinking. Furthermore, the observed student-centered outcomes, except for those related to media literacy, align with previous findings by Peel et al. (2019), Zangori et al. (2017), and Topçu and Çiftçi (2023), reinforcing the value of integrating SSI and critical literacy into science education.

The emphasis placed by teachers on the increase in content knowledge as the primary outcome for students may reflect a long-held belief that the primary goal of education is to increase subject mastery. This perspective is supported by findings from previous studies that have consistently shown that SSI-based instruction can effectively improve students’ content knowledge. For example, studies by Durak and Topçu (2023) and Zangori et al. (2017) show that when SSI is integrated with modeling practices, it not only enhances students' understanding of scientific concepts but also encourages deeper engagement with the material. Similarly, Topçu et al. (2022) and Dawson and Venville (2013) report that even in SSI frameworks without explicit modeling components, students benefit from enhanced content knowledge as well as increased motivation to learn.

Furthermore, the link between content knowledge and student motivation aligns with research by Borko (2004) and Desimone (2009) that emphasizes the importance of well-structured PD programs in transforming teacher practice. These PD programs can help educators shift their focus from merely presenting content to creating learning environments that encourage critical thinking and real-world application of knowledge (Friedrichsen et al., 2020). The integration of SSI into science education supports this transformative approach as it increases students' motivation and engagement by encouraging them to connect scientific knowledge to societal problems (Ke et al., 2020).

Additionally, the emphasis on content knowledge may be influenced by systemic factors such as the NGSS standards (NRC, 2012) and Türkiye's science curriculum (MoNE, 2018), which prioritize content mastery and are designed to prepare students for high-stakes assessments. As Evans (2014) and Louca and Zacharia (2012) have noted, such pressures may lead educators to focus primarily on content presentation rather than supporting inquiry-based practices that foster deeper understanding and skill development.

Furthermore, findings from studies by Gray and Bryce (2006) and Ekborg et al. (2013) highlight the importance of addressing both content knowledge and the broader skills required for scientific literacy in SSI-based instruction. As suggested by studies by Zangori et al. (2018) and Capps et al. (2012), effective SSI instruction should aim not only to improve students' understanding of scientific content but also to develop argumentation, critical thinking, and evidence-based reasoning skills.

In summary, while focusing on content knowledge as the primary outcome reflects an enduring educational paradigm, the inclusion of SSI-based instruction offers educators a valuable opportunity to broaden their goals. By prioritizing not only content mastery but also the development of skills necessary to navigate complex issues, teachers can increase student motivation and engagement, ultimately leading to more meaningful learning experiences (Durak & Topçu, 2023; 2024; Bossér et al., 2015).

The emphasis on teachers finding media literacy tools valuable and the result that students' media literacy skills have improved may be related to the experience of integrating media literacy skills into science lessons through the SIMBL framework because in Türkiye media literacy education is commonly provided as a separate course. Media literacy education has been an elective course taught by social studies teachers in Türkiye at the middle school level since 2007, and it is also offered as an elective course to prospective teachers at some universities (Karaman & Karataş, 2009). This separation from science education may explain why teachers like T-1 and T-2 have only recently begun to appreciate the relevance and applicability of media literacy within their own disciplines. Prior to participating in the PD program, T-1 and T-2 did not have significant experience embedding media literacy strategies in their science education. Therefore, their engagement with the SIMBL framework provided them with critical opportunities to not only explore media literacy tools but also to effectively implement them in their teaching practices. This is consistent with the idea that PD can significantly impact teachers' pedagogical approaches and enable them to see the potential for integrating previously compartmentalized concepts into a coherent learning experience (Desimone, 2009; Topçu et al., 2022).

Similar to previous literature on the integration of modeling and SSI (Peel et al., 2019; Zangori et al., 2017), both T-1 and T-2 indicated that the implementation of the SIMBL unit engaged students in negotiating complex issues. However, despite the teachers expressing the contributions of system mapping in this regard -T-1 mentioned that it "taught students to think one step ahead," and T-2 stated, "students saw that there can be different dimensions to each topic and that these dimensions can be interconnected in various ways, especially through the system map."- there was no explicit explanation about how exactly system mapping serves these purposes or emphasized its being significant structural integration of modeling and

SSI. This oversight diminishes the importance of systems mapping as a critical structural integration of modeling and SSI. Research increasingly recognizes systems maps as socioscientific models and frames them as modeling approaches that interweave SSI with systems thinking (Ke et al., 2023). Through this lens, systems mapping can offer profound benefits and help students appreciate the complexity of SSI, such as climate change, which involves multifaceted interactions among scientific, social, and economic components. These components operate at multiple levels, from individual behaviors to community practices to national policies, creating dynamic systems that require a detailed understanding of causal relationships and emergent properties (Ke et al., 2020; Sadler et al., 2007). Interestingly, previous studies have shown that students often struggle to grasp these complexities from a systems perspective. Instead of recognizing the multidimensional nature of SSI, they often propose overly simplistic solutions and reflect simple causal reasoning (Sadler et al., 2007). This difficulty may stem from educators' discomfort or uncertainty about how to incorporate social dimensions into their teaching (Hancock et al., 2019; Friedrichsen et al., 2021; Ke et al., 2023). In this context, integrating systems mapping into the SIMBL framework can be effective in encouraging students to think about systems about SSI by explicitly demonstrating the interconnectedness of these issues and the importance of considering different perspectives.

