Enhancing Bilingual/ESL Teachers’ STEM Instruction with Targeted Content and Disciplinary Literacy Professional Development: A Study on Knowledge and Practice Outcomes

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Abstract: Background: The increasing presence of English learners (ELs) in U.S. schools underscores the need for effective instructional strategies tailored to their diverse needs, especially in STEM subjects. Previous research primarily focused on self-reported teacher knowledge and specific curricular programs, often neglecting the integration of content and language knowledge. The study aimed to evaluate the impact of a professional development (PD) program aligned with a previously reported teacher training knowledge framework aimed at improving bilingual/ESL teachers’ subject matter knowledge (SMK), pedagogical knowledge (PK), and disciplinary literacy knowledge (DLK).

Methods: This study employed a quasi-experimental design involving 30 teachers in three cohorts, each experiencing different levels of subject matter and disciplinary literacy knowledge. The program was assessed over four time points using multiple-choice tests on math and science knowledge and an instructional strategy rubric to evaluate teaching quality.

Results: Significant improvements were observed in both content knowledge and instructional quality across all cohorts, with the greatest gains in cohorts that started the PD with a focus on SMK. Teachers’ understanding of disciplinary literacy and its integration with subject matter knowledge significantly enhanced their teaching effectiveness.

Conclusions: The findings suggest that structured PD programs that integrate disciplinary literacy with content knowledge effectively enhance teacher professional knowledge and classroom practices. Starting PD with a strong focus on content knowledge prepares teachers to better apply disciplinary literacy strategies, thereby supporting more effective instruction for ELs.

Implications: This study highlights the importance of considering the sequence of professional learning and the integration of content and disciplinary literacy strategies in PD programs. Future PD efforts should focus on these elements to maximize the impact on teacher development and student outcomes in bilingual/ESL settings.

Keywords: STEM education; bilingual education; ESL; professional development; teacher knowledge; disciplinary literacy; instructional quality; English learners

1. Conceptual Framework

The significant and increasing presence of English learners (ELs) in U.S. schools [1] highlights a pressing educational challenge: despite their growing numbers, ELs often receive insufficient instruction in key areas like science and mathematics [2], hindering their academic achievements. As a result, tailoring instruction to accommodate the diverse needs of ELs remains a fundamental issue in education. To address this concern, there is a steady rise in research centered on the professional knowledge required by teachers who educate ELs. This body of work identifies several concepts, including the contextual understanding of ELs and the influence of language and culture in their education [3–6]. This work also largely relies on teacher self-reports of knowledge and practice [7,8] or...
is focused on examining the impact of specific curricular programs designed for ELs learning (e.g., [9,10]). Most of this work does not target equal attention to raising teacher content and language knowledge. This article addresses current research gaps with a test of a previously published teacher training knowledge framework for teachers who serve ELs [11]. A previous publication reported on the initial impact based on two time points of data. The current study reports on complete data assessing the impact of PD aligned to this framework on teacher subject matter knowledge and instructional practice.

In light of current educational reforms emphasizing disciplinary literacy as a key learning outcome, there is a pressing need to articulate and validate a conceptual model that merges disciplinary literacy with disciplinary language practices [5,12,13] and deep conceptual learning [14]. We have described the research informing the model in past work [11,15] and thus only summarize this background here. To be clear, employing the STEM acronym does not suggest a necessary amalgamation of these disciplines. While such integration can enhance instruction, it is not universally applicable across all curricular areas (see [11]). Moreover, although current reforms advocate for the broader integration of crosscutting concepts, it is essential that this integration also supports a deep understanding of each distinct content area.

1.1. Traditional Conceptions of Professional Knowledge Targets

1.1.1. Subject Matter and Pedagogical Knowledge

Our proposed model builds on [16]'s framework for teacher professional knowledge, which identifies three core knowledge types: subject matter knowledge (SMK), pedagogical content knowledge (PCK), and curricular knowledge (CK). SMK encompasses the organization and structural understanding of subject concepts, essentially conceptual understanding. CK involves familiarity with the curriculum and teaching materials appropriate for specific grades, while PCK focuses on the optimal ways to present and frame subject matter to enhance student comprehension [16]. This view considers the organization, construction, and presentation of knowledge, addressing misconceptions along the way. However, instruction based on [16]'s model alone may not fully meet the educational needs of English learners (ELs); PCK must also incorporate knowledge of strategies to engage ELs effectively in classroom activities [17–20]. Furthermore, the role of discipline-specific language knowledge aligned with disciplinary norms, though critical, has been less explored in teacher development studies.

1.1.2. Professional Knowledge for Teachers Who Serve ELs

Previous studies have laid out various frameworks that detail the necessary knowledge, skills, and attitudes for teachers working with ELs, underscoring the pivotal role of language and culture in fostering effective learning environments for these students (e.g., [17,21]). We agree that language and culture should be highlighted in such models. However, we center our framework on cultivating disciplinary content and build upon [16]'s foundational framework, further refined through subsequent research in the fields of mathematics [22,23] and science [24–26]. Pedagogical knowledge (PK), as broadly outlined in [16]'s initial works, encompasses general teaching knowledge, including theories of teaching and learning, in addition to strategies for optimal classroom management [24,27]. PK serves as a crucial element in professional development for content teachers of ELs, aiding them in understanding how students assimilate both content and language, which in turn influences their teaching strategies [28].

Figure 1 illustrates our proposed professional knowledge model for teachers who serve ELs in STEM classrooms (adapted from [11]). Three knowledge domains—subject matter knowledge (SMK), pedagogical knowledge (PK), and linguistics knowledge (LK)—are depicted as three intersecting circles. The intersecting areas between any two circles signify one layer of integration. Thus, the intersection of SMK and PK gives rise to pedagogical content knowledge (PCK). Similarly, English language development strategies (ELD-S) are derived from the amalgamation of LK and PK. Finally, disciplinary literacy
knowledge (DLK) derives from the blending of LK and SMK. We contend that DLK is crucial for grasping abstract content knowledge and engaging in principled disciplinary communication. Therefore, we reason that teachers trained in DLK can improve instructional effectiveness for ELs. Ref. [13] describe a similar concept known as disciplinary linguistic knowledge, which they define as the “knowledge of the academic discourse of a discipline or content area.” This idea aligns with the DLK shown in Figure 1. However, in our model, DLK merges SMK and LK, specifically focusing on the conceptual framework of the discipline. Furthermore, DLK, when supplemented with methods that foster STEM conceptual comprehension, transforms into STEM disciplinary literacy (STEM-DL). Disciplinary literacy knowledge, in our model, expands [13]’s definition by including broader aspects of disciplinary understandings not limited to the linguistic phenomena that give rise to communication norms. In addition to disciplinary linguistics, DLK in our model emphasizes the organization of knowledge (or conceptual understanding) as well as the norms for interacting within the discipline.

