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From Ideal to Practical—A Design of Teacher Professional Development on Socioscientific Issues

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Abstract: As consensus towards teaching science for citizenship grows, so grows the need to prepare science teachers to pursue this goal. Implementation of socioscientific issues (SSI) is one of the most prominent theoretical and practical frameworks developed to support scientific literacy and preparing students as informed citizens. However, implementation of SSI holds great challenges for science teachers. Longitudinal professional development (PD) programs were designed to overcome these barriers, yet at the same time many educational systems lack the resources, both in terms of budget and time to meet such intense programs. In this paper, we introduce a design of a short-term PD course that was conducted in Israel. The PD was specifically tailored for secondary school science teachers, with the goal to support them in implementing SSI. Employing an educational design research framework, we tested our PD design over a span of three consecutive years. Through an iterative design process, we were able to make modifications to the program based on data collected and analyzed from the previous year. The structure of the PD is based on four SSI aspects: (a) introduction to SSI, (b) argumentation in SSI context, (c) SSI operationalization, and (d) science communication. In this paper, we provide detailed explanations for each of these aspects, justify the changes made to the PD design, and highlight both promising and less effective strategies for engaging teachers in SSI. Ultimately, we propose a comprehensive SSI PD model that can effectively prepare teachers to take their initial steps in implementing SSI, while remaining adaptable to diverse educational systems.

Keywords: socioscientific issues; professional development; argumentation; informal logic; British parliamentary debate

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1. Introduction

In recent years, educational policies have placed significant importance on the preparation of students as scientifically literate and well-informed citizens [1,2]. In pursuit of this objective, the socioscientific issues (SSI) framework has emerged as a promising approach and has been advocated for integration into science curricula [3,4]. SSI are characterized by their ill-structured nature, controversiality, and social relevance, often encompassing ethical considerations [5,6]. These issues span a wide spectrum, ranging from local to global in scope. For instance, Tal and Kedmi [7] developed a curriculum unit focusing on the environmental impact of rapid development along the Israeli coastline, while Zangori et al. [8] designed a curriculum centered around the topic of global warming.

Integration of SSI in school curricula has been shown to support students' learning of new scientific content knowledge [9,10]; improve informal reasoning, argumentation, and discourse [11]; engage and motivate students in science learning [12]; and cultivate character development and citizenship responsibility [12,13].

Despite the considerable potential benefits of integrating SSI into science classrooms, science teachers continue to exhibit hesitancy in implementing them [14]. This reluctance primarily stems from factors such as teachers' low self-efficacy; incongruence between SSI pedagogy and teachers' identity and beliefs [15]; limited familiarity and experience with facilitating argumentation [5,16]; insufficient availability of supporting materials [17–19]; and institutional barriers that discourage teachers from incorporating SSI, such as an overwhelming number of standardized tests, content-focused curricula, and unsupportive school environments [16].

Moreover, teachers who implemented SSI reported various challenges they faced in enacting SSI curriculum. These included the need to adapt to a student-centered approach, positioning oneself as a facilitator rather than an instructor [5,20] and a need to adapt to the multidisciplinary nature of SSI, which often requires teachers to find creative ways to integrate various disciplines in a curriculum that is otherwise compartmentalized [21,22]. Teachers also reported difficulty in facilitating SSI discussions that align with its controversial nature, pointing out the challenge of evaluating arguments in a live discussion [23,24].

Lee and Witz [25] conducted a study that identified teachers who successfully addressed some of the aforementioned challenges. These teachers shared a common characteristic: they possessed firsthand experiences integrating social and scientific aspects prior to their teaching careers, contributing to their sense of agency in implementing SSI curricula. However, relying solely on teachers' personal backgrounds is insufficient for achieving large-scale change. To facilitate widespread transformation, a teacher professional development (PD) intervention emerges as the most promising approach, as it offers teachers enriching experiences and opportunities to cultivate agency [26–28]. Therefore, the most effective strategy for overcoming teachers' hesitancy in implementing SSI and preparing them for the associated challenges is development of PD programs that support teachers in integrating SSI [29].

SSI PD

The integration of SSI into science education has been supported by various PD programs for teachers. Cohen and colleagues [30] implemented a 30 h PD for biology teachers, incorporating SSI and inquiry-based learning into their instruction. The program consisted of four phases: orientation, experimentation, conceptualization, and reflection, and was delivered throughout the school year. Peel and colleagues [31] designed a PD for secondary school science teachers with varying levels of experience and teaching disciplines. Participants collaborated to design an SSI unit for their classrooms. During the PD, the teachers experienced activities as if they were students. The design of the PD was guided by the teaching and learning framework [18], and socioscientific-reasoning framework [32], providing a theoretical foundation for its structure and content. Bayram-Jacobs et al. [33] found that teachers' implementation of ready-to-use SSI materials positively impacted their SSI pedagogical content knowledge.

Despite the contribution of these works to the field, they did not provide a general structure for SSI PD programs or specified key components that should be addressed in such PDs. Additionally, the scalability and retention of teachers' utilization of SSI tools and skills learned in the PD has not been fully explored. Furthermore, long-term SSI PD programs, making a prominent portion of previous studies, may not be feasible for many educational systems and contexts.

This paper addresses a reality in which many educational systems and schools lack the necessary resources to implement long-term, continuous SSI PD for in-service teachers. However, the need to integrate SSI and support teachers in implementing it remains crucial. Recognizing that these resource limitations may persist in the foreseeable future, we adopted a practical approach aimed at finding a middle ground solution that offers just and equitable opportunities to all communities. In this endeavor, we rely on rigorous research design and evidence demonstrating the potential impact of short-term PD programs on teachers' practices. Our ultimate goal is to design a comprehensive SSI PD model that can effectively support teachers in contexts where long-term PD programs are not feasible [34–36].

2. Theoretical Framework—Research and PD Design

2.1. Research Design

We based our research design on the educational design research (EDR) framework [37], which was successfully implemented in other PD design contexts [38,39]. The approach, which is problem- and theory-oriented, is based on a reciprocal relationship between the two, as they inform researchers through an iterative inquiry process. To follow the iterative character of the EDR, we analyzed the data collected from the PD each year and revised the succeeding year's PD according to the analysis. Furthermore, the EDR's problem orientation encouraged us to clearly define the problems our PD was designed to solve, as already elaborated. Additionally, in alignment with the EDR's theory orientation, we based our research design on a thorough literature review.

The EDR framework requires the measurement of the PD's impact on each iteration. However, measuring the impact of a PD is complex and depends on the measured aspects [40,41]. Ideally, evidence for the impact of a PD program demonstrates a thread that runs between teachers' change and student learning gain; yet, it is challenging to achieve due to the resources it requires. Such resources require a prolonged sustainable research force, which will collect data from the initiation of the PD, through teachers' implementation, and up to the assessment of students' learning progression. It also requires conducive conditions that facilitate research that cuts through contexts like teacher PD, school administrators, and students [42].

King [43] recognizes three major aspects of teacher PD outcomes: personal, professional, and cultural. The personal outcomes relate to affective aspects, including self-efficacy and attitudes. Self-efficacy refers to an individual's judgment of his/her capability to perform actions at a desired level [44]. The literature mentions three major factors affecting teacher self-efficacy: (1) mastery experience, (2) vicarious experience, and (3) social persuasion [45,46]. Teachers' self-efficacy is essential in their motivation to undertake a certain task. For example, teachers' beliefs in their competence in building and assessing arguments are essential for self-initiating SSI lessons [47]. Also, PDs that successfully change teachers' self-efficacy correlate with long and more sustainable implementation of a desired educational change [48–51].

Attitudes refer to a psychological tendency expressed by an individual's evaluation of a particular object/entity with some degree of favor or disfavor [52]. Since forming an attitude requires an evaluation of the object in question, a change in attitude requires circumstances that foster a reevaluation of the object. Within the educational context, PDs were shown as a promising avenue for changing teachers' attitudes, resulting in a change in practices [53,54]. However, it is important to note that a change in attitudes towards an object does not necessarily follows a behavioral change [52,55], and theories about the psychological mechanism that leads to such a change are beyond the scope of this research.

The professional outcomes of teacher development programs are primarily contingent on the quality of utilization and comprehension of newly acquired knowledge and skills. An extensive body of literature shows that effective professional development programs enable teachers to enhance their instructional practices and improve their students' academic performance [27,56,57]. Nevertheless, establishing a definitive causal link between professional development programs and teachers' learning outcomes remains challenging, as it requires extensive data collection prior to, during, and subsequent to the program. Managing such research involves administrative challenges, such as coordinating and mediating various stakeholders collaborating with the researchers, and methodological challenges, such as data collection at multiple time points and triangulating data obtained by multiple research methods [42,43].