Furthermore, the lack of detailed explanations of how systems mapping facilitates these insights may limit students' ability to construct meaningful knowledge about complex social systems. Socioscientific models require students to include social components alongside scientific knowledge and encourage them to ask critical epistemic questions such as "What scientific and social components are relevant to the topic I am investigating?" and "How are these components related?" This interdisciplinary approach allows students to explore the connections between science and other fields, leading to a more integrated understanding of the societal issues at hand (Ke et al., 2023). It is therefore crucial that educators emphasize the epistemic dimensions of systems mapping, guiding students on how to represent knowledge, how to justify their choices, and how to develop systems thinking skills that encompass both scientific and societal considerations. By doing so, educators can help students more effectively navigate the complexities of SSI and ultimately enhance their ability to make informed decisions and engage in critical discussions about pressing societal issues. Therefore, while T-1 and T-2 recognize the value of systems mapping in fostering students' understanding of complex problems, a more explicit focus on the epistemic underpinnings of this process can further enrich students' learning experiences. By effectively integrating modeling and SSI, the SIMBL framework has the potential to deepen students' engagement with complex societal systems and enhance their critical thinking skills in addressing real-world challenges.

In conclusion, the significant impact of each teacher's implementation of the SIMBL framework reveals the various ways in which their approaches shaped student learning and engagement. T-1's focus on systems mapping and media literacy was transformative, promoting a deep understanding of complex SSIs and equipping students with critical thinking and decision-making skills. While T-2 acknowledged gains in content knowledge, she encountered challenges with student engagement and emphasized the need for more support in transitioning students to active, inquiry-based learning environments. In contrast, T-3's structured yet highly directed approach limited opportunities for critical engagement and independent thinking, reflecting a mismatch between her teaching methods and the SSI framework. This analysis highlights the importance of aligning instructional strategies with the goals of SSI-based instruction to optimize student outcomes. It also highlights the critical role of media literacy in science education, an often overlooked component that, when effectively integrated, can enhance students' ability to navigate complex information landscapes. Furthermore, the findings highlight the value of systems mapping in helping students engage with the multidimensional nature of SSI, but more explicit guidance on its epistemic aspects is needed to fully realize its potential. Overall, this discussion demonstrates that although each teacher's approach may have yielded different results, the SIMBL framework offers significant opportunities to increase student engagement with real-world problems when implemented with an emphasis on encouraging active participation, critical thinking, and systems-based reasoning. These results are supported by broader research on the effectiveness of PD programs in transforming teacher practice and student learning, and reinforce the need for structured PD that helps educators effectively integrate innovative frameworks such as SIMBL into their classrooms.

5.4 External Domain

The communication dynamics among teachers during the PD program and subsequent implementation of the SIMBL framework provide insights into the impact of these interactions on teaching practices and outcomes. Research consistently emphasizes that effective PD relies on active teacher participation, collaboration, and reflective practice (Borko, 2004; Desimone, 2009). In this study, the different communication styles of T-1, T-2, and T-3 provide a lens for understanding how external interactions shape their effectiveness in implementing the SIMBL framework.

T-1 exhibited an assertive communication style, proactively seeking clarification and engaging in reflective practices that highlighted her dedication to professional growth. This aligns with research by Desimone (2009) showing that teachers who actively seek feedback and clarification tend to experience more PD. T-1 engaged in continuous feedback revision and self-assessment, reflecting the type of self-directed learning that Topcu et al. (2022) and Friedrichsen et al. (2020) suggest is critical to successfully adopting complex instructional frameworks. Her post-lesson reflections and extensive communication established a clear connection between her interactions in the external field and the evolving field of practice (Topcu et al., 2022). T-1's approach aligns with the "Embracing" profile of Friedrichsen et al. (2020), who emphasize teachers' enthusiasm for adopting new practices through reflective engagement.

In contrast, T-2 demonstrated a collaborative approach, actively engaging in discussions and exhibiting a commitment to cooperative learning through partnerships with peers. As noted by Garet et al. (2001) and Borko (2004), collaborative learning in PD promotes deeper understanding and leads to more sustainable changes in practice. T-2's interactive style reflects the "Explorer" profile (Friedrichsen et al., 2020), where teachers use collective inquiry, shared reflection, and peer feedback to improve their teaching practice. Her active participation in peer discussions and openness to collaborative feedback are consistent with the findings of Zangori et al. (2017, 2018) and Louca & Zacharia (2012), who emphasize that collaboration among educators during PD supports the adoption of new pedagogical approaches such as the SIMBL framework. The strong communication ties and peer support exhibited by T-2 facilitated a deeper understanding of the necessary pedagogical changes, enabling more effective SIMBL implementation.

T-3, while maintaining effective communication with her colleagues and the researcher, experienced difficulty in articulating her anxieties, which negatively affected her engagement during the implementation phase. This hesitancy impacted her ability to engage fully with the SIMBL framework, highlighting a critical barrier in the PD process. Gray & Bryce (2006) suggest that teachers who are reluctant to voice their challenges in group settings may feel isolated or unequipped to navigate new pedagogical approaches, resulting in less effective practice. T-3's communication, often limited to messaging after lessons rather than real-time discussions, suggests that uncertainty or anxiety can hinder collaborative learning and reflective inquiry (Friedrichsen et al., 2020). Her experience points to the need for more personalized support during PD, as teachers who struggle with confidence or who are hesitant to share concerns may benefit from targeted scaffolding (Evans, 2014; Bümen et al., 2012).

In summary, the various communication styles of T-1, T-2, and T-3 reveal how external domain interactions -whether assertive, collaborative, or restrictive- directly impact their success in implementing the SIMBL framework. Teachers like T-1 and T-2 who consistently engaged in reflective dialogue and collaborative feedback demonstrated more successful teaching outcomes, confirming the findings of Topçu et al. (2022) and Friedrichsen et al. (2020). Meanwhile, T-3’s experience highlights the importance of addressing personal concerns and providing individualized support to effectively engage with new teaching approaches. Future PD programs should not only encourage open dialogue, reflective inquiry, and collaboration, as emphasized by Borko (2004), Garet et al. (2001), and Ke, Sadler, et al. (2021) also provides specific support to meet teachers’ diverse needs (Capps et al., 2012; Topçu & Çiftçi, 2023; Bosser et al., 2015). The inclusion of more personalized feedback loops and differentiated support structures may be important to help teachers like T-3 overcome implementation challenges, thereby increasing the overall effectiveness of PD initiatives.