![Figure 1](image_url). Professional knowledge domains and amalgamated knowledge domains for science and mathematics teachers who serve ELs. STEM-DL—STEM disciplinary literacy; PCK—pedagogical content knowledge; DLK—disciplinary literacy knowledge; ELD-S—English language development strategies knowledge.

Figure 1 also illustrates the collective knowledge at the intersection of the three overlapping circles (the central point of the Venn diagram), which we term STEM disciplinary literacy or STEM-DL. We argue that STEM-DL is fundamental for addressing both the content and language learning needs of ELs. Our model, which depicts the knowledge encompassing STEM-DL, provides essential details on how professional knowledge signifies advanced expertise among teachers of ELs. Our model stands out from other definitions of disciplinary literacy in professional knowledge (e.g., [13]) due to its focus on knowledge that fosters conceptual understanding within a discipline. Specifically, STEM-DL represents the integration of disciplinary literacy knowledge (DLK), pedagogical content knowledge (PCK), and English language development strategies (ELD-S) in ways that facilitate ELs’ meaningful engagement in classroom activities, an engagement that promotes the acquisition of STEM conceptual knowledge and fosters meaningful interactions within the discipline.
1.1.3. Disciplinary Literacy Knowledge

Understanding the discourse patterns specific to the language use within a discipline, also known as disciplinary literacy knowledge (DLK), provides teachers with an additional layer of professional knowledge [11]. This knowledge helps them (a) provide comprehensible input and (b) identify the most effective scaffolding strategies for individual learners within STEM contexts based on their language needs. We assert that it is essential for teachers to learn how students utilize language within a discipline to communicate and negotiate ideas [29]. This view aligns with recent shifts in content area learning research, which emphasizes how students build knowledge, negotiate meanings, and engage in disciplinary discourse communities (e.g., [20,30–32]). Addressing the linguistic needs of English learners (ELs) within specific disciplines requires teachers to understand how these disciplines communicate and negotiate ideas [33]. This understanding includes linguistic knowledge (LK), which involves understanding the basic units of language, their regular and irregular forms, and their interrelations [34] with broader discourse markers realized in disciplinary practices. Our model integrates these concepts from the perspectives of disciplinary literacy and the development of a deep conceptual understanding of subject matter knowledge, as described below. That is, disciplinary literacy is more than gaining meaning from text or being able to produce written accounts of disciplinary ideas. Thus, disciplinary literacy encompasses a broader scope than mere linguistic analyses of discipline-specific registers. It is also different from [35] in that their model emphasizes a narrower set of semiotic resources in describing the skills students need to achieve disciplinary literacy. The [35] focus is on students’ disciplinary reading and writing skills, appropriately calling attention to receptive skills and underscoring the impacts of core academic language skills. Ref. [35] define this knowledge as understanding “… cross-disciplinary lexical, grammatical, and discourse resources to achieve precision, to pack dense information concisely and, to explicitly mark how ideas are connected” (p. 17). This framing overlaps with our notion of disciplinary literacy but falls short of making direct connections to conceptual understanding or engagement in disciplinary practices, as this work targets the assessment of reading comprehension and not disciplinary knowledge or engagement in disciplinary practices per se. Further, our model gives equal attention to subject-specific language patterns in multiple registers and modalities (see [33]), whereas the [35]’s model predominately targets cross-disciplinary academic language structures. That is, they do not consider non-academic language registers.

1.1.4. Subject Matter Knowledge

Subject matter knowledge, as characterized by Shulman, involves conceptual understanding. Our definition of conceptual understanding involves grasping principles and interconnected concepts within a particular field [36–38]. Moreover, deeper learning is achieved as more relationships within this knowledge are understood. Conceptual understanding develops through the formation of connections that aid in grasping new content and solving problems. These connections include (a) linking prior knowledge of concepts to new information, (b) understanding relationships between various concepts and knowledge of the topic, and (c) integrating different methods of representing information [39–42]. Therefore, it is also essential for teachers to acquire both conceptual subject matter knowledge (SMK) and the corresponding pedagogical knowledge (PK) to assist ELs in forming meaningful connections among concepts [43].

1.1.5. Professional Knowledge at Intersections

In addition to subject matter knowledge (SMK), pedagogical knowledge (PK), and linguistics knowledge (LK), knowledge that reflects the combined knowledge at the intersections of these categories are also important components of teacher professional knowledge [26]. Much of past research has focused on two of the intersections: (1) pedagogical content knowledge (PCK)—which reflects knowledge at the intersection of PK and SMK—and (2) general English language development strategies (ELD-S)—which reflects
knowledge at the intersection of PK and LK [8]. An example of such a focus is the consensus model [44], which emphasizes the integration of CK, PK, and contextual knowledge to form a comprehensive professional knowledge base. PCK is highlighted as a critical component that bridges content and pedagogy, facilitating effective teaching practices tailored to specific topics. As such, PCK includes the knowledge and skill in the delivery of topic-specific instruction in a very specific classroom context. From this perspective, teachers’ beliefs and orientations act as filters and amplifiers, affecting how they interpret and apply their professional knowledge in classroom settings. Thus, knowledge about ELs’ needs is embedded in their beliefs and orientations corresponding to the specific context. Although initial validation studies [26,45] are promising in the monolingual context, whether it is useful for multilingual contexts remains an open question. Further, there is no specific articulation of specific knowledge bases for meeting the needs of ELs, which is needed to be useful for bilingual and multilingual contexts.

