41. Evaluating the effectiveness of a virtual laboratory for inorganic chemistry education / A. Tatenov, Z. Sarsenbaeva, G. Azimbaeva [et al.] // Research in Science and Technological Education. – 2025. – Vol. 43, №2. – P. 377-389. – URL: https://doi.org/10.1080/02635143.2023.2275139.

42. Araripe E., Zuin Zeidler V. G. Advancing sustainable chemistry education: Insights from real-world case studies // Current Research in Green and Sustainable Chemistry. – 2024. – Vol. 9. – P. 100436. – URL: doi.org.

43.Chemistry students' soft skills development through the integration of Think Pair Square (TPSq) using a socio critical and problem oriented approach in acid-based learning / T.Hadinugrahaningsih, R. Amalia, E. Fitriani [et al.] // Journal of Physics: Conference Series. – 2019. – Vol. 1402, №5. – P. 055075. – URL: https://doi.org/10.1088/1742-6596/1402/5/055075

МРНТИ 14.25.09 https://doi.org/10.51889/3005-6217.2026.88.2.002

Philip A.[1]*, Ebenezer Y.O.[2]

[1]Nazarbayev University, Graduate School of Education, Astana, Kazakhstan

[2]STEM Education Research Innovation and Partnerships, Accra, Ghana

[*]e-mail: philip.aikins.pa@gmail.com

SCIENTIFIC WRITING SKILLS FOR CHEMISTRY STUDENTS: COMMON CHALLENGES AND EFFECTIVE STRATEGIES

Abstract

Scientific writing is a cornerstone of professional chemistry, yet undergraduate and graduate students frequently struggle with the transition from general academic writing to technical, discipline-specific communication. This review synthesizes research on common writing challenges in chemistry education, including difficulties with laboratory report structure, results and discussion sections, hypothesis formulation, data presentation, chemistry-specific conventions, literature use, and the linguistic barriers experienced by English learners as a second language.

The paper also evaluates effective pedagogical strategies, including scaffolded assignments, journal-style writing, writing-to-learn activities, calibrated and double-blind peer review, interactive video workshops, information-literacy instruction, and graduate-level review article writing.

The literature shows that student writing improves most effectively when instruction is explicit, repeated, discipline-specific, and integrated across the curriculum rather than isolated within a single course. A practical departmental framework is proposed to support chemistry students from introductory laboratory reports to advanced manuscript-style writing. Overall, scientific writing should be treated not only as a communication skill but also as a mechanism for developing chemical reasoning, professional identity, and participation in the scientific community.

Keywords: scientific writing, chemistry education, laboratory reports, writing-to-learn, peer review, information literacy, graduate writing, academic communication.

А.Филип[1]*, Й.О. Эбенезер[2]
[1]*Назарбаев Университеті, Жоғары білім беру мектебі, Астана, Қазақстан*
[2]*STEM-білім беру саласындағы зерттеулер, инновациялар және серіктестіктер орталығы, Аккра, Гана*
[*]*e-mail: philip.aikins.pa@gmail.com*

ХИМИЯ СТУДЕНТТЕРІНЕ АРНАЛҒАН ҒЫЛЫМИ ЖАЗУ ДАҒДЫЛАРЫ: КЕҢ ТАРАЛҒАН ҚИЫНДЫҚТАР МЕН ТИІМДІ СТРАТЕГИЯЛАР

Аңдатпа

Ғылыми жазу кәсіби химияның негізгі құрамдас бөліктерінің бірі болып табылады. Дегенмен, бакалавриат және магистратура студенттері жалпы академиялық жазудан техникалық, пәнге тән ғылыми коммуникацияға көшу барысында жиі қиындықтарға тап болады. Бұл шолу химия біліміндегі жазуға қатысты кең таралған мәселелерді жинақтайды. Олардың қатарына зертханалық есептердің құрылымы, нәтижелер мен талқылау бөлімдерін жазу, гипотеза құрастыру, деректерді ұсыну, химияға тән жазу ережелері, ғылыми әдебиеттерді пайдалану және ағылшын тілін екінші тіл ретінде меңгерушілердің тілдік кедергілері жатады. Мақалада сондай-ақ тиімді педагогикалық стратегиялар қарастырылады. Олардың ішінде кезең-кезеңімен құрылымдалған тапсырмалар, ғылыми журнал стиліндегі жазу, оқу арқылы жазу (writing-to-learn) әдістері, калибрленген және қос соқыр рецензиялау, интерактивті бейне семинарлар, ақпараттық сауаттылықты дамытуға арналған оқыту және магистратура деңгейіндегі шолу мақалаларын жазу тәжірибесі бар.