5.5 Professional Development Models of the Teachers

The IMPG framework facilitated the identification of important insights into the PD of the teachers in this study, highlighting their varied growth trajectories. As suggested by Borko (2004) and Desimone (2009), effective PD involves active teacher engagement and iterative cycles of learning, practice, and reflection. Both T-1 and T-2 exhibited positive developments during the PD program, but with notable differences. While their developmental paths aligned in many respects, T-2's lack of a 'DC to PeD' (domain of consequence to personal domain) connection highlights a gap in reflective practice, which is essential for sustained teacher growth (Friedrichsen et al., 2020). Despite T-2's limited experience with SSI and MbL at the start, she demonstrated the most significant growth, aligning with findings from Gray and Bryce (2006) and Topçu et al. (2022), who emphasize that growth can be most pronounced in teachers with limited initial knowledge when appropriate scaffolding and support are provided.

T-1, on the other hand, had a more stable foundation in SSI and had an advantage in implementing the SIMBL unit in an established classroom that had been teaching for approximately three years, which offered potential advantages in terms of established discussion habits and classroom management (Capps et al., 2012). This experience led to a more successful integration of modeling; a finding consistent with Zangori et al. (2017) indicating the importance of a supportive classroom environment for effective SSI instruction. In contrast, T-2 encountered challenges with student engagement as she implemented the SIMBL unit in a new classroom where relationships and norms were not yet fully established, mirroring the challenges described by Ke et al. (2020) regarding classroom dynamics in new environments. This difficulty likely hindered reflection from the outcome domain to the personal domain and prevented deeper professional growth.

However, T-3 showed limited development, primarily confined to the personal domain, without significant progress in the areas of implementation and outcome.

Similar to the findings of Friedrichsen et al. (2020), T-3's reliance on traditional teaching methods and reluctance to engage with innovative approaches such as the SIMBL framework created barriers to meaningful implementation. Although the PD program improved T-3's knowledge of SSI, modeling, and MbL, this did not translate into effective classroom practices because T-3 admitted to struggling with SIMBL integration, especially when working with a younger student group, a challenge documented in previous research on teachers' reluctance to adopt new pedagogies (Justi & van Driel, 2006; Evans, 2014). Moreover, T-3's subject-focused approach and limited proactive communication with peers and facilitators during the implementation phase further hindered her professional growth. As noted by Garet et al. (2001) and Bosser et al. (2015), collaboration and seeking feedback are vital components of successful PD. T-3's avoidance of these elements, coupled with her hesitancy to reflect on her practice and seek support, set her apart from T-1 and T-2, who actively engaged in collaborative reflection and feedback during the PD process (Topçu & Çiftçi, 2023). This lack of communication and reflection limited the potential for cross-domain learning and hindered deeper professional growth (Friedrichsen et al., 2020; Bümen et al., 2012).

In summary, the IMPG framework provided a comprehensive lens through which to examine the varying impacts of the PD program. T-1 and T-2 experienced significant benefits, albeit with challenges unique to their contexts, while T-3's growth remained limited due to a combination of personal, pedagogical, and contextual factors. These findings align with the broader literature on teacher PD, illustrating how individual teacher characteristics, classroom contexts, and active engagement with reflective practices influence the effectiveness of PD programs (Topçu et al., 2022; Zangori et al., 2018; Ke, Sadler et al., 2021).

5.6 Teacher Profiles

The use of Clarke and Hollingsworth's (2002) Interconnected Model of Professional Growth (IMPG) framework provides valuable insights into the development of teachers in this study. The IMPG emphasizes that the personal domain, which includes teachers' knowledge, beliefs, and attitudes, is critical in shaping how teachers engage in PD programs. Although significant belief changes are not expected in this short-term program, the findings confirm that teachers' preexisting beliefs and prior experiences greatly influence their learning, practice, and perceptions of outcomes, which is consistent with previous research (Friedrichsen et al., 2021).

When examining the three teacher profiles (T-1, T-2, and T-3), the role of prior experience is particularly salient. T-1 was an experienced teacher with a master's degree and 12 years of experience, as well as a background in research on teacher roles in SSI-based instruction. Given her background, T-1 was already knowledgeable about SSI instruction and had previously implemented it in her classroom, which meant that her students were already familiar with it. T-1 demonstrated successful application of the SIMBL framework, reflecting her preexisting familiarity with both the teaching method and the content. Her classification as a "Competent" aligns with the "Embracers" profile in Friedrichsen et al. (2020) and the "Enterprising" category from Topçu et al. (2022), as her personal domain was already aligned with the goals of the PD. This alignment between the personal and external domains is essential, as research shows that coherence between teacher beliefs, knowledge, and curriculum innovations is key to successful PD outcomes (Desimone, 2009).

T-2 also held a master's degree and, despite having less experience with SSI instruction, exhibited a high level of commitment and adaptability. Her integration of supplementary activities into the unit plan demonstrated her proactive learning approach, and she was classified as a "diligent" teacher. However, considering her relative inexperience with SSI-based instruction and the challenges she faced in achieving full student participation, T-2 fits more appropriately into the "Explorer" category from Friedrichsen et al. (2020) and "Enterprising" from Topçu et al. (2022). This profile is characterized by a strong willingness to engage with new instructional approaches despite limited prior experience (Friedrichsen et al., 2020). T-2's case highlights how the IMPG framework accounts for the role of engagement in the PD, showing that even when teachers are not initially aligned with the PD content, their motivation and openness to learning can foster meaningful professional growth (Jones & Carter, 2013). While her journey in implementing the SIMBL framework was not without difficulties, T-2's efforts reflect a need ongoing exploration of student-centered teaching methodologies.

