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Formation of students' written scientific speech in chemistry: A comparative study of scaffolding strategies

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Abstract

The development of scientific writing in school chemistry represents a crucial direction in modern pedagogy, aimed at fostering students' skills in academic argumentation, meaningful structuring of knowledge, and subject-specific language literacy. In this study, we examine various scaffold strategies (cognitive, linguistic, and hybrid) and propose an original model, SWC (Scientific Writing in Chemistry), which integrates pedagogical and cognitive mechanisms for the formation of scientific writing. Our model is based on a seven-step scaffold support algorithm and combines genre-based, process-oriented, and content-language approaches. A comparative theoretical study has been conducted with visual and tabular verification of the SWC model's effectiveness across key parameters: cognitive load, language support, scientific accuracy, and cross-disciplinarity. We present algorithms, task templates, methodological guidelines, and a risk table. Our findings demonstrate that SWC is a pedagogically balanced and functional model for developing scientific writing in the context of chemistry education.

Keywords: Academic writing, Chemistry education, Cognitive literacy, Genre-based approach, Pedagogical model, Scaffold strategies, Scientific writing, SWC.

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1. Introduction

Modern pedagogy increasingly recognizes the need to integrate language, thinking, and scientific inquiry into a unified cognitive-communicative model. In the philosophy of science [1, 2], it is asserted that scientific knowledge cannot exist outside linguistic form: hypotheses, justifications, experiments, and conclusions all are expressed through language. Thus, scientific writing functions not only as a means of communication but as a form of science itself within educational processes [3, 4].

From a post-structuralist perspective [5], scientific discourse is a regime of truth production within a specific field of power and knowledge. Therefore, accustoming students to scientific discourse in writing is not merely teaching them how to write but introducing them to the epistemological culture of science, its norms, genres, and modes of justification. This is particularly significant in the natural sciences, where language is closely intertwined with logic, formalism, and precision.

In the context of digitalization and the internationalization of education, scientific writing becomes a core component of academic literacy and students' scientific agency. International assessments (e.g., PISA) increasingly require students not only to recall facts but to articulate scientific positions, construct arguments, and use disciplinary language. Thus, fostering scientific writing becomes not only a methodological task but also a sociocultural and ideological one, preparing students for participation in a knowledge-based society. With the growing focus on the humanization and individualization of education, greater emphasis is placed on students' cognitive autonomy and their ability to express personal understanding of subject matter. Scientific writing development involves more than following templates; it fosters reflection, metacognition, and scientific identity [6, 7].

A central concept in our study is scaffolding as a temporary, adaptive pedagogical support that helps students reach higher levels of performance [8]. In the context of writing instruction, we distinguish two types of scaffolding: cognitive scaffolding, which supports logical structuring, argumentation, and concept formation; and linguistic scaffolding, which aids the use of scientific language, genre conventions, terminology, and coherence.

However, this division is largely theoretical. The most effective approaches are hybrid models that integrate both cognitive and linguistic support [9]. In chemistry, a discipline characterized by high levels of abstraction and terminological complexity, such integration is especially critical [10].

Based on this conceptual framework, our study follows three key premises:

- *Scientific writing in chemistry requires both cognitive processing of scientific content and mastery of scientific discourse.*
- *Different types of scaffold support target different components of writing competence.*
- *A comparative analysis of these strategies can help identify the most effective approach for developing students' scientific writing.*

Our central hypothesis is that a hybrid scaffold strategy (cognitive-linguistic) yields higher learning outcomes than one-sided approaches.

Overall, our research is grounded in the sociocognitive theory of writing, Flower and Hayes [11] genre theory, Hyland [12] and sociocultural learning theory. We apply a typology of scaffolding [13], an experimental pedagogical design (pre-post), and a multi-level assessment framework for writing proficiency using four criteria: structural coherence, terminological precision, logical flow, and genre compliance.

Thus, our research philosophy naturally combines pedagogical constructivism, linguistic functionalism, and cognitive writing theory.

2. Literature Review

It is evident that the development of scientific writing in school education is gaining increasing importance due to the need to foster students' critical thinking, scientific argumentation, and the ability to explicitly express knowledge. We believe this task is particularly relevant in science subjects, especially in chemistry, due to the high conceptual density and abstract nature of the material.

Fang emphasizes that science texts possess a specific linguistic style, such as nominalization, passive voice, technical terminology, and logical cohesion, which make them difficult for middle school learners to comprehend. Similarly, Norris and Phillips [14] argue that scientific literacy is impossible without mastery of scientific writing, as it provides the cognitive representation of knowledge.

Dowd et al. [15] demonstrate that scientific writing does not merely reflect content but actively shapes understanding through the recontextualization of knowledge. Yore et al. [16] likewise claim that writing practices stimulate metacognition and scientific reflection.