Әдебиеттерге жүргізілген талдау студенттердің жазу дағдылары ең тиімді түрде оқыту нақты, жүйелі, пәнге бағытталған және оқу бағдарламасының барлық кезеңдеріне кіріктірілген жағдайда дамитынын көрсетеді. Яғни, жазу дағдыларын дамыту тек бір пәннің шеңберінде оқшауланбай, бүкіл оқу бағдарламасы бойынша жүзеге асырылуы тиіс. Химия студенттерін кіріспе деңгейдегі зертханалық есептерден бастап ғылыми мақала стиліндегі күрделі жазба жұмыстарына дейін қолдауға арналған практикалық кафедралық құрылым ұсынылады. Жалпы алғанда, ғылыми жазу тек коммуникация құралы ретінде ғана емес, сонымен қатар химиялық ойлау қабілетін, кәсіби сәйкестікті және ғылыми қауымдастыққа қатысуды дамыту механизмі ретінде қарастырылуы тиіс.

Кілт сөздер: ғылыми жазу, химия білімі, зертханалық есептер, оқу арқылы жазу (writing-to-learn), рецензиялау, ақпараттық сауаттылық, магистратура деңгейіндегі жазу, академиялық коммуникация.

Филип А.[1]*, Эбенезер Й.О.[2]
[1]*Назарбаев Университет, Высшая школа образования, Астана, Казахстан*
[2]*Исследовательский центр инноваций и партнёрства в STEM-образовании, Аккра, Гана*
[*]*e-mail: philip.aikins.pa@gmail.com*

НАВЫКИ НАУЧНОГО ПИСЬМА ДЛЯ СТУДЕНТОВ-ХИМИКОВ: РАСПРОСТРАНЁННЫЕ ТРУДНОСТИ И ЭФФЕКТИВНЫЕ СТРАТЕГИИ

Аннотация

Научное письмо является одной из ключевых составляющих профессиональной деятельности химика, однако студенты бакалавриата и магистратуры часто испытывают трудности при переходе от общего академического письма к технической, дисциплинарно-специфической научной коммуникации. В данном обзоре обобщаются исследования, посвящённые распространённым проблемам письменной подготовки в химическом образовании, включая трудности со структурой лабораторных отчётов, написанием разделов результатов и обсуждения, формулированием гипотез, представлением данных, соблюдением специфических для химии норм и стандартов, использованием научной литературы, а также языковыми барьерами, с которыми сталкиваются изучающие английский язык как второй.

В статье также рассматриваются эффективные педагогические стратегии, включая поэтапно структурированные задания, написание работ в формате научных журналов, методы «обучения через письмо» (writing-to-learn), калиброванное и двойное слепое рецензирование, интерактивные видеосеминары, обучение информационной грамотности и написание обзорных статей на уровне магистратуры.

Анализ литературы показывает, что качество студенческих письменных работ наиболее эффективно улучшается тогда, когда обучение является чётким, систематическим, ориентированным на конкретную дисциплину и интегрированным в учебную программу, а не ограничивается отдельным курсом. Для поддержки студентов-химиков предлагается практическая кафедральная модель, охватывающая развитие письменных навыков от начальных лабораторных отчётов до подготовки рукописей в формате научных статей.

В целом научное письмо следует рассматривать не только как средство коммуникации, но и как механизм развития химического мышления, профессиональной идентичности и участия в научном сообществе.

Ключевые слова: научное письмо, химическое образование, лабораторные отчёты, обучение через письмо, рецензирование, информационная грамотность, письмо на уровне магистратуры, академическая коммуникация.

Introduction. The capacity to articulate scientific concepts effectively is a defining characteristic of professional success in the 21st-century chemical enterprise. Beyond the mastery of fundamental chemical principles, chemists must possess the versatility to convey complex technical information across a spectrum of media, addressing diverse audiences ranging from specialized peers to the broader public [1]. Despite this mandate, the undergraduate chemistry curriculum has historically struggled to integrate scientific communication as a core competency. The importance of teaching these skills has been recognized in the pedagogical literature for decades, with extensive reviews of didactic activities spanning from 1991 to 2010 highlighting the ongoing search for effective instructional methods [2].