In comparison, T-3, with less teaching experience and limited professional growth opportunities, struggled with the implementation of the SIMBL framework. Her discomfort with teaching scientific concepts and promoting higher-order thinking, particularly in a student-centered environment, contributed to her classification as a novice teacher. T-3's difficulties align with the "Dismissers" profile in Friedrichsen et al. (2020) and the "Hesitant" category in Topçu et al. (2022). The IMPG lens reveals that T-3's challenges were likely exacerbated by misalignment between her personal domain and the PD's external demands. Without sufficient prior experience or confidence in student-centered methodologies, T-3 was unable to fully embrace the SSI approach, a phenomenon often seen in teachers with deep-rooted traditional teaching habits (Gray & Bryce, 2006; Desimone, 2009).

The analysis of the three teacher profiles illustrates the broader challenges in SSI-based instruction, particularly for in-service teachers who may lack graduate education or remain stucked in traditional teaching methods. The low participation in the voluntary PD programs and the challenges faced by teachers like T-3, as noted in this study, suggest that these barriers are not isolated events but reflect a broader problem in integrating innovative teaching frameworks such as SIMBL. Implementing such frameworks requires significant shifts in pedagogical roles as teachers shift from content transmitters to facilitators of student learning; this process requires both time and the development of new skills (Ekborg et al., 2013; Zeidler et al., 2011). Moreover, T-2's challenges, despite her willingness to innovate, highlight the additional demand that SSI-based instruction places on teachers, particularly in terms of ongoing student engagement and the extension of curriculum time. These findings suggest that while some teachers, like T-1 and T-2, can succeed with adequate support and motivation, systemic barriers—such as curriculum constraints, time limitations, and insufficient PD—may hinder broader adoption of the SIMBL framework. To overcome these challenges, PD programs need to provide not only initial training but also continuous support, reflective practice opportunities, and resources to manage the complexities of student-centered teaching. These strategies could enhance teacher engagement, as well as facilitate the deeper alignment of teachers' personal domains with innovative approaches like SSI-based instruction (Opfer & Pedder, 2011; Friedrichsen et al., 2020).

In conclusion, this study contributes to the literature by highlighting the interplay between teachers' beliefs, prior experiences, and PD in shaping their capacity to implement new instructional frameworks like SIMBL. While short-term PD may not significantly alter deeply ingrained beliefs, it can still foster professional growth, particularly when teachers exhibit a strong willingness to engage and reflect on their practice. However, the broader challenges faced by in-service teachers, particularly those rooted in traditional methodologies, suggest that effective integration of SSI-based instruction will require more than individual teacher effort—it demands systemic support, sustained PD, and alignment with educational policies to foster meaningful and lasting change in science education.

6
CONCLUSION

The conclusion of this study synthesizes key findings regarding the integration of Socioscientific Issue and Modeling-Based Learning (SIMBL) framework into science education through a targeted professional development (PD) program. By examining the middle school science teachers’ experiences as they engaged with the SIMBL framework, this research provides valuable insights into teachers' professional growth. The implications of these findings extend to both classroom practice and teacher education, offering guidance for the development of effective PD programs. Recommendations are also provided for enhancing curriculum design and teacher education, as well as for expanding future research to further refine and support the successful integration of SIMBL in diverse educational contexts.

6.1 Conclusion

This study investigated the implementation of the SIMBL framework in science education, elucidating crucial insights into the multifaceted pedagogical approaches of three teachers – T-1, T-2, and T-3. The findings demonstrate the significant influence of teachers' backgrounds, beliefs, and experiences on their engagement with constructivist methodologies and the integration of SIMBL into their teaching practices. T-1 and T-2 were able to successfully leverage the SIMBL framework to enhance their instruction, thereby demonstrating its potential to enrich SSI-based learning. In contrast, T-3 encountered considerable difficulties in adapting to innovative pedagogical concepts, underscoring the vital necessity for comprehensive PD that is tailored to the specific contexts of individual teachers.

The analysis of the domain of practice revealed that, while all three teachers engaged with the SIMBL framework to varying degrees, their unique trajectories emphasised the necessity for ongoing, iterative PD. T-1's proactive engagement demonstrated how continuous reflection and constructive feedback can facilitate successful implementation, thereby enhancing instructional quality and improving student outcomes. T-2's difficulties in fostering student engagement demonstrated the inherent complexities of SSI-based instruction, where repeated practice is essential for the full integration of student-centred methodologies. Meanwhile, T-3's continued reliance on traditional teaching methods and her difficulties in adapting to the SIMBL framework serve to reinforce the importance of aligning PD programs with the existing beliefs and pedagogical approaches of the teachers in question.

The varying impacts of the SIMBL framework on student learning and engagement serve to elucidate further how each teacher's approach shaped educational outcomes. T-1's emphasis on systems mapping and media literacy engendered transformative experiences for students, facilitating the development of critical thinking and decision-making abilities in the context of intricate SSIs and markedly augmenting their understanding of these subjects. Although T-2 acknowledged gains in content knowledge, her difficulties with student engagement demonstrated the necessity for more comprehensive assistance in adapting to active, inquiry-based learning environments. Conversely, T-3's structured yet highly directed approach constrained opportunities for critical engagement, reflecting an incompatibility between her teaching methods and the objectives of SSI-based instruction. Moreover, the analysis emphasised the pivotal function of media literacy in science education, a frequently neglected element that, when effectively integrated, can enhance students' abilities to navigate complex information landscapes. The value of systems mapping was identified as a key element in enabling students to engage with the multifaceted nature of SSI. However, this also highlighted the need for more explicit guidance on its epistemic elements to fully realise its potential.