The cultural outcomes of a PD are often evaluated based on their influence on teachers' collaboration with their peers, either through informal interactions or within the context of a professional learning community. Indeed, a growing body of evidence has emerged, demonstrating a positive impact of teachers' collaboration during a PD on its outcomes [42,43,58,59]. Teachers often report a sense of belonging and increased agency as a result of participating in collaborative activities with their colleagues. Furthermore, integrating collaborative elements into professional development programs aligns with a sociocultural approach and reflects our growing understanding of the role that societal factors play in shaping knowledge construction [60,61].

2.2. PD Design

Our PD design principles were guided by Desimone's core conceptual framework of teachers' professional development design: (a) content focus, (b) active learning, (c) coherence, and (d) collective participation [42].

However, we did not address one principle from the framework, namely "sustained duration," which refers to the period during which the PD is spread (e.g., one day, semester) and the number of hours dedicated to the PD. Although Desimone acknowledges that there is no indication of a tipping point in which those parameters are impactful, she alludes to a semester-long PD as a necessary minimum [42]. The reason for not addressing this principle is because, as we already mentioned, it does not align with the reality in many educational settings. Therefore as a practical alternative, it is worth building on a body of evidence showing that short-term PD can have a long and sustaining effect [34,36].

Drawing from the literature on SSI, we set four components for the SSI PD: (a) introduction to SSI, (b) argumentation in SSI context, (c) SSI operationalization, and (d) science communication. Figure 1 shows how the four PD components are interconnected and complement one another, adhering to the coherence principle. Next, we describe each component in detail, highlighting its alignment with the PD design principles.

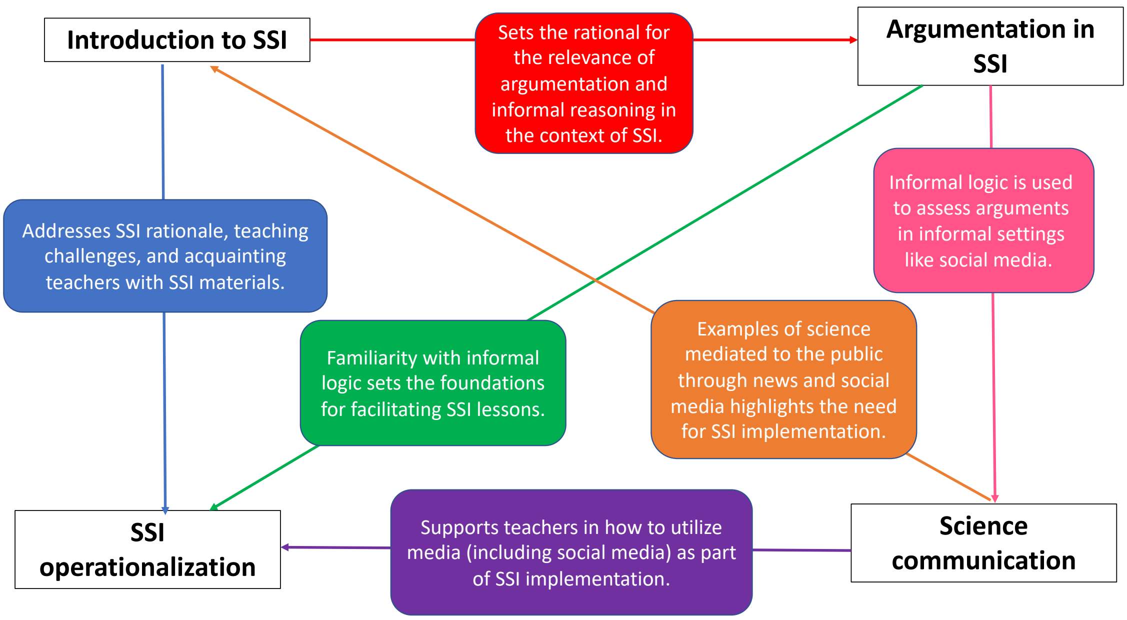

Figure 1. Connections between the professional development program components. Each colored box briefly explains how a component is related to the box in which its connecting arrow points to.

2.2.1. Part 1: Introduction to SSI

In this component, we explicitly addressed the content knowledge aspect of PD, with the aim of providing a general orientation through discussion and active learning. We established a clear definition and the criteria for SSI by discussing different examples of SSI (e.g., water fluoridation, GMOs). Additionally, we provided examples of issues that can be confused with SSI (e.g., teaching controversial historical figures such as Fritz Haber). Acknowledging the significance of curriculum materials in supporting teachers' instruction and implementation of new pedagogies [33,62,63], we provided teachers with dedicated time to explore and customize ready-to-use SSI materials. The SSI materials utilized were developed as part of the European Commission-funded "ENGAGE" project [64], whose primary goal was to support secondary science teachers across Europe in SSI implementation. As part of the project, a team that the authors were part of developed open-sourced, ready-to-use modules aligned with many European countries' secondary school science curricula. Each module included a teacher's guide, student worksheets, and presentation materials. More information about the ENGAGE materials can be found on the project website [64] and in other publications [33,65,66]. The various modules covering various SSI and scientific concepts allowed teachers from different disciplinary backgrounds to collaborate and choose a module that best meets their needs. To increase the sense of agency and autonomy over the materials, teachers were encouraged to adjust the module in alignment with their beliefs, needs, and context in which they work. This task followed a reflection on the materials and a discussion among teachers about their reasons for any adjustments they made. The common goal of all the modules was supporting students in making an informed decision about the issue the module focused on. The ideas teachers learned as they were using the modules were arguing from evidence, weighing options and strategies, and supporting discussion. This program segment is very similar to other SSI PD programs, which start with an exposition and experience with SSI material [30,31].

2.2.2. Part 2: Argumentation Content

SSIs' controversial nature and complexity bring about disputes and various arguments between stakeholders [6,67]. Therefore, argumentation and evaluating the merit of arguments are innate to an SSI context [47,68,69]. Toulmin's argumentation pattern (TAP) is one of the main approaches cited in the literature for integrating and facilitating argumentation in the science classroom [70–72]. However, in the context of SSI, results were inconclusive, and scholars suggested the implementation of informal logic as Toulmin's argumentation pattern and other suggested argumentation, like CER (claim, evidence, reasoning), are less reliable in the context of ill-structured, controversial issues that include moral aspects [69,73,74]. Moreover, Toulmin's argumentation pattern fails to serve as an analytical tool in a live discussion where dialogic argumentation with dialectical characteristics occurs. Evaluating an argument using Toulmin's modeling tool involves recognizing the various components, such as claim, data, warrant, and rebuttal, and synthesizing an evaluation of each to determine the argument's merit. This cognitive task may be reasonable to expect from a teacher when evaluating a written argument or a short dialogue transcript, yet not in the context of a dynamic, back-and-forth live discussion between multiple individuals, such as in a classroom or group setting.

Informal fallacies are errors that occur in natural language arguments and stem from the context and content of the argument rather than its structure. Considering the context of an argument involves evaluating its relevancy to the issue being discussed. For example, the red herring fallacy presents irrelevant information alongside relevant information, distracting from the main topic of discussion. Examining the content of an argument involves scrutinizing the premises on which it is based. For instance, the false dilemma fallacy assumes that there are only two options, which may not necessarily be the case. Assessing informal fallacies enables the evaluation of arguments made in a colloquial speech live discussion and is especially useful in a dialectical context. Indeed, the literature showed that familiarity with informal logic and the ability to identify informal fallacies is most useful in assessing arguments in everyday natural language and context [75–77]. Therefore, we perceive informal fallacies as a valuable method that teachers can utilize to facilitate discussions and assess student arguments in an SSI context. The operationalization of using informal fallacies allows teachers to facilitate, monitor, and discuss as they engage students in evaluating arguments in a context in which colloquial language is used (e.g., political debate, TV commercial, trial). However, to make a case for the usability and practicality of informal fallacies as an argument assessment tool, it is essential to acknowledge and address teachers' prior knowledge about other argumentation frameworks [78]. Therefore, we introduced three argumentation frameworks, each assessing arguments from a different perspective. The frameworks presented were formal logic, Toulmin's model of argument, and informal logic. We briefly present the rationale and strategies used for each argumentation assessment framework.

Formal logic: Most teachers in this research are familiar with basic formal logic from their psychometric tests (somewhat equivalent to SAT as an assessment tool allegedly predicting success in higher education). Formal logic was introduced to draw a clear line between formal and informal logic [79]. By making a distinction between the two, we wished to illustrate the limitations of the former, especially in the context of SSI [69]. Also, teachers reflected on inferences they expected their students to derive from sets of premises.