We argue the intersection of subject matter knowledge (SMK) and linguistics knowledge (LK or disciplinary literacy knowledge, DLK) provides the necessary specificity for teacher educators. Yet far less research has targeted DLK [13,46]. Ref. [11] present detailed descriptions of the kinds of activities and practices that reflect each of these professional knowledge domains. We stress that opportunities to increase knowledge in these domains will support teachers in making the language for reasoning, arguing, etc., intentional and transparent to ELs [33,47]. To develop professional knowledge for making language explicit to ELs, we draw on systemic functional linguistics (SFL) [48] and our previous work in the development of teacher knowledge in bilingual learning contexts [11,15]. Literacy practices (or genres) are recurrent forms of texts used for specific purposes with predictable organization in structure and linguistic features [49]. To develop knowledge of literacy practices, we used SFL to increase teachers’ understanding of specific linguistic features that vary between genres (e.g., description versus explanation) and clausal-level features that make reasoning and explanation more transparent to students [50–52]. This work is grounded in studies reporting on extensive investigations of classroom disciplinary discourse practices highlighting the necessity of nurturing science communication between teachers. These studies indicate students’ understanding of scientific concepts benefits from the connections between spoken and written scientific discourse (e.g., [18]). Our work with teachers links these practices with the organization of activity and content to facilitate linking concepts that also develop a conceptual understanding of disciplinary ideas. We also emphasize the need to integrate authentic talk among students to increase student agency in the learning process [33,53]. That is, teachers can model and prompt disciplinary discourse, but students need to be given multiple opportunities to negotiate meaning and discourse used in student-to-student interactions. There is also a need to plan for the long-term development of concepts in authentic contexts, which can be supported by consistent enactment and reflection, as [47] have shown, but a focus on disciplinary knowledge is also needed to provide equal attention to building connections to maximize the development of disciplinary concepts.

1.1.6. STEM-DL

To effectively enhance both conceptual content and language learning for English learners (ELs), teachers need well-developed knowledge that integrates the three domains in our model: pedagogical knowledge (PK), linguistic knowledge (LK), and subject matter knowledge (SMK). We define this integrated knowledge as STEM disciplinary literacy (STEM-DL). This type of knowledge transformation is essential for teachers to provide ELs with access to the curriculum in ways that support conceptual learning and engage them as active members of a discourse community. Aligning with [16,54]’s original concept of SMK, understanding how knowledge is justified involves mastery of the language used for making claims and constructing arguments that are recognized within the specific domain and discourse community. Therefore, engaging in science and mathematics not only requires an understanding of how concepts link through discipline-specific principles
but also a comprehension of the discourse patterns that mirror the norms of communities of practice, or ‘talking science and mathematics’.

From this perspective, language is not merely a static element to be acquired by learners but an active force that significantly shapes learning [55–59], particularly through activities designed to amplify the diverse voices present in interactions [60,61]. We consider science and mathematics practices as the application of knowledge that demonstrates an understanding of how knowledge is organized, constructed, and justified within these subjects. Students need to develop this kind of knowledge to meaningfully engage in activities and to reflect on how these activities connect with past experiences and can be applied to new situations [62,63]. That is, teachers need to be able to create classroom environments that support disciplinary sense-making, a skill that requires knowledge reflected in the intersectionality of each of the three types of professional knowledge, STEM-DL—and utilized for instructional decision-making (e.g., content organization, scaffolding approaches, and content specific feedback).

1.2. Study Context

Given this conceptual framework, the primary purpose of the study was to test the impact of PD aligned with this framework on teacher knowledge and instructional practice. Three cohorts of teachers participated in different forms of this PD experience: the first cohort started with a focus on developing subject matter knowledge, SMK (SMK + DLK); the second cohort started with a focus on developing disciplinary literacy knowledge (DLK + SMK); and the third cohort started with a focus on developing subject-specific pedagogical knowledge, PCK (PCK + DLK). All cohorts received DLK content, but only the first two cohorts received PD aimed to develop SMK. Given that DLK is the amalgamation of SMK and LK, the third cohort received some SMK content in the context of understanding disciplinary language practices. However, cohorts 1 and 2 received extensive and explicit mathematics and science content instruction, whereas the cohort 3 (PCK + DLK) PD group received more PCK content instead of focused subject matter content. Since our model emphasizes professional knowledge for developing deep content knowledge, we compared the effect of different levels of subject matter exposure on teacher outcomes. We reasoned that doing so was appropriate because understanding the nuances of disciplinary literacy requires deep understanding and experience with the content. We also examined the impact of the sequence of instructional content by varying what professional knowledge was addressed first, SMK (cohort 1) or DLK (cohort 2). We expected these groups would result in initial differences in content and instructional impact, but these differences would dissipate by the end of the PD experience.

We define instructional quality as the degree to which teachers offer ELs meaningful opportunities to learn (OTL) targeted content. OTL is described as “equitable conditions or circumstances within the school or classroom that facilitate learning for all students” [64] (p. 260). In environments with ELs, OTL involves addressing instructional factors that (a) reduce language demands while still conveying essential ideas, concepts, and their interrelations, (b) equip students with strategies to understand the linguistic input they encounter, enhancing their comprehension, and (c) create opportunities for them to produce content-related linguistic output in their second language [53,64]. Previous research has demonstrated that these instructional factors can boost ELs’ engagement, perseverance, and academic success [33,62].

The hypotheses we examine are as follows:

1. Increased opportunities to develop subject matter knowledge (SMK) lead to further improvements in teaching quality;
2. Professional development that enhances teachers’ disciplinary literacy knowledge (DLK) improves teaching quality.
2. Methodology
2.1. Participants and Design

The Mathematics and Science Training for Teachers of English Learners (MaSTTEL) project involved 30 teachers who worked with mainstream and English learner (EL) students in the southwestern panhandle of the USA. Of these, 29 taught at the elementary level, while one taught 7th-grade science. This middle school teacher was included in the study because the 7th-grade science curriculum aligns with certain elementary science concepts, especially in biology. The teachers reported an average of 6.98 years of teaching experience, with a range from 1 to 28 years. Among the elementary teachers, 25 held certifications in bilingual education or English as a second language (ESL). However, the 7th-grade teacher was certified to teach science from fourth to eighth grade but did not have a bilingual or ESL certification. As elementary school teachers, none of the teachers had certifications in mathematics. All participants taught at least five EL students, with the proportion of ELs in their classrooms varying from 31% to 98% and an average of 58%. Teachers were randomly assigned to one of three professional development (PD) experiences: (1) SMK + DLK, (2) DLK + SMK, and (3) PCK + DLK. For cohorts 1 and 2, we varied the order of the subject matter content to see if the sequence affected teachers’ short- and long-term outcomes. Additionally, the timing of each PD session was staggered across academic semesters due to logistical constraints related to the availability of courses. Cohort 1 began their PD in the spring semester, cohort 2 started in the fall semester, and cohort 3 started in the spring of the following year.