Communication styles were identified as a further key factor influencing the success of the teachers' implementation of the SIMBL framework. The assertive and collaborative engagement of T-1 and T-2 through reflective dialogue and feedback resulted in more effective teaching outcomes, which align with the findings of relevant literature. In contrast, T-3's inflexible communication style underscored the necessity of addressing personal concerns and offering tailored assistance for effective engagement with novel teaching methodologies.

This study makes a contribution to the existing literature by emphasising the interplay between teachers' beliefs, prior experiences and PD in shaping their capacity to implement innovative instructional frameworks such as SIMBL. This highlights that while short-term PD may not significantly alter deeply ingrained beliefs, it can facilitate professional growth when teachers demonstrate a strong willingness to engage with and reflect on their practices. However, the difficulties encountered by in-service teachers due to their reliance on traditional methodologies suggest that the effective integration of SIMBL instruction requires a systemic approach, sustained PD, and alignment with educational policies to facilitate meaningful and lasting change in science education.

Ultimately, the findings of this study advocate for sustained PD that not only enhances teachers' content knowledge but also transforms their pedagogical beliefs and practices. By aligning PD with teachers' existing beliefs and classroom experiences, educational programs can effectively empower educators to integrate innovative strategies into their teaching. This approach not only benefits those like T-1 and T-2, who have successfully embraced the SIMBL framework, but also provides crucial support for teachers like T-3, ensuring that all educators are equipped to foster effective student engagement and learning in science education.

6.2 Limitations of the Study and Recommentadions for Future Research

The limitations of this study reflect constraints encountered during its execution:

1. A significant portion of the data was derived from self-reports by the teachers, including interviews and unstructured communications. This reliance introduces potential biases, such as social desirability and recall bias, as participants might present themselves more favorably or inaccurately recall their experiences. Same questions were asked at different times and communicated just after or before the lessons to mitigate these biases. Future studies could further address this limitation by involving independent evaluators and incorporating objective measures, such as student performance data.
2. Classroom observations were conducted only for selected lessons due to significant disruptions caused by two separate earthquakes. These disruptions altered classroom schedules, limiting the scope and representativeness of the observations. Consequently, the findings may not fully capture the breadth and depth of teachers' implementation of SIMBL units. Future research could expand observation periods and include more frequent classroom visits to provide a more comprehensive understanding of instructional practices.
3. The study included only three teachers, all of whom were female, which may limit the generalizability of the findings due to potential gender bias. Future studies should consider a more diverse participant pool to explore whether similar outcomes are observed across varied demographics.

The findings of this study offer invaluable insights for future research and the enhancement of science education. In light of the challenges researchers face, several key implications emerge.

- **Enhancement of PD Programs:** The three-phase PD program increased teachers' knowledge levels and supported them in the design process. PD programs should consider benefiting this design.

- **Enhancement of Supportive Tools:** The findings underscore the importance of incorporating structured frameworks like the SSI Selection Guide and Planning Heuristic into PD programs. These tools effectively support teachers in integrating SIMBL into their curriculum. PD programs should consider adapting these tools to enhance teachers' pedagogical practices and ensure meaningful engagement with SSIs.
- **Curriculum Design and Implementation:** The study highlights the effectiveness of the SIMBL framework in guiding teachers to design and implement units that incorporate modeling and SSIs. Curriculum developers and educators can use the insights gained from this research to create more engaging and relevant science curricula that address real-world issues. This approach not only enhances student learning but also fosters negotiation of complex issues and media-literacy skills.
- **Policy and Educational Reform:** Policymakers can use the findings to advocate for the integration of SSI and MbL in science education standards and guidelines in teacher education programs. By promoting these approaches, educational systems can better prepare pre-service teachers to navigate complex societal issues and contribute to informed decision-making in their communities.
- **Future Research Directions:** The study opens several avenues for future research. Longitudinal studies are needed to examine the sustained impact of PD programs on teachers' practices and student outcomes.

By considering these, educators, policymakers, and researchers can leverage the study's insights to enhance science education practices, ultimately leading to improved student engagement, learning outcomes, and societal impact.

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A
PLANNING TOOLS IN PD PROGRAM

Issue Selection Guide (adopted from Peel et al., 2018)			
Possible Issue:			
I. Is the topic a socioscientific issue (SSI)?	What are the scientific ideas related to the topic?	What are the social, political, economic, and/or ethical considerations related to the topic?	
II. Is this a productive SSI for your class?	Are these scientific ideas consistent with the curriculum objectives (or other expectations)? Which objectives will be targeted?	Are the social considerations developmentally appropriate for your students? Is it relevant and/or accessible?	Will your students be interested in this topic? If not, are there parallel or related topics that might be more challenging for your students?
III. What instructional moves are needed?	How will the topic be focused or scaled to achieve the intended learning outcomes? Are local, national, or global themes emphasized?	Which aspects of the underlying science need to be simplified or de-emphasized?	Should authentic or hypothetical scenarios be highlighted?