Central to this challenge is a deeply rooted pedagogical tradition that emphasizes the "rhetoric of conclusions." As noted by Schwab, chemistry education often prioritizes the transmission of scientific facts–the "products of the context of epistemological justification"–rather than the processes of knowledge generation or the historical and philosophical development of the discipline [3]. This ahistorical, product-focused approach permeates textbooks and curricula, often rendering the act of scientific inquiry and the communication of that inquiry as secondary objectives [3]. Consequently, meaningful curriculum reform has been notoriously slow; while calls for restructuring the chemistry curriculum have persisted for over 60 years, substantive changes remain elusive [4].

When communication is addressed in undergraduate programs, it is frequently delivered through fragmented, course-by-course interventions rather than a cohesive, departmental strategy [5]. This lack of coordination creates a paradox wherein faculty and administrators universally identify research, writing, and communication as vital professional skills, yet fail to allocate sufficient instructional time to cultivate them [6]. The result is often a disconnect where students struggle to produce work of professional quality because their writing instruction is general rather than discipline-specific and sporadic rather than continuous [6].

To address these deficiencies, contemporary educational research advocates for a shift toward comprehensive, scaffolded curricula. Innovative models are emerging that move beyond isolated assignments to embed communication training deeply within the student experience. These strategies include the use of "bookend" models, which provide structured support for critical thinking and communication in both junior and senior years [7]; integrated courses that combine information literacy, ethics, and peer review [8]; and scalable, technology-enhanced interventions such as interactive video workshops that provide consistent, technical writing training without requiring specialized expertise from every instructor [9]. These comprehensive models have successfully improved student readiness for both graduate school and the professional workforce [10].

Table 1 summarizes the transition from traditional, isolated pedagogical approaches to these emerging, integrated frameworks.

Table 1- Paradigms of Scientific Communication Instruction in Chemistry

Feature	Traditional/Fragmented Model	Comprehensive/Integrated Model
Curricular Scope	Course-specific; isolated assignments [5]	Departmental, multi-year, or “bookend” design [7]
Instructional Focus	Implicit; emphasizes the “rhetoric of conclusions” [3]	Explicit; emphasizes knowledge generation and the writing process [3]
Instructional Methods	Generic writing guidance [6]	Discipline-specific instruction integrated with information literacy and ethics [8]
Scalability	Low; dependent on individual instructor interest [5]	High; utilizes scaffolded assignments, peer review, and interactive video workshops [9]
Professional Goal	Incidental reporting of experimental results	Integrated development of career-ready scientific communication skills [1]

This paper explores the common challenges that undergraduate chemistry students face when attempting to navigate professional scientific writing. It synthesizes findings from current literature to evaluate the efficacy of various instructional strategies–from intensive seminar courses and collaborative peer review to scalable digital scaffolding. By analyzing these approaches, this work provides a framework for educators to transition from fragmented, ad hoc writing assignments to a coherent, department-wide culture of scientific communication that better prepares students for the complexities of modern chemical practice.

Scientific Writing as a Discipline-Specific Skill in Chemistry. Scientific writing in chemistry differs from general academic writing in its purpose, structure, evidence base, and stylistic conventions. A chemistry report is not simply a narrative description of what happened in the laboratory. It is a structured argument that connects an experimental question, a method, a body of evidence, and a defensible interpretation. Students must learn to write with precision, objectivity, and economy while also demonstrating chemical reasoning. This requires the integration of language, data literacy, visual communication, and disciplinary knowledge.

Chemistry writing also involves strong visual and symbolic dimensions. Students are expected to incorporate equations, reaction schemes, spectra, tables, calibration curves, molecular structures, chromatograms, and other graphical representations into the written text. These visual elements are not decorative; they function as evidence. Effective writing therefore requires students to introduce figures and tables, describe the relevant trends, interpret their meaning, and explain how they support the conclusion. Many novice writers struggle because they treat figures as self-explanatory or repeat numerical values without explaining their chemical significance [11].