To test the research hypotheses, data were collected on instructional quality and subject matter knowledge in mathematics and science for all PD groups. Each cohort was comprised of ten teachers. Data collection occurred at four time points: prior to the start of the PD experience (time 1: T1), after two intensive courses were completed (time 2: T2), after the fourth course was completed (time 3: T3), and after the final course was completed (time 4: T4). A repeated measures design was utilized to investigate the impact of PD focus and sequence on subject matter knowledge and instructional quality.

2.1.1. MaSTTEL Program Components

Since we have described the program components in detail elsewhere [11,15], we provide a brief description of the PD program components presented below.

2.1.2. Content Distinctions among PD Approaches

Table 1 presents professional knowledge targets for each course that distinguished the two PD approaches. Teachers in cohorts 1 and 2 took two courses explicitly targeting deep subject matter knowledge (SMK): one course targeting STEM disciplinary literacy knowledge (STEM-DL), another targeting interdisciplinary science, and one centered on assessment practices. In the content courses, mathematics and science professors worked with education professors to develop teachers’ SMK in ways that reinforced inductive reasoning and conceptual understanding, as well as targeted the content outlined in state content standards for elementary and middle school students (through eighth grade). Teachers in cohort 3 took two courses targeting both pedagogical knowledge (PK) and pedagogical content knowledge (PCK) instead of the subject matter content. These courses targeted both strategies for integrating ELs in activities, namely comprehensible input and scaffolding strategies. The remaining three courses mirrored those that cohorts 1 and 2 completed on targeting DLK, interdisciplinary science, and STEM assessment.

All PD cohorts completed one course targeting LK and DLK by targeting knowledge of discipline-specific discourse patterns and strategies that supported the development of disciplinary literacy. This course focused on developing teacher knowledge of linguistic elements found in language functions of science and mathematics (e.g., description, explanation, argumentation, etc.). The goal of this course was to raise teachers’ linguistic knowledge so that focused instructional attention was given to strategies that go beyond key vocabulary and modified text to scaffold language (e.g., [52,62,65]). Thus, the intent
was to develop teachers’ knowledge of language functions that would empower them to develop lessons targeting a language-based approach to teaching deep disciplinary content when combined with sufficient SMK. It is insufficient to merely identify and provide discipline-specific strategies to teachers. Professional development should also emphasize teachers’ goals for students’ literacy learning and how their implementation of strategies may vary based on these objectives [66]. The assumption we make is that teachers need both deep subject matter and disciplinary literacy to transform that knowledge to increase student OTL STEM-DL content. Thus, we expected the course to work differently depending on whether or not teachers received PD focused on developing SMK. In other words, we expected cohorts 1 and 2 to yield stronger teacher growth in SMK than in cohort 3 because those who received the SMK content would have two sources of content knowledge: (a) the content courses and (b) the DLK course. Recall that DLK is the amalgamation of SMK and LK.

Table 1. Targeted professional knowledge by program course and PD cohort.

<table>
<thead>
<tr>
<th>Course</th>
<th>Professional Knowledge Target</th>
<th>Order</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Math for Elementary Teachers</td>
<td>Science SMK relevant for elementary and middle school content</td>
<td></td>
<td>1</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>2. Science for Elementary Teachers</td>
<td>Mathematics SMK relevant for elementary and middle school content</td>
<td></td>
<td>2</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>3. STEM DL</td>
<td>DLK: linguistic mechanisms for math and science genres; description, explanation, argumentation, justification for teaching conceptual content</td>
<td></td>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>4. Interdisciplinary Science</td>
<td>approaches to develop specific science and mathematics conceptual content targets</td>
<td></td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>5. STEM Assessment</td>
<td>monitor ELs developing DLK to support talking and doing science and mathematics.</td>
<td></td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>6. Current Trends in Mathematics Instruction</td>
<td>PK and PCK: problem-based pedagogical approaches to develop specific mathematics conceptual content targets</td>
<td></td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
</tbody>
</table>

Note: C—cohort; C1—SMK + DLK; C2—DLK + SMK; C3—PCK + DLK. Each cohort took five courses. The numbers refer to the order of the courses taken for each cohort.

2.1.3. Focused Feedback

All teachers were given the chance to critically reflect on their teaching practices [11,67]. Instructors of the course, the project’s instructional coach, and the teachers themselves used web-based resources to document lessons and reflect on their practice at various times throughout their participation in the program. This setup enabled ongoing feedback on their teaching, allowing teachers to reflect on their growing skills to engage ELs effectively in math and science and to share their progress and obstacles with peers. This continuous reflection and feedback process was supported by the English Learner Instructional Strategy Rubric (ELISR, described below), which guided the evaluation of their teaching methods.

2.2. Instruments

2.2.1. Content Knowledge in Mathematics and Science

Teacher content knowledge was evaluated using multiple-choice exams based on the Texas Essential Knowledge and Skills (TEKS) for mathematics and science previously developed [11,15]. The test items were sourced from publicly available state student accountability assessments and teacher certification exams. This method was chosen due to the unavailability of other suitable measures of subject matter knowledge (SMK) for public use or because they were not tailored for elementary school educators. The teacher certification assessments (TExES) in Texas mirror the format of student tests, providing
a broad range of items for constructing our project-specific assessment. After selecting potential test items, they were reviewed and rated by a panel consisting of teachers, district administrators, and researchers to ensure they matched the content taught in third through eighth grades [15].

The final mathematics test comprised 40 multiple-choice questions and took about one hour to complete, corresponding to five strands from the TEKS: numbers and operations (10 items), patterns and algebraic thinking (8 items), geometry (11 items), measurement (6 items), and probability and statistics (5 items). These items spanned content from kindergarten through eighth grade. The overall reliability of the test was confirmed by a Cronbach’s alpha of 0.89 (n = 32), with subscale reliability ranging from 0.75 to 0.80.