Scaffolding a pedagogical strategy of step-by-step support for learners was first proposed by Stender and Kaiser [17] and further developed within the framework of content-language integrated learning, Coyle [18]. Reiser [19] distinguishes two key mechanisms of scaffold support: structuring the learning task and problematizing content, both of which help overcome barriers to scientific communication.

Ikawati [20] developed a genre-based pedagogy in which students learn to construct texts by following models of scientific genres. This approach enhances the compositional and logical aspects of writing, thus forming academic literacy.

Martin and Rose [21] developed a genre-based pedagogy in which students learn to construct texts by following models of scientific genres. This approach enhances the compositional and logical aspects of writing, thus forming academic literacy.

On the other hand, the process-based approach Grabe and Kaplan [22] view writing as a stepwise cognitive process involving planning, drafting, revising, and reflecting. While this method has proven effective in developing writing strategies, it often lacks subject or genre specificity.

The integration of content and language (CBI, CLIL) is particularly effective in multilingual and bilingual contexts. Cumming [23] proposed the distinction between BICS and CALP, showing that subject-language literacy requires purposeful pedagogical design. Coyle et al. [24] developed the CLIL model based on the four Cs: Content, Communication, Cognition, and Culture. Brinton et al. [25] introduced Content-Based Instruction as an effective methodology for language acquisition through immersion in subject content.

3. Materials and Methods

This study is theoretical and model-oriented, aiming at a comparative analysis of scaffold strategies in the context of developing students' scientific writing in chemistry. The methodology is based on synthesizing genre-based, cognitive, content-language, and process-oriented approaches, integrated with the concept of instructional scaffolding.

As the main conceptual tool, we designed and validated the SWC (Scientific Writing in Chemistry) model. It is structured around seven logical stages of scaffold support, guiding students from sample analysis to the generation of original scientific texts. These stages align with the ideas of gradually shifting the zone of proximal development, regulating cognitive load, and forming scientific writing competence step by step.

The pedagogical architecture of our model is grounded in:

- *A genre-based approach, fostering scientific metalanguage and compositional literacy;*
- *A cognitive-linguistic framework, informed by the concept of academic CALP-literacy;*
- *The integration of content and language in line with the CLIL approach is especially significant for chemistry, a subject marked by high terminological and conceptual density.*

To justify the SCIWRI model, we drew upon empirical research in scientific writing across STEM disciplines, which has shown that scientific writing not only reflects internalized content but also serves as a tool for rethinking it. Thus, we position SWC as an integrative pedagogical mechanism equally oriented toward the development of subject-specific thinking, academic writing, and students' cognitive agency.

The choice of chemistry as a subject domain is informed by our pedagogical practice, its high level of conceptual abstraction, and linguistic specificity, making it particularly sensitive to scaffold-based teaching strategies (Moje, 2008). Our comparative methods involved expert calibration of writing models based on four key parameters: cognitive load, language support, depth of reflection, and level of student participation.

4. Results

4.1. Scientific Writing in Chemistry

Within the framework of our study, we identified and substantiated the key components, mechanisms, and stages involved in the development of students' scientific writing in chemistry based on a comparative analysis of existing scaffolding strategies. Our results are presented as an integrative model, a description of scaffolding mechanisms, and a pedagogical implementation algorithm adapted for chemistry education.

We developed the SWC (Scientific Writing in Chemistry) model, which conceptualizes scientific writing as the result of integrating three interrelated cognitive-discursive domains. These domains are interpreted as follows:

- *Cognitive component, related to the assimilation of conceptual content, logical relations, and the causal structure of chemical processes;*
- *Linguistic component, involving the mastery of subject-specific terminology, connective language structures, genre-specific expressions, and features of scientific style;*
- *Metadiscursive component, reflecting the student's ability for reflection, textual compositional logic, and articulation of authorial stance.*

Figure 1 presents a block diagram of the SWC model, illustrating the structural organization of scientific writing development. At the top, we identify three core components: the cognitive (conceptual framework, causal logic), linguistic (terminology, connectors, genres), and metadiscursive (text structure, reflection, style).

These are integrated into a unified pedagogical core (SWC model). Through scaffold support, this core is transformed into the target outcome: scientific writing in chemistry.