Toulmin's model of argument assessment [80] was presented because of its well-established practicality in science teaching [70] and teachers' familiarity with the CER framework [81]. First, we briefly refreshed teachers' memory with concrete examples of implementing Toulmin's model. Next, teachers assessed monologues and dialogues about SSI using the model, allowing them to identify the disadvantages of Toulmin's method.

Informal logic: We focused on informal fallacies, a prominent theme in informal logic [82,83]. We scaffolded the identification of fallacious arguments in a number of steps. First, teachers were introduced to different fallacies (e.g., begging the question, straw man, red herring). Next, teachers assessed written arguments that contained fallacies and then progressed to assess video dialogues. Then, teachers engaged in writing dialogues that purposely embedded fallacies. The dialogues revolved around an SSI the teachers chose to inquire. Those who wished were encouraged to role-play their dialogue.

We acknowledge the significant contribution of the SSI reasoning framework in supporting argumentation [32,84]. However, the extended duration required for comprehensive implementation of the framework poses challenges in many educational settings, including the context of our research. Hence, we focused on using informal fallacies as a framework that may support teachers in assessing arguments in the SSI context and serve as an alternative in situations where time constraints limit the feasibility of long-term implementations [85–87].

2.2.3. Part 3: SSI Operationalization

This part of the PD program consisted of concrete and practical examples for integrating SSI into the science lessons curricula. This component was divided into three subparts: (a) modeling an implementation of an SSI lesson, (b) experiencing types of discourse aligning with SSI, and (c) utilizing the format of a British parliamentary debate (BP).

- Modeling implementation of an SSI lesson

In addition to providing teachers with ready-to-use ENGAGE materials, we introduced a model of a chemistry lesson we developed and implemented based on the SSI instructional model proposed by Sadler et al. [18].The PD's facilitator, who is one of the authors and a former high school chemistry teacher, shared his experience in developing and implementing an SSI unit. The modeling approach entailed a detailed explanation of integrating SSI into the existing curriculum. This modeling activity aimed to offer teachers a vicarious experience within a familiar context, allowing them to envision themselves as competent professionals [45,88]. Of note, the identity of the modeler plays a crucial role in enabling teachers to relate to the experience.

Given that the ENGAGE materials did not perfectly align with the existing curriculum, it was vital to expose teachers to a model demonstrating the integration of SSI into an already established curriculum, hence providing an additional avenue for teachers to implement SSI. As part of the lesson model activity, teachers participated in discussions concerning the design principles and collaborated in small groups to explore various ways of integrating SSI within their existing curriculum.

- Experiencing and identifying types of discourse conducive to SSI implementation

Facilitating a student-centered discussion that encourages multiple voices is a core pedagogical principle across SSI literature [47,89,90]. However, facilitating such discussions is challenging, given its difference from typical discussions in the science classroom that stems from three reasons. First, the controversial nature of the issues requires teaching strategies and activities that facilitate and mitigate any tensions that might arise during a dialectical event [47]. Second, SSI usually includes an ethical component that extends the science classroom discussion scope beyond empirical-based arguments [69]. Third, the discussion aims to make an informed decision in uncertain circumstances, which is at odds with a norm that often portrays the scientific method as allegedly generating definite answers [4]. Therefore, we focused on introducing teachers to strategies that facilitate an SSI discussion. We explicitly introduced different types of discussions, such as brainstorming, synthesizing, and sense-making [91]. Next, we introduced and let teachers participate in short playful activities that potentially spark a discussion about SSI. For example, teachers were presented with a call for action, like forcing people to vaccinate. They were asked to choose one of four optional cards that regard that call: agree, disagree, agree/disagree but with certain caveats, and need some more information to decide. Each group was asked to move to each corner of the room representing their chosen card. This activity allows teachers to recognize the differences in opinions between students and organize discussion groups accordingly.

- Using the British parliamentary (BP) debate

To address teachers concern about lack of control over the class during a controversial SSI discussion [90,92], we adopted the BP debate style as an activity that could facilitate an SSI discussion in a more constructive, organized, and engaging manner. The British parliamentary debate is a formal style of debate commonly practiced in the United Kingdom and European countries. It follows a structured format associated with parliamentary settings. The debate involves two teams, the proposition and the opposition, each consisting of two or more speakers. The debate centers on a pre-determined motion or topic that is announced before the debate begins. The teams are provided time to prepare for the debate and once it starts the teams argue either in favor (proposition) or against (opposition) the motion. After the debate ends, judges evaluate the performance of both teams based on criteria such as persuasiveness, logical reasoning, style, and overall impact. The judges then provide feedback and announce a winner based on their evaluation.

Before deciding to integrate BP into the PD, we examined the literature while consulting with debate champions and coaches. Next, we prepared a lesson plan that integrated a BP debate over an SSI and next enacted it in the classes that we and other teachers who volunteered taught in.

Surprisingly, despite its vast popularity, the literature had a limited number of reports about implementing debate in science classrooms. Some benefits of BP debate have been reported by Eckstein and Bartanen [93], who found that it prepared students for global citizenship by enabling them to communicate ideas to people of other cultures and that it was easy to learn for all parties involved, with low temporal and fiscal cost. Aclan and Aziz [94] also showed that participants improved in language and communication skills.

The rules and structure of a BP debate were presented to the teachers by a former European debate champion. During the presentation, teachers were able to participate in short debates over different SSIs. Each PD ended with a full BP debate as a culminating event. The debate motions (i.e., topics) were selected in advance, and included, for example: (1) "this house will allow fracking in the Adulam region" (a valuable natural and historical region in Israel), (2) "this house will allow phosphate mining in the Brir field" (an area in very close proximity to a city and a Bedouin village). The complexity of the motions required adequate preparation; therefore, teachers were given time and referred to resources to learn about the issues and plan their arguments. The PD conductor (who is also a former debater) served as the judge and wrote down all arguments that were conveyed during the debate.

2.2.4. Part 4: Science communication (SC)

Science communication is the field that examines the means and strategies in which science in communicated to the public [95]. Researchers have acknowledged the influence of the media and social media on shaping public attitudes, beliefs, about the scientific enterprise, and the impacts those have on decision-making [96]. Moreover, scrutinizing information on different media platforms is a central skill required to nurture scientific literacy among citizens [97,98]. It was recommended to integrate media and the news into the science classroom as a strategy for supporting SSI and preparing students for citizenship [99]. We introduced teachers to various studies relating to science communication. For example, we presented data on the Israeli public scientific literacy level, and the abundance of science related reporting in the Israeli media (TV and radio) compared with other countries [100,101].

3. PD Context

This research was conducted in Israel, where SSIs are not part of the science curriculum at any grade level. Also, there is an overemphasis on standardized testing, which hinders genuine attempts to implement progressive pedagogies [102,103]. Nonetheless, at the same time, attempts were being made to promote progressive pedagogies. In 2017, the Israeli Ministry of Education announced a new initiative to include OMER questions in the science matriculation exams. OMER is a Hebrew acronym for value, relevance, and engagement. For example, a possible question that students can be asked in the biology matriculation exam is: "Do you think those who oppose vaccination should be forced to vaccinate their children? Please justify your argument." Secondary level science teachers and teacher educators are still struggling with preparing students for these types of questions, as they lack material, strategies, and guidance, which underscores the need for relevant PDs and involvement with SSI.

3.1. Research Population

The teacher population was diverse, and included 137 junior high, MUTAL (science for all), and high school teachers of different science disciplines, with most teaching biology, followed by chemistry and physics (only 1–3 physics teachers each year). We recruited science teachers from various disciplines because, as already argued, SSI are not designated to a specific discipline, grade, or level [104]. PD teachers were provided with information regarding the PD's involvement in a research study on the implementation of socioscientific issues (SSI) in the science classroom. They were given the opportunity to opt out of any research-related activities if they wished to do so.

3.2. PD Timeline

Each PD cohort lasted for 30 academic hours. During each year, we offered both face-to-face and hybrid PD programs. The face-to-face PD programs were generally scheduled over four consecutive days in the summer, while the hybrid PD courses included eight academic hours of face-to-face meeting. The remaining 22 h were taken from biweekly synchronous and asynchronous meetings and activities. Data from all PD cohorts were gathered over three years. After each year, we modified the PD program based on insights gained from the previous one. Table 1 presents the number of teachers participating in each cohort, and per research cycle (one year).

Table 1. PD cohorts during three years.