Similarly, the science knowledge assessment was crafted using publicly released test items and reviewed for alignment by an expert panel. It included 44 questions across four TEKS domains: matter and energy (11 items), force, motion, and energy (12 items), earth and space (10 items), and organisms and environment (11 items). The distribution of these items reflects the focus areas most prevalent in elementary-level science. The overall reliability for the science measure was slightly lower than the math test at a Cronbach’s alpha of 0.79 (n = 30), with acceptable reliability. Subscale reliabilities varied from 0.60 to 0.70, indicating usefulness for program evaluation. This science test also assessed knowledge from kindergarten through eighth grade standards.

2.2.2. English Learner Instructional Strategy Rubric (ELISR)

The quality of instruction was evaluated using the ELISR [11,15], a scoring framework with 12 dimensions developed from research on the impact of opportunities to learn (OTL) on English learner (EL) achievement [53,64]. The ELISR measures changes in classroom practices that enhance ELs’ learning opportunities. It includes six dimensions focused on ELs OTL variables such as objectives, differentiation, comprehensible input, scaffolding, feedback, and assessment. Another five dimensions assess teachers’ facilitation of conceptual understanding, encompassing higher-order thinking skills, prior knowledge, content knowledge, academic literacy, and questioning.

The academic literacy and questioning dimensions particularly aim to enhance students’ reflective and communicative capacities, making their thought processes visible and fostering meaningful interactions around ideas and problems [68–70]. For instance, academic conversations help ELs engage in discourse to articulate claims, respond to evidence, and present counterarguments, thereby contextualizing language use within academic tasks [33,61,71]. Additionally, classroom management is included in the ELISR, as effective management is essential for creating an optimal learning environment and is associated with positive academic, behavioral, and emotional outcomes [72,73]. Thus, these communication and management strategies are needed to foster deep conceptual understanding and maintain student engagement and persistence.

Nine of the ELISR dimensions comprised four instructional behaviors (items) scored on four-point Likert scales ranging from 0, representing “no evidence”, to 3, representing “consistent evidence”. The remaining three ELISR dimensions comprised three instructional behaviors scored on a four-point (0 to 3) Likert scale. Thus, the total possible score for this measure is 135.

2.2.3. Scoring Recorded Lessons

Six graduate students from the research team (four were former elementary teachers and one a former high school teacher) viewed the video-recorded lessons and made judgments for each dimension of the ELISR. Training on the ELISR began with a careful review of the scoring guidelines. For each dimension, video recordings of instruction that reflected examples and non-examples of instructional qualities were presented to contextualize the dimension qualities. Following this discussion, raters viewed three videos and scored them individually. Scores were shared, and discrepancies were discussed until a consensus was reached. For each dimension, the percentage of exact-score agreement was based on the
sum of the scores for the process items that comprised each dimension. Percentage exact-score agreement is a rough measure of agreement because it does not take into account the percentage of agreement due to chance [74]. Therefore, the percentage of exact-score agreement is an inflated reliability estimate. A more accurate index of reliability is the Kappa coefficient, as it does take into account chance agreement [74]. The percentage of exact score agreement for the 12 dimensions ranged from 79% to 85%, and Kappa coefficients from 0.67 to 0.81; agreement for the total score was 0.95 (all dimensions combined). These indices indicate strong inter-rater reliability [74]. In light of the favorable reliability observed, the ELISR appears to be a reliable measure of the quality of instruction for ELs.

3. Results and Analysis

The analysis employed three general linear model (GLM) analyses with repeated measures to evaluate the impact of professional development (PD) experiences on teacher knowledge and teaching effectiveness across four time points (T1 to T4) and among three PD cohorts. Teachers were grouped into three cohorts, each receiving different sequences of subject matter knowledge (SMK), disciplinary literacy (DLK), and pedagogical knowledge (PK) training. Descriptive information is provided in Table 2. The analyses provided insights into both time and cohort effects on each dependent variable, as well as the interaction between cohort and time.

Table 2. Descriptive data for each dependent variable by PD group.

<table>
<thead>
<tr>
<th>PD Type</th>
<th>Time 1</th>
<th>Time 2</th>
<th>Time 3</th>
<th>Time 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mathematics Content Knowledge</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMK + DLK (^a)</td>
<td>25.40 (0.38)</td>
<td>30.40 (1.52)</td>
<td>36.10 (1.02)</td>
<td>37.80 (0.63)</td>
</tr>
<tr>
<td>DLK + SMK (^b)</td>
<td>24.30 (0.38)</td>
<td>25.90 (1.52)</td>
<td>35.90 (5.70)</td>
<td>38.30 (0.63)</td>
</tr>
<tr>
<td>PK + DLK (^c)</td>
<td>24.30 (0.38)</td>
<td>28.90 (1.52)</td>
<td>28.90 (1.02)</td>
<td>29.80 (0.63)</td>
</tr>
<tr>
<td></td>
<td>Science Content Knowledge</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMK + DLK</td>
<td>26.60 (0.26)</td>
<td>29.9 (1.05)</td>
<td>34.70 (1.21)</td>
<td>42.40 (0.24)</td>
</tr>
<tr>
<td>DLK + SMK</td>
<td>26.80 (0.36)</td>
<td>31.80 (1.05)</td>
<td>39.40 (1.20)</td>
<td>43.20 (0.24)</td>
</tr>
<tr>
<td>PK + DLK</td>
<td>27.00 (0.26)</td>
<td>34.40 (1.15)</td>
<td>30.40 (1.19)</td>
<td>30.21 (1.24)</td>
</tr>
<tr>
<td></td>
<td>Instructional Effectiveness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMK + DLK</td>
<td>56.30 (5.50)</td>
<td>95.70 (4.65)</td>
<td>102.40 (2.78)</td>
<td>111.50 (9.54)</td>
</tr>
<tr>
<td>DLK + SMK</td>
<td>53.96 (5.06)</td>
<td>65.15 (4.64)</td>
<td>100.10 (2.78)</td>
<td>119.20 (6.53)</td>
</tr>
<tr>
<td>PK + DLK</td>
<td>61.10 (5.16)</td>
<td>71.35 (4.65)</td>
<td>76.30 (2.78)</td>
<td>82.90 (6.53)</td>
</tr>
</tbody>
</table>

Note: Numbers in parentheses are standard errors. Sample sizes: PD \(^a\) = 10, PD \(^b\) = 10, and PD \(^c\) = 10.