Figure A.1 SSI Selection Guide (Peel et al., 2018)

Planning Heuristic (adopted from Peel et al., 2018)		
Steps	**Directions**	**Example from the White Butterfly Unit (Author et al., 2023)**
Explore possible issues, big ideas in science, and target practice(s).	Explore possible socio-scientific issues (SSI). You can use example socio-scientific issues or refer to the SSI selection guide.	Scientific themes: Ecological Interactions, Global Warming, Climate Change, Energy Flow, Biodiversity, Air Pollution, Lifecycle of the "white butterfly" Scientific practices: modelling, argumentation SSI: Population change in "white butterfly" and its effect on local ecosystems
Search level-appropriate targets related to scientific themes from the MoNE (2018) objectives.	Determine how much of this topic can be worked on with your students, according to their level.	7th Grade: Define ecosystem, species, habitat and population concepts and also give examples to these concepts (MoNE, 7.5.1.1) Question the importance of biodiversity for natural life (MoNE, 7.5.2.1) Discuss the threats to biodiversity based on research data and produce solution recommendations (MoNE, 7.5.2.2) Investigates and gives examples of plants and animals that are extinct or endangered in our country and the world (MoNE, 7.5.2.3).
Narrow the focus of the content to be covered and the issue.	Which aspects of the underlying science need to be simplified or de-emphasized?	Investigates and gives examples of plants and animals that are extinct or endangered in our country and the world (MoNE, 7.5.2.3).
Develop unit-level performance expectations.	In addition to the MoNE outcomes, write the knowledge and skills students will gain by the end of the unit as outcomes.	Define ecosystem, species, habitat and population concepts and also give examples to these concepts (MoNE, 7.5.1.1) Question the importance of biodiversity for natural life (MoNE, 7.5.2.1) Discuss the threats to biodiversity based on research data and produce solution recommendations (MoNE, 7.5.2.2) Develop and use multiple models to explain the interaction between population change in "white butterfly" and local ecosystem Develop explanations to which factors may influence ecosystems in what way Use and interpret graphics, charts and statistics to find relationship between weather, air pollution, hazelnut harvest and population growth of "white butterfly"
Develop unit assessments.	Determine how you will assess whether students have achieved these outcomes. For example, final projects can be used.	Models- model based explanations Unit Test End-of-Unit Classroom Activity (Role-playing)
Design unit outline.	When creating the unit, ensure that the six components of the SIMBL framework) are emphasized in the unit.	Attached
Develop lesson plans.	Lesson plans.	Attached
Present the unit.	Provide feedback on each other's units	
Review and evaluate the unit	Return to one of the earlier steps (1-7), make modifications, and progress.	

Figure A.2 Planning Heuristic (Peel et al., 2018)

B
INTERVIEW QUESTIONS

Table B.1 Interview questions organized by content and IMPG domains

Interview Questions	**Content**			**IMPG Domains**				**Interview#**		
	SSI	**MbL**	**SIMBL**	**PD**	**ED**	**DP**	**DC**	**1**	**2**	**3**
How do you think students learn science best?				✓				✓		
What are your general goals for teaching science to your students?				✓				✓		
What do you think about your approach to curriculum design and science teaching?				✓				✓		

Table B.1 Interview questions organized by content and IMPG domains (continued)

What do you think about engaging students in the social aspects of a topic?	✓			✓				✓		✓
Before the workshop, did you include the social aspects of science topics in your lessons? If so, can you explain how you did this?	✓			✓				✓		
Have you heard of SSI or SSI-based teaching before the workshop?	✓			✓				✓		
If you were to explain SSI-based teaching to another teacher, what would you say?	✓			✓				✓		✓

Table B.1 Interview questions organized by content and IMPG domains (continued)

Would you recommend SSI-based teaching to other science teachers? Why?	✓			✓				✓		✓
How do you think the inclusion of SSI in classes can help advance students' understanding?	✓			✓				✓		✓
Which aspects of your teaching and learning goals and beliefs are in line with the SSI approach? What are the incompatible aspects?	✓			✓				✓		
What are your thoughts on models and modeling?		✓		✓				✓		✓

Table B.1 Interview questions organized by content and IMPG domains (continued)

How can models and modeling be useful for your students?		✓		✓				✓		✓
What would you say if you explained the models and modeling to another teacher?		✓		✓				✓		✓
Do you think there is a purpose of having multiple models of the same objects?		✓		✓				✓		

Table B.1 Interview questions organized by content and IMPG domains (continued)

When you think of your science lessons where a model is introduced and / or used to help you understand something. What was this model? How did you use it? Did it help you understand and / or teach the scientific phenomenon?		✓		✓				✓		
What do you think is the relationship between a model and "modeled"?		✓		✓				✓		
Have you heard of the SIMBL framework before the workshop?			✓	✓				✓		

Table B.1 Interview questions organized by content and IMPG domains (continued)

How can incorporating models and modeling into SSI teaching (the SIMBL) benefit your students?			✓		✓			✓		✓
When you attended the SIMBL workshop, what were some of your “ah-ha” learning moments?					✓				✓	

C
VISUALS FROM CLASSROOM OBSERVATION

Figure C.1 Video presentation in the classroom

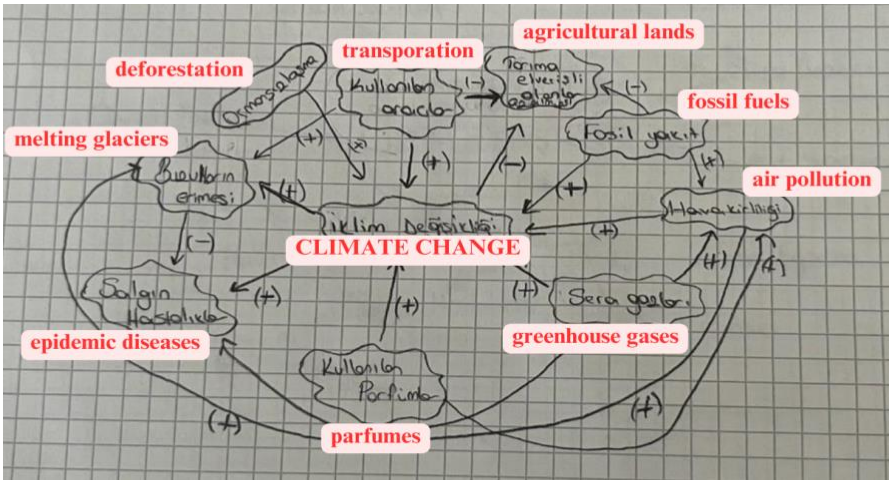

Figure C.2 System map created by a student

EVALUATE YOUR SOURCES FORM

Text Title: Climate Change

Currency

• Is the text current enough for your research topic, or does it include outdated information?