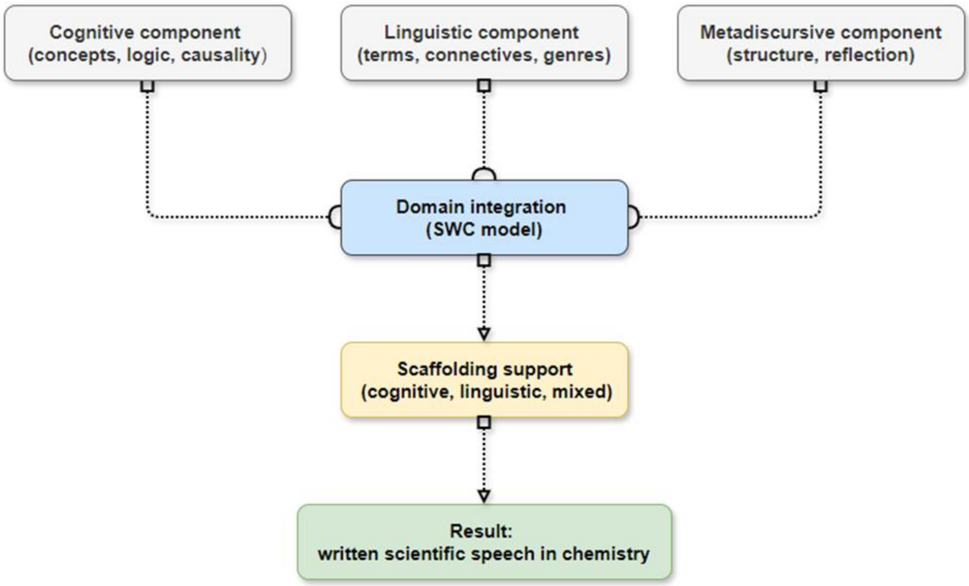

Figure 1.
Block diagram of the SWC (Scientific Writing in Chemistry) model.

As we can see, the model is based on three foundational domains: cognitive, linguistic, and metadiscursive, each of which is autonomous but interconnected.

The central block "Domain Integration" serves as the pivotal point where isolated knowledge and language skills are synthesized into scientific writing. This aligns with contemporary genre-based learning theories [26, 27], which assert that mastery of academic writing requires the coordinated development of both meaning and language.

Integration here is not a mechanical aggregation but a pedagogical construction shaped through tasks, lessons, scaffold support, and learner reflection.

The next block, "Scaffold Support," emphasizes that even with integrated components, students cannot immediately produce scientific texts. They require temporary, adaptive, and gradually reduced support, provided through scaffold interventions.

According to our model, scaffolding acts as a pedagogical transmission mechanism that converts the internal structure of the SWC model into student actions from analysis to writing. This may include:

- *Conceptual mind maps,*
- *Sentence and phrase templates,*
- *Sample scientific paragraphs,*
- *Checklists for structure and logic.*

Such support streamlines the transformation from internal thought to external scientific expression, developing cross-disciplinary literacy.

The final block "Scientific Writing in Chemistry" is not simply a final product, but the result of intentional pedagogical design. Unlike the traditional view of writing as a tool for assessment, SCIWRI sees writing as a tool for conceptualization, structuring, and understanding subject content.

Thus, the model demonstrates that scientific writing does not emerge spontaneously; it must be purposefully cultivated through pedagogical modeling and scaffold support.

Our model redefines scientific writing not as a set of formal linguistic skills but as a complex pedagogical construction that unites subject understanding, verbal expression, and cognitive autonomy.

From the literature and pedagogical practices analyzed, we concluded that scaffolding functions as a temporary conceptual and linguistic framework, supporting the student's transition from oral or fragmented speech to coherent scientific text. In this context, we identified three key types of scaffolding strategies:

Table 1.
Key Types of Scaffolding Strategies.

Type of Scaffolding	Primary Function	Examples of Implementation
Cognitive	Structuring subject content, logic, and concepts	Concept maps, causal chains, and reaction graphs
Linguistic	Mastery of scientific language and genre formulas	Phrase templates, lexical lists, paragraph models
Hybrid	Synthesis of cognitive and language support	Planning + terminology + sample texts

The cognitive scaffold ensures logical rigor and scientific accuracy, but does not always result in clearly articulated, genre-appropriate texts. The linguistic scaffold improves stylistic and structural aspects but, when lacking conceptual grounding, may lead to superficial template repetition. The hybrid scaffold fosters both conceptual precision and genre fluency, enabling the learner to move from semantic anchoring to linguistic autonomy.

Thus, a key proposition of our study is that a linear approach to writing instruction focused solely on lexico-grammatical skills or content knowledge is insufficient.

Our analysis shows that effective scientific writing instruction is possible only through the synthesis of three components: cognitive, linguistic, and metadiscursive.

This aligns with the work of Gibbons [28] who emphasizes the importance of integrating language and content instruction, and with the model of Halliday and Martin [29], which views scientific discourse as a unique form of logical-linguistic activity.

Notably, the greatest potential for holistic writing development lies in hybrid scaffolding, which combines conceptual and linguistic support. This supports Sharma [30]'s assertion that scientific writing in STEM disciplines requires both formalized thinking and mastery of disciplinary language.