Cohorts Number	Registered Teachers	Completion	Teacher Population	Cycles and Number of Cohorts
1	40	4	MUTAL—science for all	Cycle one—three cohorts
2	24	21	Junior and high school teachers	
3	25	4	Junior high and one biotechnology teacher	
4	23	16	Junior and high school teachers	Cycle two—three cohorts
5	47	26	Junior and high school teachers	
6	6	6	High school chemistry teachers	
7	28	28	Junior and high school teachers	Cycle three—two cohorts
8	32	32	Junior and high school teachers	
Total	225	137		

4. Research Questions

We asked the following questions to evaluate our PD design and its potential to support teachers in SSI implementation:

1. What impact did the PD program have on teachers' attitudes, self-efficacy, and enactment of SSI?
2. Which activities and settings best supported teachers in SSI implementation as informed by the iterative PD design process?

5. Research Instruments

5.1. Teachers Perceptions Questionnaire

A pre- and post-five-point, mixed Likert-scale-type questionnaire (Appendix A.1) and an open-ended questionnaire were presented to participants via Google Docs. There were 22 Likert type-items subdivided into five categories (Table 2). The questionnaire also included open-ended questions that had a different focus between the pre- and post-test (Appendix A.2). The questions in the pre-test focused on teachers' prior SSI knowledge and experience, while the post-test questions focused on teachers' learning experience and plans for implementing SSI. The teachers were asked to fill out the questionnaires immediately before the PD course began (pre), and immediately after it ended (post). To establish content validity, seven science-education researchers, with three holding a strong background in SSI, were separately asked what each question measures. Responses revealed full agreement. Internal consistency reliability was used to test the questionnaire's reliability. We administered the questionnaire to 150 science teachers (junior and high school teachers) who did not take part in the PD. All categories were found reliable according to Cronbach's α test (Table 2). A Wilcoxon test was conducted to determine any significant difference between the pre- and post-PD teachers' responses.

Table 2. Reliability of SSI and argumentation questionnaire.

Category (*n* Stands for No. of Items in Each Category	Example Items	Reliability (Cronbach's α)
SSI attitudes (*n* = 3) (Attitudes)	*It is important to implement SSI in science teaching.*	0.715
SSI Implementation (*n* = 3) (Knowledge and skills)	*I conduct discussions about SSI in my classroom.*	0.796
Attitudes to argumentation (*n* = 2) (Attitudes)	*Argumentation skills are important in the SSI context.*	0.742
SSI and argumentation (*n* = 8) (Self-efficacy)	*I feel confident in discussing and teaching SSI in my classroom.*	0.797
SSI and argumentation pedagogical tools (*n* = 6) (Knowledge and skills)	*I believe that I have enough pedagogical tools to analyze the soundness of arguments about SSI.*	0.771

5.2. Retention Questionnaire

A year following the completion of the PD, a questionnaire was administered through Google Forms to assess participating teachers' implementation of SSI (Appendix A.3). The questionnaire was distributed to teachers who had completed the PD program and its associated requirements. The questionnaire aimed at measuring the PD's impact by eliciting information about teachers' motivations, decision-making processes, preparation time, strategies of implementing SSI, and overall experience in teaching SSI lessons. Additionally, it aimed at revealing teachers' reasons for not implementing SSI.

Given the varying nature of SSI implementation [6], it was deemed essential to establish criteria for meaningful implementation. We defined a meaningful implementation as one that met the following criteria: (1) prior preparation for the lesson, (2) duration of at least two academic hours, and (3) design that enabled student engagement in argumentation with peers. The first criterion was set to prevent us from considering cases as SSI lessons, in which teachers report impromptu changes in lesson plans, often prompted by students' questions [16,21]. Additionally, prior preparation indicates teachers' agency and intention of implementing and weaving SSI into the existing curriculum and teaching routine. The second criterion was set to establish a reasonable time threshold. Because SSI is not a formal part of the Israeli science curriculum, we considered a minimum of two academic hours as an appropriate threshold. The third criterion was set to exclude reports of student-centered and lecture-like SSI implementation [16,92,105]. Among implementations that met these criteria, further differentiation was made between those who incorporated the use of BP debate and those who did not.

5.3. Teacher Interviews

Interviews were conducted to collect information regarding teachers' attitudes, self-efficacy, knowledge, and skills they may have gained during the PD sessions. We were mostly interested in finding how competent teachers felt in applying the new skills and knowledge they learned, and whether they intended to harness them to implement SSI. Twenty-seven teachers who participated in the PD were interviewed; six teachers were interviewed in the first cycle, eleven in the second, and ten in the third. The interviews were semi structured (Appendix A.4), conducted face-to-face, and lasted between 45 and 90 min, depending on teachers' effort to elaborate on the questions answered and the dialogue developed during the interview. To focus on teachers' personal experience of the PD, Josselson's (2013) relational approach [106] was adopted for the interviewing process. This approach emphasizes establishing a reciprocal relationship between the interviewer and interviewee, aiming to gain understanding of an individual's experience and point of view. As such, the interviewer encourages the interviewee to reflect on their experience and share their narrative. Guiding questions included prompts such as: "tell me about your experience", "what did it mean for you?", and "can you describe your thoughts and feelings about the experience?".

All interviews were transcribed and analyzed using Atlas.ti software [107]. The analysis was based on Shkedi's three-step analytical process [108]: initial analysis, mapping analysis, and focused analysis. Codes were based on both Desimone and King's frameworks. We particularly looked for themes that refer to personal outcomes, professional outcomes, and cultural outcomes. For example, expressions of teachers' awareness to SSI were initially coded as "awareness", but upon further analysis recategorized as an "affective outcomes" category that went under the broader category of "teachers' personal outcomes". Table 3 summarizes the number of teachers who responded to questionnaires and/or participated in an interview.

Table 3. Number of participants as aligned with each research tool.

Research Tool	Number of Participants
Pre- and post-questionnaires	N = 61
In-depth interviews	N = 27
Retention questionnaire	N = 40

6. Results

The results section is divided into two parts, each part providing evidence pertaining to address each research question.

6.1. RQ1—What Impact Did the PD Program Have on Teachers' Attitudes, Self-Efficacy and Enactment of SSI?

In this part, we show evidence of the PD's impact on teachers. We describe the PD's impact on affective aspects (attitude and self-efficacy), professional aspects (knowledge and skills), and cultural aspects (teacher collaboration).

6.1.1. Affective Outcomes

The findings from the open-ended questionnaire, as presented in Table 4, demonstrate a significant improvement across all categories. Particularly notable are the measures related to attitude and self-efficacy. We observed a significant increase in the importance teachers attributed to science, society, and inquiry (SSI) and argumentation, although these items had relatively high pre-PD scores (Table 4, $\rho = 0.0066, 0.0246$, respectively). The initial high scores for items measuring the importance of SSI and argumentation were expected, given that the PD program was elective and likely attracted teachers who already held a positive attitude towards SSI.

Table 4. Paired *t*-test results of SSI and argumentation questionnaire (N = 61).

Categories	Mean Change from Pre-Course Score	Mean Pre-Course Score (SD)	Mean Post-Course Score (SD)	ρ-Value	PD Commitment
SSI importance	0.227	4.385 (0.652)	4.612 (0.476)	0.0066	SSI introduction
SSI practice	0.276	3.236 (0.640)	3.512 (0.674)	0.0003	SSI pedagogy
Argumentation importance	0.233	4.133 (0.838)	4.367 (0.650)	0.0246	Argumentation
SSI and argumentation self-efficacy	0.242	3.573 (0.735)	3.815 0.657)	0.0073	Argumentation
Argumentation pedagogical tools	0.445	2.749 (0.630)	3.193 (0.715)	0.0001	Argumentation—debate, informal fallacies

Although the questionnaire data indicated a shift in teachers' attitudes towards SSI implementation, moving from a very positive to an extremely positive stance, the interviews provided a deeper understanding of the nature of this change. Through the analysis of interview data, a recurring theme of "awareness" emerged when teachers were asked about the PD's impact. The quotes from EY and TI represent this theme and demonstrate the PD's impact on stressing the importance of SSI in the science classroom.

EY: "The discussions over SSI established the fact and made me aware that there is a lack of implementation of SSI in science teaching and the need to cultivate civil awareness and activism among my students became much clearer."

TI: "During my years of teaching, I have always been drawn to everyday-life issues. Usually, these issues are broad and touch many different disciplines. The PD made the importance of implementing such issues in the science class much clearer and provided the tools for doing that, so I am more aware of it."

Interestingly, the interviews revealed that the PD reinforced prior beliefs of some teachers about SSI and even goals of science teaching as well. JN's quote is a prominent example to such reinforcement.

JN: "After a very tough year at school, when I seriously thought about quitting teaching, I took this PD course which reminded me why I had been attracted to teaching in the first place—to shape and change the environmental perception of the next generation."