3.1. Impact on Math and Science Knowledge

3.1.1. Time Main Effects

The main effect of time was significant for both content knowledge measures, indicating a change in knowledge scores across the four time points: \(F(3, 81) = 164.08, p < 0.001\), partial \(\eta^2 = 0.861\) and \(F(3, 81) = 175.76, p < 0.001\), partial \(\eta^2 = 0.86\) for math and science knowledge, respectively (Table 3). These results suggest development in math and science knowledge, with significant variation at different stages of the measurement period irrespective of training group. Post hoc comparisons show that each of the pairwise comparisons (T1→T2; T2→T3; T3→T4, etc.) were statistically significant for both science and math, all \(p\)-values’s < 0.001. Figure 2 presents the main effects of the grouped estimated marginal means. The growth in science knowledge (T4 mean = 38.6 of 44 or 87.73% correct) was comparable to the math knowledge growth (T4 mean = 35.30 of 40 or 88.25% correct).
Table 3. Results for math knowledge, science knowledge, and instructional effectiveness (n = 30).

<table>
<thead>
<tr>
<th>Source</th>
<th>Mathematics Knowledge</th>
<th>Science Knowledge</th>
<th>Instructional Effectiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sum of Squares</td>
<td>df</td>
<td>Mean Square</td>
</tr>
<tr>
<td><strong>Within Subject Effects</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>2138.87</td>
<td>1.32</td>
<td>1621.48</td>
</tr>
<tr>
<td>Time × Cohort</td>
<td>486.68</td>
<td>2.64</td>
<td>184.48</td>
</tr>
<tr>
<td>Error</td>
<td>351.95</td>
<td>35.62</td>
<td>9.88</td>
</tr>
<tr>
<td><strong>Between Subject Effects</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cohort</td>
<td>417.65</td>
<td>2</td>
<td>208.83</td>
</tr>
<tr>
<td>Error</td>
<td>696.85</td>
<td>27</td>
<td>25.81</td>
</tr>
</tbody>
</table>

Figure 2. Time and cohort main effects on content knowledge measures and the ELISR. Note: For the Content Knowledge graph, the different patterns reflect the two content areas; the different patterns in the ELISR means reflect the three different PD experiences. * p-value < 0.05; ** p < 0.01.
3.1.2. Cohort Main Effects

The main effects of the PD cohort on math and science knowledge were also statistically significant (Table 3), reflecting variations in content knowledge growth across different PD cohorts: F(2, 27) = 8.09, p = 0.002, partial η² = 0.374 and F(2, 27) = 16.78, p < 0.001, partial η² = 0.554 for math and science content measures, respectively. This indicates that the type of PD a participant received significantly affected their math and science knowledge scores. Post hoc comparisons revealed that cohorts 1 (SMK + DLK) and 2 (DLK + SMK) math scores were not significantly different, but differences between cohorts 1 and 2 (SMK + DLK and PK + DLK) and cohort 3 (PCK + DLK) were significantly different. Also evident from Figure 3 is that all individual participants in cohorts 1 and 2 increased their content knowledge. However, the development of content knowledge for cohort 3 was stagnant for many of the participants, particularly for the science scores.

![Graphs of Math Scores, Science Scores, ELISR Total Scores, and Academic Literacy](image)

**Figure 3.** Individual scores by cohort and time for each dependent variable.

3.1.3. Time by Cohort Interactions

The interaction between time and cohort was also significant for both content areas, which indicates different trends in content knowledge progression among cohorts, F(6, 81) = 18.67, p < 0.001, partial η² = 0.58 for math, and F(6, 81) = 43.59, p < 0.001, partial η² = 0.76 for science. These interaction effects suggest the increase in content knowledge over time is not uniform across cohorts; differences are likely attributable to varying PD experiences. Figure 4 reveals that cohorts 1 and 2 (two groups that received strong subject matter PD) outperformed the cohort 3 PD group that did not receive content support (PCK + DLK group) at T3 and T4. At T2, cohort 1 (SMK + DLK) had the highest math mean, as expected, because this group had the most math SMK exposure at T2. However, we also expected cohort 2 to outperform cohort 3. However, this pattern was not observed, suggesting that the math PCK with disciplinary literacy content at T2 supported teachers’ math content knowledge growth more than it supported cohort 2 (DLK + SMK) knowledge. At T2, this group only received the disciplinary literacy training and science SMK training. Still, the cohort 3 science mean was also higher than cohort 2 even though they
had received only DLK and PCK at this point, suggesting that the PCK and DLK training better supported short-term gains in teacher content knowledge. However, by T3, math and science data trends are consistent with our hypotheses. Cohorts 1 and 2 consistently outperformed cohort 3 (PCK + DLK). Also, as expected, the differences between Cohorts 1 and 2 diminished over time. On the other hand, the difference in teacher outcomes between cohorts 1 and 2 and cohort 3 grew, favoring the first two cohorts who received both subject matter knowledge and disciplinary literacy knowledge.

Figure 3. Individual scores by cohort and time for each dependent variable.

3.1.3. Time by Cohort Interactions

The interaction between time and cohort was also significant for both content areas, which indicates different trends in content knowledge progression among cohorts, \( F(6, 81) = 18.67, p < 0.001, \) partial \( \eta^2 = 0.58 \) for math, and \( F(6, 81) = 43.59, p < 0.001, \) partial \( \eta^2 = 0.76 \) for science. These interaction effects suggest the increase in content knowledge over time is not uniform across cohorts; differences are likely attributable to varying PD experiences. Figure 4 reveals that cohorts 1 and 2 (two groups that received strong subject matter PD) outperformed the cohort 3 PD group that did not receive content support (PCK + DLK group) at T3 and T4. At T2, cohort 1 (SMK + DLK) had the highest math mean, as expected, because this group had the most math SMK exposure at T2. However, we also expected cohort 2 to outperform cohort 3. However, this pattern was not observed, suggesting that the math PCK with disciplinary literacy content at T2 supported teachers’ math content knowledge growth more than it supported cohort 2 (DLK + SMK) knowledge. At T2, this group only received the disciplinary literacy training and science SMK training. Still, the cohort 3 science mean was also higher than cohort 2 even though they had received only DLK and PCK at this point, suggesting that the PCK and DLK training better supported short-term gains in teacher content knowledge. However, by T3, math and science data trends are consistent with our hypotheses. Cohorts 1 and 2 consistently outperformed cohort 3 (PCK + DLK). Also, as expected, the differences between Cohorts 1 and 2 diminished over time. On the other hand, the difference in teacher outcomes between cohorts 1 and 2 and cohort 3 grew, favoring the first two cohorts who received both subject matter knowledge and disciplinary literacy knowledge.