The proposed seven-step algorithm (see block diagram) forms a cross-disciplinary trajectory where students gradually enter scientific discourse: from analyzing others' texts to composing their own. This approach is consistent with Vygotsky [31]'s principles of developmental learning, particularly the zone of proximal development, where scaffold support mediates the transition from external regulation to internalized writing control.

At each stage, scaffolding performs distinct functions:

- *Mobilizing conceptual resources (Stages 1–2),*
- *Formalizing thought through speech and writing (Stages 3–4),*
- *Developing reflection and authorial voice (Stages 5–7).*

Thus, we argue that scaffold strategies should not be seen as external aids but as temporary constructs for internalizing meaning.

This allows us to emphasize the novelty of our model:

- *It conceptualizes scientific writing as a cognitive-discursive construction,*
- *Offers a concrete algorithm for scaffold support in chemistry education,*
- *Provides a comparative framework for evaluating strategies across pedagogically meaningful dimensions (content, language, structure, autonomy),*
- *And is adaptable to other subject areas (e.g., physics, biology, geography) with minimal changes to content structures.*

In this context, our model may be used to:

- *Design chemistry lessons and modules focused on written output,*
- *Develop methodological guidelines and task templates,*
- *And integrate scaffold-based strategies into digital platforms (LMS, online environments).*

4.2. Algorithm for Developing Scientific Writing

Based on the SWC model and the mechanisms of scaffold support, we formulated a seven-stage algorithm for developing students' scientific writing in chemistry (Figure 2). This algorithm includes the following components:

1. *Analysis of scientific text samples (genre introduction);*
2. *Identification of key concepts and logical relationships;*
3. *Oral formulation of explanations of phenomena and processes;*
4. *Draft writing of a scientific text fragment following a given structure;*
5. *Editing based on logic, terminology, and coherence;*
6. *Reflection on the structure and language of the text;*
7. *Finalizing the text with gradual scaffold removal.*

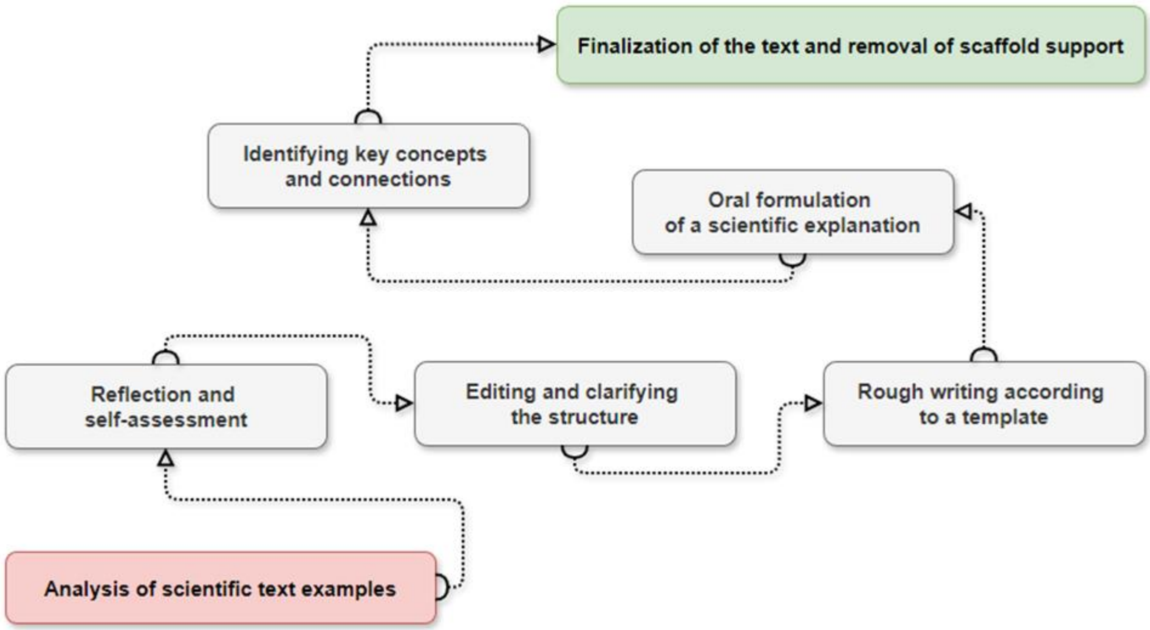

Figure 2.
Algorithm for Developing Students' Scientific Writing in Chemistry.

This algorithm is not a rigid instruction but a flexible pedagogical pathway in which scaffold tools vary depending on the student's level, the topic, and the educational objective.

Based on our analysis of pedagogical literature, curriculum requirements, and linguistic studies, we identified the following key characteristics of scientific writing developed through scaffold support:

- *Terminological precision;*
- *Logical-semantic coherence;*
- *Genre-based structure (introduction, hypothesis, description, conclusion);*
- *Scientific style, including objectivity, generalization, and evidence-based reasoning;*
- *Reflectivity and writing awareness (cross-disciplinary level).*

In the SWC model, these characteristics are viewed as resulting components of scaffold-based pedagogical intervention.