The questionnaire's findings further revealed teachers' self-efficacy improvements (ρ = 0.0073). These results were corroborated by insights gained from the interviews. Specifically, teachers expressed a heightened sense of confidence in various aspects of SSI instruction, including facilitating SSI discussions, conducting debates, assessing students' arguments, and preparing SSI lessons. The quote from LL serves as compelling evidence for this increased sense of competency, as it demonstrates a strong commitment to implementing SSI and sharing acquired knowledge with colleagues.

LL: "I learned about the debate, how to conduct a debate and set goals for an SSI lesson. . .I think that the debate can support the students gain a better and deeper understanding of the learning material. . .I am sure I will implement the debate and spread the word to others."

The quote from RV illustrates the PD's effect on teachers' sense of competency in assessing arguments in everyday life and the way it affected her argumentation practice in their classroom.

RV: "After the PD course, I listened to the radio, I was listening to the arguments and it felt completely different. . .I got to assess and name students' arguments, a thing I didn't know how to do before the PD."

The quotes from YU and JN are both examples of a vicarious experience showing the impact the modeling of integrating SSI into an existing curriculum had on teachers' self-efficacy.

YU: "Modeling a six-week lesson plan that showed an integration of SSI with the scientific curriculum helped me thinking about ways I can pull off such a thing."

JN: "Having a demonstration of how SSI is integrated into an existing curriculum, made me think this is something I can do, this is something I can adopt in my own class."

6.1.2. Knowledge and Skills Outcomes

The pre- and post-questionnaire data analysis revealed a significant improvement in the "SSI and argumentation pedagogical tools" category (ρ = 0.0001). Complementing the Likert questionnaire, the responses to open-ended questions show that teachers identified argument assessment and the BP debate as particularly beneficial. Following the PD, 92% of the teachers expressed confidence in implementing a debate as part of an SSI lesson.

Additionally, teachers expressed a strong appreciation for the ready-to-use materials developed by the ENGAGE project team. These materials were highly regarded for their practicality and supportiveness. Notably, teachers valued the minimal preparation requirements associated with these materials, enabling them to seamlessly integrate them into their regular schedules without significant time constraints.

In the pre-course questionnaire, when asked to provide examples of SSI and explain them, teachers offered general examples without providing specific details. For instance, they listed climate change, genetic engineering, and biodiversity as examples of SSI, but did not elaborate on the associated dilemmas. Notably, there was a lack of local SSI examples specific to Israel or their respective communities. In contrast, the post-course questionnaire revealed a significant shift in teacher responses. All teachers reported that the professional development (PD) program exposed them to a wide range of local SSIs from which they could choose to implement in their classrooms. Moreover, the issues mentioned by the teachers were framed as questions or calls to an action. For instance, their answers were structured in a way that posed questions like, "Should we raise taxes on meat to reduce its consumption and ecological footprint?" This shift in the quality and specificity of the examples provided by teachers in the post-course questionnaire demonstrates the impact of the PD in broadening their understanding of local SSIs and encouraging them to formulate issues in a more engaging and actionable manner.

Evaluating informal logic as a practical tool for assessing arguments within SSI discussions revealed diverse perspectives among the participants. A thorough analysis of the teachers' responses uncovered three distinct viewpoints: (a) 50% of the respondents acknowledged the contribution of informal logic to the development in their personal argument assessment skills and regarded it as a valuable tool for supporting students in both argumentation and argument assessment; (b) 30% of the participants recognized the improvement in their personal argumentation assessment skills through informal logic, yet did not perceive it as a practical tool/skill for assisting students in argumentation; and (c) 20% of the teachers either reported no discernible impact from informal logic or did not provide a response to the question.

A significant shift became apparent during the third cycle of the study, characterized by an increased emphasis on active learning and role-play associated with informal logic. Notably, 75% of the teachers recognized the practicality and applicability of informal logic within the classroom. Subsequent sections delve into the changes implemented and their corresponding impact.

The following quote from LM's interview exemplifies the connection between the influence of the learning experience with informal logic on their personal life and the agency to implement it in their classroom.

> *LM: "On my way to the interview, I was listening to a political show on the radio, and because of the PD I noticed the fallacies in the interviewee's arguments. It made a difference in my personal life, and I am excited to take it into the class. I think it will be an invaluable skill for my students."*

6.1.3. Collaboration Outcome

Teachers addressed the collaborative aspect of the PD as having a positive effect on their learning and overall experience. The interview analysis reveals that all the teachers from the third cycle and none from the first one addressed collaboration. The following quotes are representative examples of the collaborative aspects that teachers mentioned.

The following quote by JE criticizes the way collaboration was facilitated, expressing their will for more frequent teacher regroupings that would have increased teacher acquaintance. Specifically, JE mentions that the group's mixing came rather late in the PD.

> *JE: "The discussions were nice, and I really liked collaborating with other teachers. However, more attention should have been paid to mixing groups more often, as mixing of groups took place at the end of the third day, which limited the opportunities of meeting and working with more teachers."*

In the following quote, MA expresses their will to collaborate with teachers from other disciplines besides science. This sentiment was commonly expressed by other teachers as well. The rationale some teachers provided for collaborating with colleagues outside of the science discipline was that collaboration would allow them to share the load that comes with the multidisciplinary nature of SSI. This means that the science teacher would focus on the scientific aspects of the issue, while the civics or history teacher would focus on the social aspects of the topic.

MA: "I would like to collaborate with someone and not only implementing SSI on my own. For example, I can collaborate on SSI with the Geography teacher as we did last year on another issue. I already have some ideas about collaborating with my colleague who teaches cinema. Those are the types of collaborations I believe can make the implementation of SSI meaningful."

6.1.4. The Effect of the PD on SSI Implementation

Figure 2 depicts the frequency of SSI implementation among teachers during the subsequent school year following the PD. The implementation types are categorized into four distinct categories, as outlined in the methods section. Of the 42 teachers who responded to the questionnaire, 26 engaged in pre-planned SSI lessons, with 10 incorporating a BP debate as part of their instructional approach. Additionally, 5 teachers reported spontaneous SSI lessons throughout the year, while 11 teachers indicated no implementation of SSI.

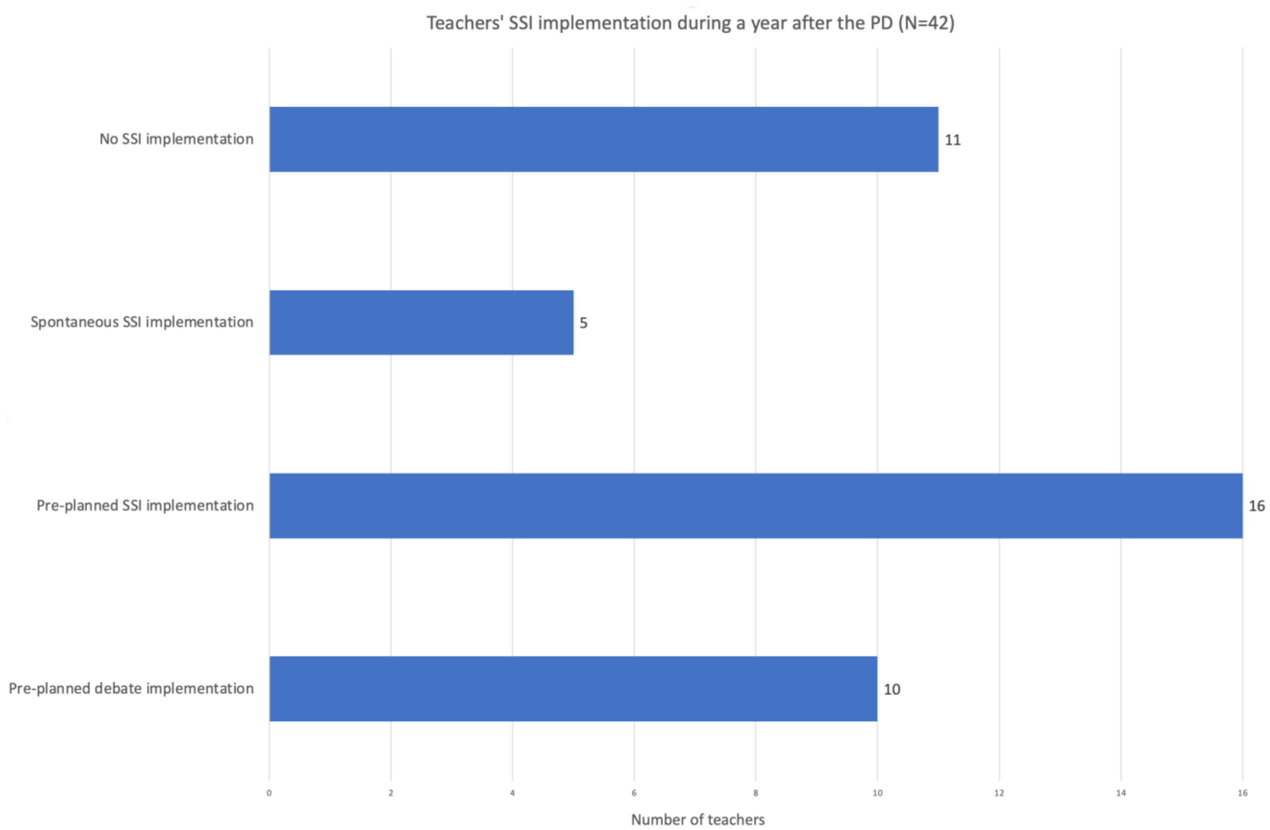

Figure 2. Retention questionnaire results, measuring teachers' SSI implementation during the year that followed the PD. The y axis shows from the bottom of the chart: (a) Pre-planned implementation of a debate or other SSI activities lasting at least 4 academic hours, (b) pre-planned SSI lessons that lasted 1–3 academic hours, (c) spontaneous SSI lessons (episodic discussions in class), (d) no implementation of SSI.