■ YES ☐ NO

Competence

• What is the source of the text?

Greenline, in addition, the opinions of Assistant Professor Dr. Soneser Yurdakul are included

• Is the expertise of the source suitable for providing information about the subject of the text?

Yes

Reliability

• What subject matter does the text cover?

climate change, sustainable fashion

• Does the information in the text rely on evidence and statistics?

■ YES ☐ NO

Or is the same topic repeated with different sentences?

☐ YES ■ NO

• Does the content of the text rely on the author's opinions?

■ YES ☐ NO

• Do you think the content of the text is biased?

☐ YES ■ NO

• Has the author provided sources for the data and quotes used?

■ YES ☐ NO

➢ Do you think the information in this text is reliable? Why?

Although the text includes some personal opinions, it is reliable and quite logical from my perspective. Moreover, it is a text written in accordance with the words of an informed person

➢ Was it difficult for you to understand this text? Why?

I think I need to read it a few times because it's not a topic I'm very familiar with

Purpose

• What is the purpose of the text?

Written to explain the relationship between the effects of climate change and the concept of sustainable fashion

• Are there any expressions indicating bias in the text?

☐ YES ■ NO

Give examples:

There are no similarities because the effects of climate change are already evident. It is up to people to make deductions and understand what is right and what is wrong.

• Do you think the information in the text is aimed at directing and/or selling?

☐ YES ■ NO

Figure C.3 Media literacy activity sheet (translated in English)

D
LESSON SEQUENCES

Table D.1 Lesson sequence for the climate change unit

Lesson (time)	Focus	Objectives	Activities
1 (40 min)	Preliminary information about climate change	Students will be able to define and demonstrate their knowledge and ideas about climate change through a system map.	Brainstorming System map activity
2 (40 min)	Climate change, greenhouse effect, global warming	Students will be able to explain climate change, greenhouse effect, global warming.	Greenhouse effect experiment - PhET simulation
3 (40 min)	Individual effects	Students will be able to explain individual impacts on climate change.	Calculating carbon footprint, myths about recycling, effects of the clothing industry
4 (40 min)	Effects of governments; energy preferences - use of fossil fuels, deforestation	Students will be able to explain governments impacts on climate change.	Research activity

Table D.1 Lesson sequence for the climate change unit (continued)

5 (40 min)	Climate Change and International Negotiations (Paris, Kyoto, United Nations, Mediterranean..)	Students will be able to discuss the national negotiations about climate change.	Argumentation Back to the system map
6 (40 min)	Culminating activity	Students will be able to discuss what measures can be taken for the climate change.	Reviewing the system map Policy-making activity

Table D.2 Lesson sequence for the space research unit

Lesson (time)	**Focus**	**Objectives**	**Activities**
1 (80 min)	Preliminary information about space exploration, discussion of guiding questions	Students will be able to define and demonstrate their knowledge and ideas about space exploration through a system map.	Brainstorming System map activity

Table D.2 Lesson sequence for the space research unit (continued)

2 (40 min)	Technologies used in space exploration (telescope, satellite, rocket, etc.) and prominent scientists	Students will be able to define space technologies used in space exploration. Students will be able to explain the contributions of prominent Turkish, Islamic and Western astronomers in space exploration.	Journey to the End of Space and the Universe documentary How did we discover space? - Who discovered space? Worksheet
3 (40 min)	Telescope, which is a turning point for space research, types of telescopes and working principles of the telescope	Students will be able to explain the structure and functions of the telescope.	Telescope model design- making Why is the Webb space telescope so important? video
4 (40 min)	Observatories, which are the center of space research, the factors affecting the choice of location for the establishment of observatories and the effect of light pollution on space research	Students will be able to explain the importance of observatories for sky/space research from past to present. Students will be able to establish a relationship between the locations of observatories and light pollution.	Brainstorming

Table D.2 Lesson sequence for the space research unit (continued)

5 (40 min)	Space exploration discussions	Students will be able to discuss the environmental, social, economic and political dimensions of space exploration.	Research Argumentation Back to the system map
6 (40 min)	Culminating activity	Students will be able to defend their positions.	Students' presentations

Table D.3 Lesson sequence for the recycling unit

Lesson (time)	**Focus**	**Objectives**	**Activities**
1 (40 min)	Preliminary information about recycling	Students will be able to define and demonstrate their knowledge and ideas about recycling through a system map.	Brainstorming System map activity
2 (40 min)	Endangered animals	Students will be able to discusses examples of benefits and harms in human-environment interaction situations.	The Internet research
3 (40 min)	Pollution, overuse of the sources and climate change	Students will be able to make inferences about potential future environmental issues resulting from human activities.	Prediction-Observation-Explanation Drawing

Table D.3 Lesson sequence for the recycling unit (continued)

4 (40 min)	Local issues	Students will be able to offer suggestions for solving an environmental issue in the local surroundings or within our country.	Group activity
5 (40 min)	Orginizing information		Reviewing the system map
6 (40 min)	Culminating activity	Students will be able to answer the guiding question and defen their position.	Policy-making activity

E
ETHICAL APPROVAL

YILDIZ TEKNİK ÜNİVERSİTESİ
Sosyal ve Beşeri Bilimler Araştırmaları Etik Kurulu

Toplantı Tarihi: 28.07.2021 **Toplantı No:2021/05**

SOSYAL VE BEŞERİ BİLİMLER ARAŞTIRMALARI ETİK KURULU
TOPLANTI KARARI

Yürütücülüğünü Üniversitemiz Eğitim Fakültesi öğretim üyelerinden Prof. Dr. Mustafa Sami Topçu'nun danışmanlığında lisansüstü öğrencisi Benzegül Durak'ın yapacağı **"Sosyobilimsel konu ve model tabanlı öğrenmenin tasarımı ve uygulanmasında öğretmenlerin desteklenmesi: çoklu durum çalışması"** adlı çalışma ve bu çalışmada kullanılacak veri toplama araçları ve yöntemlerine ilişkin bilgilerde etiğe aykırı herhangi bir bulguya rastlanmamıştır.