Thus, our theoretical analysis allows us to assert that the development of scientific writing in chemistry requires comprehensive scaffold support that integrates cognitive, linguistic, and metadiscursive elements. The developed model and algorithm can serve as a foundation for future empirical studies, as well as for the design of instructional modules, teaching aids, and digital learning platforms in chemistry.

Accordingly, we offer the following practical recommendations for teachers on implementing our algorithm and model:

- *Integrate scientific writing into each chemistry module as a required learning outcome;*
- *Use cognitive scaffolds (diagrams, tables, causal graphs) before writing begins;*
- *Provide linguistic templates and scientific-style expressions, especially for weaker students;*
- *Encourage oral articulation of scientific content before written formulation;*
- *Apply drafting and step-by-step editing, including peer and self-assessment;*
- *Gradually reduce scaffold support as students become more independent;*
- *Foster integration: text analysis → oral interpretation → written formulation;*
- *Support the development of genre sensitivity: explanation, conclusion, comparison, etc.;*
- *Encourage reflection: ask students to assess not only what is written, but also how it is written.*

These teacher recommendations may serve as effective practical steps for implementing a scaffold-based approach to the development of scientific writing in chemistry classes.

We base our recommendations on the principle of the gradual development of students' writing agency: from scaffold-dependent forms (text analysis, formulaic structures) to scaffold autonomy (finalized texts, independent editing, and reflection). This aligns with Vygotsky [31]'s core concept of the zone of proximal development, where pedagogical support should be temporary, functional, and directed toward growing learner independence.

Therefore, our recommendations:

- *Account for the multi-level nature of student preparedness (scaffold templates should be introduced only where truly necessary);*
- *Emphasize the integration of oral and written forms, helping bridge the gap between thought and linguistic expression;*

- *Highlight the importance of reflective practice, which transforms writing into a tool of scientific awareness, not merely a mechanical activity.*

However, it should be noted that excessive scaffold support may paradoxically suppress writing agency if its gradual removal (defacing) is not implemented.

Inadequate teacher training for implementing an integrated (cognitive-linguistic) approach remains a systemic issue and requires the development of teaching materials and training programs. Ignoring learner diversity can exacerbate skill gaps and demotivation: adaptive scaffold solutions (e.g., tiered supports, flexible templates) must be introduced.

In conclusion, we argue that a justified and phased introduction of scaffold strategies into chemistry instruction can:

- *Enhance the quality of meaningful student writing,*
- *Avoid formalism and "copy-paste" tendencies,*
- *Foster scientific agency and critical thinking through written production,*
- *And bridge the gap between subject content and its linguistic articulation, one of the main challenges in STEM education.*

4.3. Comparative Analysis of Approaches

The SWC model (Scientific Writing in Chemistry) is positioned as a subject-oriented, scaffold-mediated system for developing scientific writing specifically in the context of chemistry. To assess its originality and effectiveness, it is reasonable to compare it with the most influential writing models presented in pedagogical and linguodidactic literature.

Table 2 presents a comparative analysis of the SWC model with other approaches to writing instruction.

Table 2.
Comparative Analysis of Scientific Writing Models.

Criterion	**SWC (this study)**	**Genre-Based Approach (Hyland [26])**	**Process Writing (Flower and Hayes [11])**	**Content-Based Instruction (CBI) (Brinton et al. [25])**
Focus	Integration of chemistry content and scientific writing	Mastery of genre structures of academic texts	Writing as a cognitive and iterative process	Language acquisition through subject content
Type of Scaffold Support	Cognitive + Linguistic + Metadiscursive	Genre schemes, examples, frameworks	Planning, drafts, feedback	Linguistic and thematic support
Writing Stages	7 steps: from text analysis to finalization	Deconstruction – Modeling – Reconstruction	Generation – Organization – Editing – Publishing	Thematic cycle: input – text work – output
Content Integration	Strong; embedded in chemistry lessons	Flexible; may be subject-neutral	Weak; often not discipline-based	Moderate; depends on course design
Target Audience	Grades 8–10, undergraduates	University students	School and university students	School learners and adult L2 students
Assessment Focus	Scientific writing with content precision and genre structure	Genre and register conformity	Cognitive growth and personal style	Language output in content context
Teacher's Role	Facilitator of meaning-language integration	Genre modeling instructor	Process navigator and reviewer	Instructor of subject-language integration

Unlike procedural and genre-based approaches, SCIWRI is grounded in a direct connection to chemistry content rather than formal mastery of a writing genre. This transforms writing from a procedural exercise into a tool for scientific understanding.

Importantly, the SWC model differs in that its scaffolding is not limited to templates or linguistic frames; it includes cognitive support (concept maps, diagrams) and metadiscursive practices (structure, reflection, reader awareness).