The following quote from RN's interview is representative of teachers who considered implementing SSI during the interviews and eventually did. This suggests that the

PD provided a model for those teachers, offering supportive scaffolding conducive to implementing a debate in their classrooms. In this quote, RN reiterates the gradual stages experienced by the teachers throughout the PD and expresses their intention to follow those stages in their classroom.

RN: "When I think about the next year and the classes I will teach, I see myself implementing the debate in stages, so students get to practice the skill. First, I will teach my students what an argument is, and about logical fallacies. Next, I will let students write arguments about whatever they wish to argue about, and to think about the other side's responses and plan their rebuttal, so they can practice their writing and won't have to stand in front of an audience with no counter argument. After that, we can conduct SSI debates and competitions."

The questionnaire revealed three prominent reasons teachers provided for not implementing SSI: low expectation of students' ability, lack of preparation time, and prior commitments. Those reasons also resonated in some of the interviews. Next, we elaborate on each reason.

- Reason 1—Low expectation of students' ability.

Three junior high science teachers stated students' lack of competency with handling complex issues like SSI as the prominent reason for not implementing SSI in their classrooms. Teachers, as exemplified in the quotes from MC and MP, attributed this lack of competency to students' developmental stage, stating that junior high students are too young and lack the adequate maturity to engage in SSI.

MC: "The students are inattentive...it depends on the students, the students I teach are not at a stage where they can handle complex issues like SSI."

MP: "The students are very difficult, so you hardly manage to cover the curriculum and prepare them for the MEITZAV (national standardized test for the junior high level). In such circumstances SSI is not something I would consider getting into."

- Reason 2—Lack of preparation time.

Despite teachers asserting their willingness to implement SSI, HD and YS quotes demonstrate a constant sense of urgency that prevents teachers from allotting enough time to prepare for an SSI lesson that also meets the curriculum standards.

HD: "I didn't have specific ideas for how to integrate SSI in the curriculum. When you are in a race, it is very difficult to design new lesson materials. There are regular tests and national tests, that you are always in a race to cover the topics for those tests. Had I had specific examples of how to implement SSI into each topic in the curriculum, I might have used it more."

YS: "There are not enough practical materials that do not require preparation in order to implement what we learned in the PD course."

- Reason 3—Prior commitments.

Some teachers did not implement SSI in their classrooms due to prioritizing other commitments; the most outstanding among these is preparing students for standardized testing. For example, the quote from AN and OB, two high-school chemistry teachers who expressed their commitment to the subject matter and the matriculation exam, express a content knowledge (CK)-oriented approach [109].

AN: "Whenever I have extra time, it means extra preparation for the matriculation exam."

OB: "No, I don't have time for SSI lessons, I teach 11th-grade for the matriculation exams and the 12th-grade for the lab enquiry exam...there is a part in which it is recommended to discusses the pros and cons of fire retardants, but actually there is no real time to discuss it—it is not the essence of the work (teaching chemistry)."

6.2. RQ2—What Activities and Settings Best Supported Teachers in SSI Implementation as Informed by the Iterative PD Design Process?

Table 5 summarizes the time allotted for each PD aspect in each year. As Table 5 shows, changes can be noted in the argumentation and SSI operationalization aspects. A significant change can be noted between years 2 and 3, as three additional hours were dedicated to SSI operationalization.

Table 5. Distribution of academic hours across different components of the PD.

	SSI Introduction	Argumentation	SSI Operationalization	Science Communication	Enrichment Lecture
Year 1	6	10	10	2	2
Year 2	6	11	11	2	0
Year 3	6	8	14	2	0

6.2.1. Changes between Cycle One and Two

In the PD's initial cycle, most teachers did not perceive informal logic as valuable for facilitating SSI discussions. Out of the eight interviewees, only two recognized the relevance of informal logic to their teaching. We introduced formal logic and Toulmin's model in response to these findings. The intention was to illustrate instances where these methods proved inadequate or challenging in evaluating arguments within an SSI context, thus creating a learning experience that effectively highlights the necessity of employing informal logic.

For instance, as part of the formal logic background, we introduced teachers to inductive reasoning through David Hume's problem of induction [110]. By presenting Hume's argument, which questions the validity and reliability of inductive reasoning, we initiated a discussion on assessing students' inductive reasoning and the potential difficulties associated with such assessments. Additionally, we contextualized the identification of informal fallacies by incorporating real-case scenarios into the discussion. For example, to illustrate the argument from authority fallacy, we presented Milgram's study [111], demonstrating the profound impact an authority figure might have on individuals to the extend they concede to physically harm others.

Based on negative feedback from interviewees and post-questionnaires, we removed the enrichment lecture that was originally included in the first cycle. This decision also created more opportunities for active learning within the program.

6.2.2. Changes between Year 2 and Year 3

The main conclusion from the second cycle was that thickening the theoretical background had a limited effect on teachers' attitudes about using informal logic to facilitate SSI discussion. The post-open-ended questionnaire from the second cycle showed that half of the teachers found informal fallacies as a helpful and practical tool for facilitating SSI discussion and assessing arguments, while the other half did not. Furthermore, some teachers reported that the preoccupation with formal logic and Toulmin's model was cumbersome; others even reported a sense of discomfort. It was apparent in teachers' feedback that they lacked the more practical experience that would enable appropriation and agency. Therefore, the main focus in the third year was to reduce the theoretical background and, instead, devise strategies and activities that would encourage teachers to be even more active participants than in the previous cycles. For example, instead of spending more time on discussing types of argument assessments, we modeled and detailed a six-week SSI unit implemented by the authors in a tenth-grade science class. We also recruited a teacher who shared her experiences in teaching SSI.

We decided to briefly introduce Toulmin's model, just as a preface that provides a context for informal fallacies. In addition, we devised activities that further contextualize informal fallacies, and which positioned teachers as active participants. For example, teachers were given a collaborative task in which each pair wrote an imaginary dialogue that intentionally included informal fallacies between two interlocutors who disagreed upon a certain SSI. Some teachers volunteered to perform their dialogue in front of their peers that followed a reflective discussion. In addition, teachers were given time to design and prepare their own SSI lesson, which also became part of the PD course requirements. In prior years, teachers asked for more "ready-to-use" materials (in addition to the ENGAGE materials); however, we decided to dedicate specific time slots to modify ENGAGE modules or to develop a 45–90 min SSI lesson plan. Teachers' interviews from the third cycle revealed how meaningful those time slots were for teachers as demonstrated in VD's quote.

> *VD: "It was nice that I had the time to write a lesson plan for my class. The fact that we were not sent with homework, but all the work was within the PD schedule, is very much appreciated. It sends a message that our time is valuable. In addition, I was able to ask the facilitator and other teachers for suggestions, which really helped me."*

An additional change between year two and three was allotting more time for teachers' discussion and interaction. For example, after completing the tasks and activities about informal fallacies, teachers were encouraged to have a reflective discussion with their peers on the viability of utilizing informal fallacies in their classroom. After each group discussion, a plenary discussion took place in which teachers shared their thoughts and insights.

7. Discussion

This paper presents findings regarding the impact of a unique and short PD program that was designed to support teachers in implementing SSI in their class. The first part of the discussion reviews the impact of the PD course on teachers' attitudes, self-efficacy, skills, and knowledge concerning SSI implementation. The second part suggests an SSI PD model based on the results of a three-year educational design research.