Etik Kurul Üyeleri

Prof. Dr. Murat DONDURAN
Başkan

Prof. Dr. Ali ERYILMAZ
Üye

Prof. Dr. Gülhayat GÖLBAŞI ŞİMŞEK
Üye

Doç. Dr. Mehmet Emin KAHRAMAN
Üye

Doç. Dr. Senay OĞUZTİMUR
Üye

Doç. Dr. Yasin ŞEHİTOĞLU
Üye

Dr. Öğr. Üyesi Güzin AKYILDIZ
Üye

Taşbina A-2013 Oda Davutpaşa Kampüsü Esenler /İstanbul Tel: (0212) 383 31 18
E-posta: sbemdr@yildiz.edu.tr Web: http://www.sbe.yildiz.edu.tr

F
MoNE APPROVAL

Evrak No : 2203300038
Tarih : 30.03.2022

Evrak Tarih ve Sayısı :31.03.2022 - E.2203310312 Yazının Ekidir

T.C.
DÜZCE VALİLİĞİ
İl Millî Eğitim Müdürlüğü

Sayı : E-10240236-20-46651940 29/03/2022
Konu : Araştırma İzin Onayı
(Benzegül DURAK)

VALİLİK MAKAMINA

İlgi :a)Millî Eğitim Bakanlığı'nın(Yenilik ve Eğitim Teknolojileri Genel Müdürlüğü) 21/01/2020 tarihli ve 81576613-10.06.02-E.1563890 (2020/2) sayılı Genelgesi.
b)Yıldız Teknik Üniversitesi Rektörlüğü'nün 17/02/2022 tarihli ve E-96187715-100-2202140024 sayılı yazısı.

Yıldız Teknik Üniversitesi Fen Bilimleri Enstitüsü Matematik ve Fen Bilimleri Eğitim Anabilim Dalı Fen Bilgisi doktora programı öğrencisi Benzegül DURAK'ın "Supporting Teachers in the Design and Enactment of Sosioscientific Issue and Model-Based Learning (SIMBL): A Multiple-Case Study" konulu tez çalışması gereği gönüllü Fen Bilimleri Öğretmenlerine yönelik ölçek uygulamak istemektedir.Uygulamaya yönelik izin talebi, ilgi (a) Genelge'de belirtilen esaslar doğrultusunda incelenmiştir.

Söz konusu araştırmanın eğitim ve öğretimi aksatmadan, sadece bir eğitim öğretim yılını kapsayacak şekilde gönüllülük esasına dayalı olarak uygulanması, ölçeklerin salgın hastalık döneminde çevrimiçi iletişim araçları ile uygulanması, kişisel verilerin gizliliğine dikkat edilmesi ve uygulamalarda sadece ekte bulunan mühürlü formun kullanılması şartı ile yürütülmesi Müdürlüğümüzce uygun görülmektedir.

Makamlarınızca da uygun görüldüğü takdirde Olurlarınıza arz ederim.

Tamer KIRBAÇ
İl Milli Eğitim Müdürü

OLUR

Yakup TATOĞLU
Vali.a
Vali Yardımcısı

Ek:
1-Komisyon Kararı(1 Adet)
2-Araştırma Araçları(5 Sayfa)
3-Tahütname (1 Sayfa)

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Telefon No : 0 (380) 524 13 80
E-Posta: istatistik81@meb.gov.tr
Kep Adresi : meb@hs01.kep.tr

Belge Doğrulama Adresi : https://www.turkiye.gov.tr/meb-ebys
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PUBLICATIONS FROM THE THESIS

Conference Papers

1. Durak, B., & Topçu, M. S. (2023, August 28)). *Supporting teachers in the design and enactment of socioscientific ıssue and model-based learning (SIMBL): A multiple-case study* [Oral Presentation]. The 15th Conference of the European Science Education Research Association (ESERA 2023), Cappadocia, Türkiye.

2. Durak, B., & Topçu, M. S. (2024, March 8). *Supporting Science Teachers in the Design and Enactment of Socioscientific Issue and Model-Based Learning (SIMBL)* [Oral Presentation]. 2024 NARST Annual International Conference, Denver, USA.

Papers

1. Durak, B., & Topçu, M. S. (2024). Navigating complexity: a multifaceted approach to teaching climate change in middle school. *Science Activities*, *61*(4), 163–179. https://doi.org/10.1080/00368121.2024.2362161.

Projects

1. Sosyobilimsel Konu ve Model Tabanlı Öğrenmenin Tasarımı ve Uygulanmasında Öğretmenlerin Desteklenmesi: Çoklu Durum Çalışması, BAP Doktora Tez Projesi-Yıldız Teknik Üniversitesi (Araştırmacı). **Proje No:** SDK-2021-4626, **Başlama Tarihi:** 09.08.2021, **Bitiş Tarihi:** 29.11.2024 **Proje Bütçesi:** 8091,42 TL. **Yürütücü:** Prof. Dr. Mustafa Sami TOPÇU. **Araştırmacı:** Benzegül DURAK