In contrast to Process Writing, which emphasizes an open-ended approach, SWC offers a clear pedagogical pathway consisting of seven scaffolded stages, each with its own set of tools and quality criteria.

Content-Based Instruction (CBI) provides thematic context but often lacks deep engagement with academic genres. By contrast, SWC is oriented toward deep scientific writing production within a clearly defined discipline.

The SWC model is not conceptually opposed to existing approaches but represents an integrative extension, adapted to the needs of STEM education, subject-specific scientific literacy, and multi-layered scaffolding in secondary school contexts.

Thus, we regard SWC as a nationally oriented, discipline-specific, and methodologically explicit variation of genre-process writing tailored for educational practice.

Figure 3 presents a radar chart comparing the four writing models.

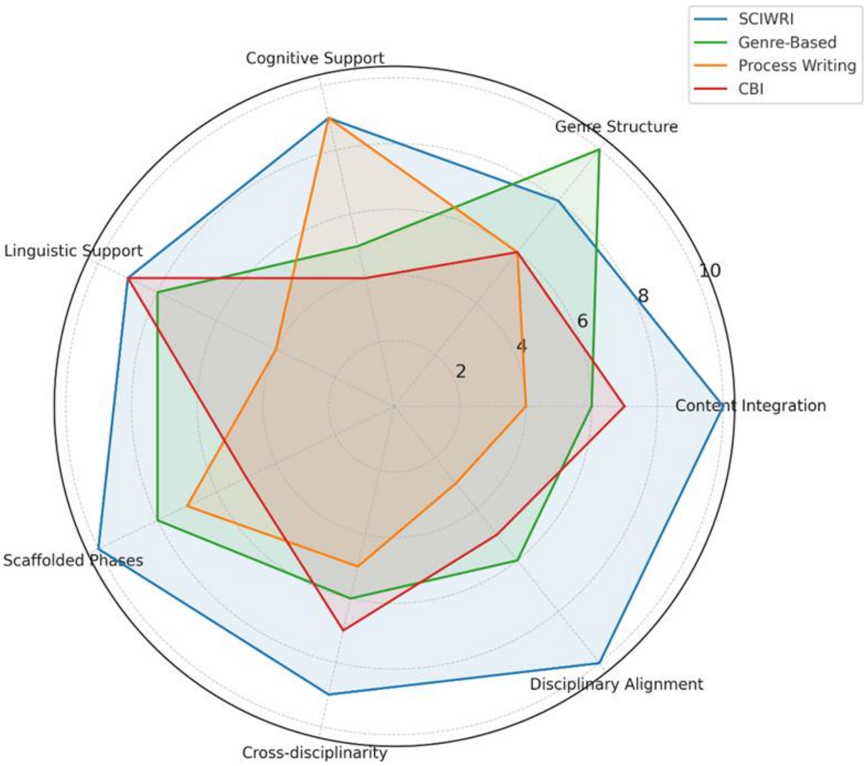

Figure 3.
Comparative Radar Map of Scientific Writing Models.

From the radar chart, it is evident that our SWC model (SCIWRI) surpasses other approaches in terms of:

- *Content–language integration*
- *Scaffolded writing progression*
- *Cognitive support*
- *Cross-disciplinary orientation*
- *Disciplinary specificity (in chemistry)*

While other models (Genre-Based, Process Writing, CBI) also show strengths, they are less balanced in integrating scientific writing into a school discipline.

This visual map in radar format allows for an integrated assessment of the strengths and weaknesses of the four theoretical-methodological writing approaches: SWC, Genre-Based Approach, Process Writing, and Content-Based Instruction (CBI). The chart reflects their comparative balance and relevance in the context of subject-based education, particularly in secondary chemistry instruction.

The radar clearly demonstrates that SWC scores consistently high (9–10) across the following criteria:

- *Integration of content and writing: Unlike most approaches, SWC begins with subject content (chemistry), turning writing into a tool for conceptualizing the discipline;*
- *Cognitive support: Concept maps, logical diagrams, and reaction graphs help link scientific thinking to written expression;*
- *Scaffolded sequencing: The seven-stage structure contrasts with more open-ended and loosely managed sequences in Genre-Based and Process Writing models;*
- *Disciplinary embedding: In SWC, writing is embedded in the chemistry module, rather than treated as an auxiliary activity.*

Therefore, we conclude that SWC addresses the limitations of other models by combining their strengths: genre rigor, cognitive depth, subject logic, and linguistic clarity.

Moreover, using a radar chart allows for the quantification of qualitative differences, making it possible to identify subtle weaknesses even in popular models (e.g., Process Writing's lack of subject integration) and to justify the selection of SWC as the most pedagogically balanced and scientifically functional model for chemistry education.