Figure 4. PD cohort by time interaction effects for each dependent variable.

3.2. Impact on Instructional Practice

3.2.1. Time Main Effects

The main effect of time was significant for the ELISR measure, indicating a change in instructional effectiveness scores across the four time points: \( F(3, 81) = 145.50, p < 0.001, \) partial \( \eta^2 = 0.843 \). Like the time main effects for content knowledge, the ELISR suggests increases in instructional effectiveness over time, with significant variation at different stages of the measurement period irrespective of the training group. Post Hoc comparisons show that each of the pairwise comparisons (T1→T2; T2→T3; T3→T4) were statistically significant, all \( p \)-values < 0.001. Figure 2 presents the main effects of the grouped estimated marginal means. Regardless of the PD group, consistent growth in instructional effectiveness was observed.

3.2.2. Cohort Main Effects

The main effects of the PD cohort on science and math instruction were also statistically significant, reflecting variations in instructional effectiveness across the different PD experiences, \( F(2, 27) = 8.17, p < 0.001, \) partial \( \eta^2 = 0.377 \). As presented in Figure 2, ELISR scores for cohorts 1 and 2 were significantly higher than cohort 3 scores. This finding suggests that a focus on content is important for elevating teacher science and mathematics practice as measured by the ELISR. The difference in ELISR scores between cohorts 1 and
2 was not statistically significant. Figure 3 illustrates that all individual participants in these two cohorts increased their ELISR scores. However, the individual development of instructional practice for cohort 3 was stagnant for many of the participants, and most did not grow at the same rate as the teachers in the other two cohorts.

3.2.3. Time by Cohort Interaction

The interaction between time and cohort for the ELISR scores was also significant, which indicates different trends in instructional effectiveness over time among the PD cohorts, $F(6, 81) = 19.05, p < 0.001$, partial $\eta^2 = 0.585$. This interaction effect suggests the increase in instructional effectiveness over time is not uniform across PD cohorts; differences are likely attributable to varying PD experiences. As depicted in Figure 4, although there were initial differences (T2) in PD impact on instructional effectiveness, the differences between cohorts 1 and 2 faded at T3 and T4. In addition, the differences between these groups and cohort 3 widened, paralleling the trends found for math and science content knowledge. Although all the groups grew from T1 to T4, cohorts 1 and 2, who received strong subject matter PD and disciplinary literacy PD, showed the greatest instructional gains over time, suggesting that both subject matter and disciplinary literacy supported teacher growth in instructional effectiveness more than cohort 3 who did not receive subject matter content. However, we do not want to diminish the observed increase in teacher effectiveness for cohort 3, which suggests that the PCK coupled with DLK can improve instruction, although the growth rate is greatly reduced.

Given the strength of the impacts of cohorts 1 and 2 PD and the argument we make about the importance of DLK on teacher practice, we also examined the time by cohort interaction for the academic literacy dimension of the rubric (Figure 4). The interaction between time and cohort was also significant, which indicates different trends in academic literacy instruction over time among the PD cohorts, $F(6, 81) = 14.40, p < 0.001$, partial $\eta^2 = 0.516$. Post hoc analysis indicates the significant difference was mostly attributable to the increase in score between T2 and T3 for cohorts 1 and 2 but not for cohort 3. Further, the cohort 3 trend line does not increase after T2, but increases are observed for cohorts 1 and 2 between T2 and T3. The increases for cohort 1 continue to increase from T3 to T4 but tappers off for cohort 2. These trends support the idea that a more developed SMK is needed to fully support DLK in STEM instruction.

4. Conclusions

This study provides important insights relevant to identifying effective strategies for enhancing teacher knowledge and instructional quality. Consistent with our hypotheses, the findings demonstrate teachers who participated in PD programs integrating both subject matter knowledge (SMK) and disciplinary literacy knowledge (DLK) exhibited notable improvements in their content knowledge and teaching practices, particularly when the PD sequence began with a focus on SMK. These results provide additional evidence of the importance of well-structured PD programs that not only emphasize the integration of content knowledge and pedagogical strategies but also consider the sequence in which these elements are introduced. By starting with a strong foundation in subject matter, teachers in this study appeared to be better prepared to incorporate disciplinary literacy techniques, which in turn enhanced their ability to support English learners (ELs) effectively in STEM subjects.

5. Discussion

5.1. Integration of Disciplinary Literacy and Subject Matter Knowledge

The findings from this study indicate significant improvements in both subject matter knowledge and instructional quality for teachers who participated in the PD programs, emphasizing both disciplinary literacy knowledge (DLK) and subject matter knowledge (SMK). These results reinforce the claim that effective PD should target not only evidence-based pedagogical content strategies but also the specific content knowledge teachers
need to effectively instruct English learners (ELs) in STEM disciplines. Cohort 1 and 2 teachers (SMK + DLK and DLK + SMK) were engaged in extended SMK content. The superior performance of these teachers over cohort 3 teachers suggests that integrating these domains fosters a deeper conceptual understanding and a more robust instructional approach. These results also support our assertions as well as those made by other scholars (e.g., [16, 26, 75]) regarding the importance of knowledge at the intersection of content and pedagogy. This study builds on this early work by identifying specific knowledge targets for teachers who educate ELs, namely disciplinary literacy knowledge. Recall that DLK reflects the transformation of knowledge of subject matter knowledge, pedagogical content knowledge, and English language development strategies. If academic language is to serve as a semiotic recourse across content classrooms [35], teachers need to gain knowledge in DLK and SMK through sustained engagement with disciplinary content as well as opportunities for enactment and reflection [47].

Further, these results are consistent with research from the content and language integrated learning (CLIL) approach demonstrating how bilingual education frameworks can significantly enrich both SMK and DLK by treating language and content as co-constitutive rather than separate educational goals [57, 58, 76, 77]. These methods align well with the CLIL-based strategies that focus on the interplay between form and meaning negotiation in bilingual settings, potentially leading to stronger and more sustained gains in both teaching efficacy and subject understanding [56, 77]. Our focus on disciplinary literacy is important and reinforced by these results. However, such a focus should not be taken to mean that formal disciplinary literacy should supplant the importance of starting with everyday language use for understanding complex ideas and phenomena. Doing so would restrict teachers’ ability to provide comprehensible input to ELs, which is a well-established effective ELD approach [78], one that was promoted in the PD provided to participating teachers. A rigid approach to STEM-DL for content learning also conflicts with findings from sociolinguistics that have shown everyday language is an important tool for developing a shared understanding of math and science practices [37, 65, 79] and is important for fostering translanguaging to enhance content learning by integrating multiple languages (and language varieties) and semiotic resources (drawing, gesture, code, and the extralinguistic context) [63] in disciplinary practices.