7.1. PD Impact

7.1.1. Attitudes

The PD had a discernible impact on attitudes and recognition of the importance of SSI in the science classroom. Prior to the PD, for many teachers SSI implementation was an episodic and anecdotal learning event at its best, serving as a respite from the so-called "real science curriculum". This perception aligns with similar findings from previous studies that showed that teachers view SSI as an initial means to engage and motivate students to learn science, yet at the same time, perceive it as disconnected from science teaching [16,112]. As mentioned, teachers expressed how the PD made them aware of the importance of SSI implementation in the science classroom. Our results agree with research showing that teachers' awareness to a range of topics, from climate change to gambling among adolescents, are correlated with teachers' attitudes and practice in the classroom [113–115]. In that sense, we move the field forward by showing that our PD design impacted teachers' awareness of SSI, consequently acknowledging it as a prominent facet of science teaching.

Changes in attitudes and acknowledgment of the importance of SSI were also manifested by an increase in familiarity with various SSI. At the beginning of the PD program, teachers typically outlined general themes pertaining to SSI. Discussing various SSI throughout the PD sessions, especially in a local context, exposed teachers to SSI that are relevant to them and their students' lives and can be integrated within the curriculum they teach. In that sense, like others, we showed that gaining knowledge is a prerequisite for a change in attitudes [116]. Our results resonates with other scholars' advocacy for integrating locally situated SSI as a promising context for engaging students' and their communities in science [67,117].

7.1.2. Self-Efficacy

The pre- and post-test results and the number of teachers who prepared and enacted an SSI lesson during the year that followed the PD serves as evidence for the PD's effect on improving teachers' self-efficacy in implementing SSI. Next, we explain this improvement by examining the alignment between specific design principles of the PD and the three factors affecting self-efficacy.

We believe that integrating more active learning, which is necessary for effective PD [27,118], enhanced opportunities for a mastery experience. Teachers' interviews reveal that first-hand experience with various strategies established confidence in utilizing them in their classrooms. Specifically, engaging in role-play activities, like the BP debate, was noted by teachers as supportive in constructing and evaluating arguments during the live discussion. This observation aligns with existing literature, highlighting role-play's potential in fostering improvements in argumentation skills, empathy, and critical thinking [119,120].

The results show that modeling a six-week integration of SSI into the chemistry curriculum triggered a vicarious experience. Other scholars documented similar results showing that teachers listening to other teachers reporting on successful experiences handling certain teaching tasks increased self-efficacy [121,122].

The collaborative nature of many activities in the PD might serve as an explanation for the effect of social persuasion on teachers' self-efficacy [122,123]. Indeed, working in small groups allowed a co-learning experience, which might nurture positive reinforcement among teachers, increasing self-efficacy. However, our data did not indicate any social persuasion indication.

7.1.3. Knowledge and Skills

The importance of content-focused teacher PD was emphasized by various researchers [27,42,124]. Unlike previous research on SSI PD, which was often discipline-oriented (e.g., high school biology teachers or climate change [30,125,126]), we focused on SSI pedagogical content knowledge [33]. We argue that the multidisciplinary nature of SSI allows a diverse group of teachers to build on each other's content knowledge, making time to focus on knowledge and skills relevant to SSI for science teachers across disciplines. We show that the content covered in the PD was relevant for teachers who teach different science disciplines and at different grade levels. However, further research is needed to determine an SSI PD design that addresses the diverse needs of different teacher populations, like middle and high school teachers, who experience different teaching commitments and challenges.

Based on the retention questionnaire and interviews, teachers not only reported acquiring new knowledge and pedagogical tools but also utilizing this knowledge and skills in their teaching. We perceive that as a significant achievement, particularly given that during the three-year period of the study, there was no official curriculum or concrete requirement from the Israeli Ministry of Education for integrating SSI within the science curriculum, apart from the OMER questions mentioned earlier. The impact of the PD course is believed to be even greater considering the teachers' self-initiative and minimal external incentives. Overall, the primary goal of the PD course, which was to equip teachers with practical tools for conducting and facilitating SSI discussions, was achieved.

To conclude the first part of the discussion, the results show an interrelated relationship between teachers' attitudes, self-efficacy, and SSI knowledge and skills. We show that the learning opportunities teachers had throughout the PD led to a sense of mastery and ownership that eventually resulted in the implementation of SSI in their classrooms. These findings are consistent with previous research by scholars such as Bandura [44], Ross and Bruce [127], and Tschannen-Moran and McMaster [121], who have demonstrated that a heightened sense of mastery increases the likelihood of teachers incorporating newly acquired knowledge and strategies into their classroom instruction.

7.1.4. Barriers to Implementing SSI

Our results align with previous findings regarding teachers' reluctance to implement SSI due to external obstructions and prior commitments [5,14,16]. Teachers provided three major reasons for not implementing SSI, all of which referred to standardized testing as a particularly significant obstruction. These findings echo reports on the negative impact of over-standardization on educational systems and teachers' well-being [128–130]. Additionally, the study unveiled that middle school teachers demonstrate a lack of confidence in their students' ability to constructively engage in SSI lessons, thereby further contributing to their reluctance to implement SSI. These doubts may stem from factors such as prior beliefs, school environment, teaching experience, and class heterogeneity. However, a more in-depth analysis of these factors is beyond the scope of the research.

7.2. Research Implications

The goal in developing an SSI PD was to design an effective short-term teacher PD that aims to support teachers unable to participate in rather demanding long-termed PDs and provide a middle-ground solution for educational systems that lack resources for supporting such longitudinal PDs. Based on a thorough literature review, we set four components necessary for SSI PD. Informed by the EDR framework [19], each component's content was iteratively developed and revised based on data collected and analyzed from each PD cycle. Next, we discuss the implications of our PD design and summarize its application to various educational contexts.

We found that introducing SSI, starting with a discussion on an SSI subject, followed by teachers' review and modification of ready-to-use materials, was successful in addressing the paucity of SSI learning materials, which was recognized as a major hurdle in efforts to implement SSI [17–19]. Moreover, those findings add to previous research showing that even a single and short use of ready-to-use SSI ENGAGE modules impact aspects of SSI pedagogical content knowledge [33]. Therefore, it is highly recommended that PD facilitators expose teachers to SSI ready-to-use materials and allocate time to modify them to their own needs. Fortunately, as research on SSI advances, ready-to-use materials from global studies are becoming increasingly available [64,131]. Facilitators need to ensure that the materials they choose align with the standards in their country or state to avoid situations in which teachers might have to choose between standard curriculum or SSI implementation.

Engaging students in argumentation is fundamental to SSI implementation [47,86]; yet, the preparation of teachers as facilitators of argumentation around SSI is still in flux [68,74]. The results demonstrate that applying formal logic and Toulmin's model as argument assessment tools discouraged many teachers. Hence, we suggest not emphasizing these types of argumentations in the context of SSI. These findings cohere with Nielsen's criticism [74] that highlighted the limitations of Toulmin's argumentation pattern as a tool for supporting discussion and argumentation in SSI context.

However, informal logic, which has been advocated as a more appropriate framework for assessing arguments in the context of SSI [73,74], was perceived by the teachers as partially applicable in their classes. Interestingly, most teachers found informal logic useful throughout the cycles, yet some teachers differentiated between its use in their personal life and the classroom. Our accomplishment is to increasingly shift teachers' views from one cycle to the following in a three-year iterative process. We acknowledge that facilitators might be overwhelmed by the literature on informal logic, and, hence, we suggest focusing on identifying common informal fallacies, which are useful in the context of ethical disputes common to SSI.

We recommend facilitating activities with a theatrical character as a vehicle to promote the identification and response to formal fallacies. Prior research has shown that theatrical activities, such as role-playing, enhance motivation and content understanding [119,120,132–135]. Particularly, we highly recommend adopting the BP debate format to engage students in a structured discussion of SSI. We also recommend obtaining the assistance of professional debaters, if possible. However, we would like to point out that we do not suggest strict adherence to the BP debate structure but rather maintain its dialectical spirit. Some of its characteristics, such as the number of speakers, order of speakers, time of speech, and other parameters, can be modified according to class size, time availability, and other considerations the teacher might have.

Our PD design specifically addressed how media resources can be used in the context of SSI as media is the main mediator between scientists and the public [37]. Yet our work was done before publications that show the spread of false evidence in social media and its possible contribution to science denial [96]. Currently, we would highly suggest focusing on the use of social media rather than more traditional media sources like TV news and newspapers, as late polls show that the majority of the pubic consumes their news on social media [136,137]. Researchers have already started studying how social media can be harnessed to enhance students' argumentation [138,139].