In sum, we assert that SWC provides an optimal balance between semantic depth, linguistic accuracy, and genre structure in scientific writing, while remaining deeply integrated into the subject matter. It has the potential to serve not only school-based STEM education but also project-based, research-oriented, and olympiad-level instruction.

4.4. Balance and Optimality of the SWC Model

Modern chemistry education faces a dual challenge: on the one hand, it must ensure the formation of a subject-based conceptual foundation for students; on the other, it must develop their ability to engage in scientific written communication aligned with academic and professional standards. In this context, our SWC model (Scientific Writing in Chemistry) appears to be the most appropriate response to these demands, combining pedagogical, cognitive, and disciplinary criteria.

As shown in Table 3, the SWC model integrates four key dimensions of an effective pedagogical tool.

Table 3.
SWC Model: Essential Dimensions of Effective Pedagogy.

Dimension	Implementation in SWC
Learnability	Clear scaffold-transition algorithm; step-by-step removal of support
Flexibility	Adaptable to topic, level, and format (lesson, project, olympiad)
Reflexivity	Inclusion of self-assessment, peer review, checklists, and progress trackers
Modularity	Separation into cognitive, linguistic, and metadiscursive components

We believe this makes SWC not just a model but a technology for designing learning environments that are scalable and applicable in diverse educational contexts, including classrooms, digital LMS platforms, research clubs, and more.

Unlike models developed primarily in the fields of language instruction (Genre-Based, CBI) or general literacy (Process Writing), SWC was initially constructed within the disciplinary framework of chemistry. This gives it several distinct advantages:

- *Direct alignment with chemistry content: Scaffold tasks are developed based on chemistry topics (reactions, substances, lab observations), avoiding artificial imposition of writing onto irrelevant content*.
- *Linguistic articulation of chemical concepts: Students learn to "verbalize" chemistry by turning formulas, diagrams, and phenomena into scientific text (e.g., explanations, descriptions, comparisons).*
- *Cross-disciplinary internalization: Students not only reproduce chemical information but also express their understanding through writing, developing reflection, structural thinking, and their own scientific stance.*

Thus, our SWC model addresses both methodological challenges (writing structure, scaffold navigation) and content-related goals (integration with chemistry, development of scientific agency).

In its entirety, it represents a pedagogically balanced and scientifically functional approach to scientific writing in secondary education.

We believe that implementing SWC can significantly enhance the quality of students' subject-based communication, improve their engagement in project and research activities, and increase their success in summative and external assessments (e.g., PISA, subject olympiads, student science conferences).

4.5. Methodological Recommendations

Using our SWC model promotes not only better quality writing but also a deeper understanding of chemistry, enhanced student reflection, and the development of scientific thinking.

The main target goals associated with the implementation of our model are systematically presented in Table 4.

Table 4.
Key Objectives for Model Deployment.

Goal	Explanation
Development of scientific writing	Systematic development of writing skills across chemistry topics
Support for meaning-language integration	Connecting conceptual chemistry content to appropriate scientific vocabulary
Increasing student autonomy	Using scaffolding only as a temporary support, with gradual removal

Based on these goals, the key principles for working with the model are formulated and presented in Table 5.

Table 5.
Principles for Applying the Model.

Principle	Commentary
Progressive scaffold support	From strong support (templates, diagrams) to independence
Integration of content and language	Chemistry is inseparable from its verbal expression
Transition from oral to written	Oral explanation - written draft – revision
Functional writing tasks	Each task must serve a subject-specific purpose (e.g., explain a reaction)
Modularity and adaptability	The writing portfolio can flexibly fit into any topic and level
Monitoring progress	Use of trackers, self-assessment, and feedback is a required component

These principles can be embedded into instruction through the following formats (see Table 6).

Table 6.
Instructional Formats for Integrating the Principles

Format	Examples
Lesson integration	Scaffold tasks included in core lesson content (not added as extras)
Independent work module	Portfolio used in project, homework, or lab-based writing assignments
Digital integration	Embedded in Google Classroom, LMS platforms with feedback loops
Pair/group work	Peer review of texts, collaborative template creation
Reflective sessions	Self-assessment forms, analysis of personal texts and writing strategies

Thus, in our SWC model, the teacher acts not as a transmitter of content but as a facilitator of scientific writing, performing multiple roles:

- *Environment organizer (providing templates, glossaries, samples);*
- *Text navigator (guiding structure and direction);*
- *Reflection coach (teaching students to ask questions about texts);*
- *Scaffold architect (gradually removing support);*
- *Cognitive writing curator (linking content to expression).*

Importantly, our model is not an add-on to the chemistry curriculum. Rather, it introduces a new culture of scientific writing as a meaningful, structured, content-rich activity. This is no longer merely the pedagogy of knowledge transmission but the pedagogy of scientific expression.