Thus, there is value in fostering dynamic and flexible language practices in bilingual communities. Teacher development programs should not only sequence and integrate SMK and DLK but also actively incorporate translanguaging strategies to leverage the full linguistic repertoire of students [80]. This approach would support teachers in utilizing all available modalities and languages to improve comprehension and engagement among ELs. Incorporating translanguaging practices by leveraging the full linguistic and semiotic resources available to teachers could further enhance this integration, suggesting that PD should also prepare teachers to use multimodal and multilingual strategies to facilitate learning [63].

5.2. Role of Sequence in Professional Development

The study also explored the sequence in which professional knowledge components were introduced in the PD program. It appears that sequence may also matter for teacher development. The findings suggest that starting PD with a focus on subject matter (SMK) before introducing disciplinary literacy (DLK) may lead to more pronounced gains in teacher knowledge and teaching efficacy in the early stages of the PD, but the difference dissipates as they complete additional PD emphasizing blending of disciplinary pedagogical knowledge and linguistics knowledge or ELD strategies relevant for math and science instruction. This pattern highlights the foundational role of robust subject knowledge in enabling teachers to apply disciplinary literacy strategies more effectively, a principle that can inform the structuring of future PD efforts [19]. Additional research should examine this further, as CLIL research has demonstrated that the timing and sequence of language and content integration greatly influence learning outcomes [77].
5.3. Implications for English Learners’ STEM Learning Opportunities

The significant improvements in instructional quality, as measured by the English Learner Instructional Strategy Rubric (ELISR), underscore the potential for well-designed PD to enhance the engagement of ELs in STEM instruction as well as learning outcomes. By providing teachers with both the language tools and the content understanding necessary for STEM education, PD programs can contribute to creating more inclusive and effective learning environments for ELs [55,63]. This finding aligns with current educational priorities to ensure equitable learning opportunities and could inform policy and practice on a broader scale. The results of this study imply that PD efforts that do not target subject matter knowledge may restrict impacts on teacher practice and knowledge. The data trends show that all three PD experiences do improve teacher outcomes, but the meaningful transformation of teacher practice happens over an extended period of focused attention on STEM-DL. At a minimum, the almost exclusive focus on pedagogical content knowledge (PCK) for content area PD or English language development strategies (ELD-S) for multilingual contexts, provided by well-intentioned district curriculum leaders, may contribute to the persistent gaps in ELs STEM achievement.

5.4. Limitations and Future Research Directions

While this study presents compelling evidence of the benefits of integrating subject matter knowledge and disciplinary literacy in professional development, there are limitations that should be considered when interpreting the findings. One key limitation is the study’s generalizability, as it was conducted within a specific demographic and geographic context, potentially limiting the applicability of the results to other settings with different student populations or educational environments. Further compounding the generalizability issue is the sample size. With only 30 teachers participating, the sample size is relatively small, which may affect the robustness and generalizability of the findings. Small sample sizes can increase the margin of error and reduce the statistical power of the study, potentially leading to less reliable conclusions. Future research should aim to include larger and more diverse samples to enhance the validity and applicability of the results.

Another limitation is the reliance on project-developed measures to evaluate changes in science and math content knowledge and instructional effectiveness. While these measures demonstrated adequate technical quality for assessing teacher growth, they might not capture all nuanced aspects of instructional practice, such as teacher–student interactions, the classroom climate, and other informal teaching dynamics that also impact student learning [81,82].

A significant limitation of this study is the absence of a true control group. Without a control group, it is challenging to determine whether the observed improvements in teacher knowledge and instructional quality can be solely attributed to the PD program. Other factors, such as concurrent educational initiatives, school-wide reforms, or external support mechanisms, could also have contributed to the positive outcomes observed. A control group would provide a baseline against which the effects of the PD program could be measured more accurately, isolating the impact of the PD from other variables. Future studies should include a control group to enhance the rigor of the research design. A well-defined control group, which does not receive the intervention, would allow for a more precise comparison of outcomes between teachers who participated in the PD program and those who did not. This comparison would help to attribute changes in teacher knowledge and instructional practice more confidently to the PD program itself. Additionally, having a control group would help in understanding the potential influence of external factors and in ruling out alternative explanations for the observed improvements. Finally, including a control group would also enable the use of more robust statistical analyses, such as difference-in-differences approaches, which could further strengthen causal inferences [83]. This approach would allow researchers to account for pre-existing differences between groups and more accurately measure the impact of the PD program over time.
Moreover, future research should explore the long-term retention of PD benefits and its translation into student achievement to further validate the efficacy of integrating subject matter knowledge and disciplinary literacy knowledge in teacher PD. Longitudinal studies with control groups can provide valuable insights into the sustainability of PD impacts and the ways in which teacher professional growth translates into improved student learning outcomes. Exploring these areas further could help refine PD programs and ensure their effectiveness across a broader range of contexts and educational challenges.

6. Concluding Thoughts

This study contributes to our understanding of the effective components and structuring of PD for teachers of English learners in STEM fields. The integration of subject matter knowledge and disciplinary literacy, especially when properly sequenced, appears to enhance both teacher efficacy and instructional quality. These findings not only support but also extend current educational theories by explicitly linking PD structure to teaching outcomes in the context of bilingual/ESL education. Future efforts should aim to refine these PD models to maximize their impact on teacher development and student success. Moving forward, it will be important for educational researchers and policymakers to consider these findings in the design and implementation of PD programs. Ensuring that PD resources are aligned not only with pedagogical best practices but also with the specific content demands of STEM education will be crucial in meeting the needs of an increasingly diverse student population.

Overall, this research contributes to the field of teacher STEM education, offering an example of how targeted professional development can significantly improve teaching practices and support the academic success of English learners in the critical areas of science and mathematics. As schools continue to diversify, such PD programs will be essential to equip teachers with the skills necessary to ensure all students have the opportunity to succeed in STEM disciplines.

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