Finally, we recommend, allocating time for designing personal SSI lesson plans or modifying existing ready to use materials, as it is likely to prompt an increasing sense of appropriation and agency [27,139]. Table 6 summarizes our recommendations regarding each component of the PD. We deliberately kept the table quite general, as it is not our intention to give a one-size-fits-all prescription for SSI PD but to provide general guidelines for activities and themes that teacher educators can use to prepare teachers for some of the prominent challenges posed by SSI teaching.

Table 6. Activities and practices recommended for SSI PD.

PD Component	Suggested Activities/Practices (Takeaways and Recommendations for the Future)
Introduction to SSI	Evoke discussion over SSI, present clear criteria for SSI, examine and analyze ready-to-use materials, provide teachers appropriate time to modify and adapt materials for their needs, and allow time for reflection.
Argumentation	Present an SSI discussion (it can be a video from a class) and ask each group of teachers to assess the arguments and discuss them. Allow teachers time to reflect on their challenges while assessing the SSI discussion. Introduce informal logic as an alternative for assessing arguments in a live discussion. Provide examples of fundamental informal fallacies; if possible, use interviews, speeches, social media posts, etc. Let each pair of teachers write a dialogue between two opposing interlocutors arguing over a controversial socioscientific topic and ask them to embed informal fallacies in their argument intentionally. If teachers are interested, allow role-playing of their dialogue.
SSI operationalization	From day one, allocate time for teachers to plan their own SSI lessons. Model an example of SSI implementation. If possible, invite teachers who can share their experience of teaching that implementation. Provide opportunities for teachers to experience engaging ways to evoke a class discussion about SSI. Examples can be found in the ENGAGE materials. Conduct a British parliamentary debate concerning a socioscientific issue in which teachers participate as speakers and judges. If time allows, it is preferable to conduct small debates throughout the PD with 2–4 participants and end the PD with debates that include at least four speakers from each group.
Science communication	Introduce teachers to contemporary research regarding public scientific literacy. Provide examples for how media items can be leveraged for SSI implementation. For example, have teachers compare two articles or posts on social media about the same issue. Those can serve as other opportunities to exercise the identification of informal fallacies.

7.3. Research Limitations

This study was limited by the fact that teachers willingly registered for the PD program, which likely meant that some had an inclination towards SSI before enrolling. Thus, the research population is not fully representative. Also, we only followed teachers in the school year that followed the PD course. The sustainability of the impact of the course remains to be established by following teachers' practice and SSI implementation in their classrooms in the coming years. We acknowledge that relying on teachers' self-reports is not a data resource as reliable as classroom observations. However, research has shown that the discrepancy between teachers' reports and observation is insignificant [57].

8. Conclusions

In conclusion, while we acknowledge the fact that 30 academic hours PD would not be as sufficient as long-term PD, we argue that the field should not ignore school and teachers' reality; hence we designed a PD that considers those real-world constrains. Despite the relatively short duration of the PD, our work successfully tackled several key barriers to implementing Socio-Scientific Issues (SSI) in the classroom.

The lack of ready-to-use materials was addressed by providing teachers a pool of materials to choose from to meet their needs. Additionally, we equipped teachers with various strategies to facilitate argumentation over controversial issues to support them in grappling with SSI's controversial nature. Moreover, we tackled the challenge of assessing arguments in SSI contexts by introducing and practicing the identification of informal fallacies in engaging ways. Furthermore, we showed that participating teachers increased their self-efficacy and eventually implemented SSI in their classroom. We think our contribution to the literature lies in designing an SSI PD model that can be of value to PD designers and facilitators worldwide, who wish to disseminate and familiarize their teachers with SSI.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Appendix A.1. Open Questionnaire (Translated from Hebrew)

Name:
Gender:
Education:
Teaching experience (in years):
Teaching in:
Elementary
Junior high
High School
Academia
Informal teaching
All questions are on a five-point Likert scale

1. It is important to integrate socioscientific issues in general studies (science for all programs).
2. I am concerned that there are issues I will not know how to handle during a socioscientific discussion.
3. I can assess students' arguments over socioscientific issues in real time during a class discussion with a relative ease
4. I feel confident to discuss and teach socioscientific issues that are up to date with current events.
5. I do not tend to address other aspects but the scientific ones in my class (e.g., economical, social, historical, political, etc.)
6. I do not think argumentation skill should be taught explicitly.
7. It is important to incorporate socioscientific issues in the teaching of students in scientific disciplines such as physics, chemistry, and biology.
8. I am able to address controversial issues in oral argumentation.

9. In a discussion on social issues, I find myself in a problem when I do not have enough knowledge to answer students' questions.
10. Teaching science content alone is sufficient to prepare students as scientifically literate citizens.
11. I explicitly teach my students argumentation skills.
12. I facilitate classroom discussions on socioscientific Issues.
13. I incorporate current issues in science into the classroom.
14. The acquisition of argumentation skills is of great importance in the context of socio-scientific issues
15. I am capable of developing a written argument on controversial topics in the context of socioscientific issues.
16. I do not know how to provide students with tools for analyzing and evaluating argumentation skills in the context of science and society.
17. I feel that I have sufficient pedagogical tools to analyze the validity of students' arguments in the context of socioscientific issues.
18. I provide a learning environment that encourages the acquisition of argumentation skills, such as group discussions, debates, mock trials, and more.
19. I would like to focus more on imparting argumentation skills to my students, but I feel that I have not received enough pedagogical tools to do so effectively in various contexts.
20. I struggle to analyze and evaluate my students' arguments in oral discussions.
21. I tend to rely on intuition when evaluating my students' arguments in socioscientific issues.
22. I am capable of constructing oral arguments on controversial topics in socioscientific issues.

Appendix A.2. SSI and Argumentation Pre- and Post-Open-Questions (Translated from Hebrew)

Pre-open-ended questionnaire:

1. Please state two strengths of the discussions you conduct in the classroom and two areas you would like to improve; please provide details as possible.
2. What are the main sources of information from which you draw information about science and society issues? Please provide detailed references to the sources of information, such as citing the names of specific sources, including online newspapers, various websites, printed newspapers, individuals, etc.
3. Please list as many current socioscientific issues that interest you as possible.
4. Please list at least three relevant current socioscientific issues relevant to Israel.
5. Please write down three key criteria that, in your opinion, constitute conditions for socioscientific issues suitable for classroom instruction.

Post-open-ended questionnaire:

1. Indicate whether the professional development provided you with tools for conducting discussions in your classroom. Please specify.
2. Did the professional development make you consider the primary sources from which you gather information on science and society issues? Please elaborate.
3. Did the professional development contribute to expanding the range of science and society issues that you believe you can teach to your students? Please specify.
4. Did engaging with formal and informal logic as methods for judging and evaluating arguments benefit you? If so, please specify in what way.
5. Do you think that after the professional development, you will be able to conduct debates in your classroom? Please elaborate.
6. Please provide comments and suggestions. What would you improve in the PD? Were the assignments reasonable? Would you like more practice or more theoretical foundation? Were there any unnecessary parts in the course? Which content or activities did you enjoy the most?

Appendix A.3. Retention Questionnaire

1. Can you talk about your experience from the professional development in retrospect?

2. Did the professional development change anything in your thinking about the following topics: teaching socioscientific issues, argumentation, and discourse?, If so please elaborate how so.
3. Have you implemented anything practical from the professional development? Can you provide details?
4. Have you taught socioscientific issues lessons since the professional development? If you did, please answer to the following questions: How many lessons did you have during the year? How many academic hours did each lesson last? How long have you prepared for the lesson? What was the lesson about?
5. If you did not implement SSI during the year that followed the PD, can you explain why?
6. Is there anything else you feel is lacking in order to incorporate socioscientific issues in your classroom? Can you provide details?
7. Have you used any of the content uploaded to the professional development website since then?

Appendix A.4. Interview Protocol (Translated from Hebrew)

1. Tell me what you think about integrating science and society issues in science education. Has anything changed after the professional development?
2. In your opinion, who should be responsible for teaching science and society issues? Can anyone besides the science teacher do it?
3. Do you currently teach such issues in your classroom? Can you describe your experience and how it has been for you?
4. What knowledge should a teacher possess in order to teach such issues effectively?
5. What learning strategies should a teacher employ to teach such issues? Will you use these strategies in the future?
6. How do moral and ethical values manifest in current science education in the country?
7. Tell me about the professional development you attended during the summer.
8. Are there any topics that you connected with more strongly?
9. What would you like to see in a professional development program that focuses on such topics?
10. What is your opinion about humanities subjects in schools? Literature, history, civics, music, etc.? Have you once collaborated with a teacher from the humanities?
11. What do you think about the curriculum in the subject you teach?

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