5. Discussion

The results of our study confirm the hypothesis that the effective development of scientific writing in a subject-specific context, particularly in chemistry, requires not isolated work on either linguistic or conceptual skills but a comprehensive, scaffold-integrated approach. The model we have developed, SWC (Scientific Writing in Chemistry), has demonstrated its methodological soundness, pedagogical applicability, and didactic versatility.

One of our main conclusions is that scientific writing in chemistry cannot be viewed as a by-product of learning, emerging spontaneously. On the contrary, we argue that it is formed as an intellectually and generically regulated practice, requiring intentional pedagogical design. This aligns with current trends in pedagogy where writing is increasingly seen not merely as a coding skill, but as a form of scientific thinking.

Our comparative analysis of scaffold strategies (cognitive, linguistic, and hybrid) revealed the clear advantages of the hybrid approach, which fosters the simultaneous development of all components of scientific writing: content, structure, and language. This corresponds to “scaffolded literacy” approaches, in which pedagogical support is understood as a temporary zone of semantic and linguistic safety, allowing the learner to gradually progress toward genuine autonomy.
We believe that scaffold tools provide students with:

- *Conceptual support (what to write),*
- *Linguistic framework (how to write),*
- *Compositional orientation (how to structure the material),*
- *And metareflective capacity, i.e., the ability to conceptualize their writing as a scientific act.*
- The SWC model surpasses Genre-Based, Process Writing, and CBI approaches in several respects:
- *In disciplinary precision and its integration into curricular content (unlike more generalized language-based models);*
- *In its level of scaffold modeling, including cognitive and metadiscursive support (which is absent in traditional genre schemes);*
- *In its structured pedagogical navigation, it offers a clearly defined trajectory of writing development (as opposed to the more open-ended nature of process writing).*

Thus, SWC can be interpreted as a hybrid, next-generation model that combines the best practices of language and content-based learning, scaffold theory, and STEM-oriented literacy.
Despite the effectiveness of our model, several aspects require further empirical validation, including:

- *Quantitative evaluation of students' scientific writing growth across varying proficiency levels;*
- *Adaptation of the model to other subjects (e.g., physics, biology, geography);*
- *Internationalization: translating scaffold tools into other languages and comparing outcomes across educational systems;*
- *Development of a digital scaffold platform, integrating templates, concept maps, editors, trackers, and automated feedback.*

Overall, we contend that our SWC model demonstrates that scientific writing in school is not an optional overlay to content but a necessary component, activating students’ cognitive, linguistic, and cross-disciplinary capacities. Therefore, its implementation in chemistry education implies a shift toward reflective, conceptual, and communicative learning in the language of science.

6. Conclusion

Scientific writing in secondary chemistry is an essential component in developing students' cognitive maturity, their ability to think scientifically, argue, justify, and structure knowledge in linguistic form.

Our theoretical study enabled the development and substantiation of an original model, SWC (Scientific Writing in Chemistry), based on the principle of scaffolded support and the integration of conceptual, linguistic, and discursive competencies.

We can now articulate the main conclusions of our research:

1. The development of scientific writing requires the simultaneous enhancement of cognitive skills (understanding and structuring chemical content), linguistic skills (adequate expression of scientific texts), and metadiscursive skills (reflection, composition, and scientific style);

2. Scaffold strategies (cognitive, linguistic, and especially hybrid) have proven effective as pedagogical support mechanisms. Their combination yields a clear synergistic effect, activating students' intellectual and linguistic resources.

3. Our seven-step algorithm for developing scientific writing enables teachers to guide learners from text analysis to independent scientific expression, step by step.

4. The comparative analysis shows that the SWC model integrates the strengths of genre-based, process-based, and content-language approaches. It demonstrates a high balance across key pedagogical criteria and possesses disciplinary precision and scalability within chemistry education.

As for practical applications, our model may be used to:

- *Plan scaffold interventions in chemistry lessons;*
- *Serve as a foundation for modular courses in scientific writing;*
- *Support project-based, research, and olympiad-level instruction;*
- *Provide the basis for digital platforms and electronic portfolios;*
- *Be included in teacher training and professional development programs.*

Naturally, our model requires further development and expansion, especially in the context of validation. Future research could include:

- *Empirical testing of the model in real classrooms across various proficiency levels;*
- *Integration of SWC into other disciplines (biology, physics, geography, computer science);*
- *Development of a scaffolded digital application, including templates, checklists, editors, and progress trackers;*
- *Investigation of the impact of scientific writing on the development of critical thinking and reflection.*

In conclusion, we assert that the SWC model overcomes the traditional separation between content and language in chemistry education. It transforms scientific writing from an auxiliary component into a tool for meaning-making, scientific thinking, and student agency.

In this way, it directly supports the transition to a modern educational paradigm, where the language of science becomes the language of the student.

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