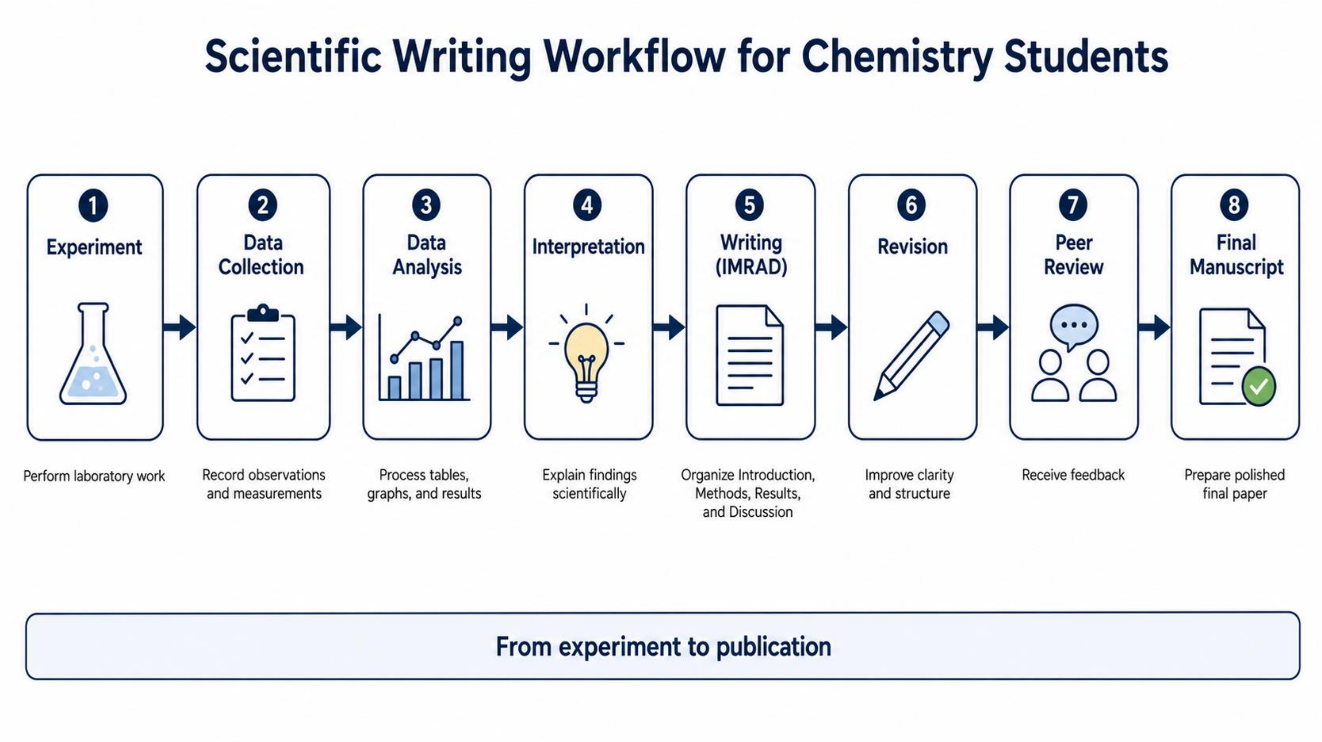

Figure 1. Scientific writing workflow for chemistry students, showing the progression from laboratory experimentation and data collection to analysis, interpretation, manuscript preparation, revision, peer review, and final publication-ready writing

Scientific writing in chemistry can be understood as a continuous process that begins with experimental work and ends with communicating evidence-based conclusions. As shown in Fig. 1, students must move from data collection and analysis to interpretation, IMRAD-based writing, revision, peer review, and final manuscript preparation. Another distinctive feature of chemistry writing is the need to follow field-specific conventions. These include appropriate use of chemical nomenclature, units, significant figures, tense, passive and active voice, citation style, safety considerations, and standardized sections such as Abstract, Introduction, Experimental, Results, Discussion, and Conclusion. Students who are unfamiliar with these conventions may produce reports that contain correct chemical content but still fail to meet disciplinary expectations. Therefore, writing instruction in chemistry must make these conventions visible and teachable rather than assume students will acquire them indirectly.

Common Challenges in Chemistry Writing. The development of scientific writing competence–defined through the essential dimensions of normativity, objectivity, and logicality – represents a significant hurdle in undergraduate chemistry education [12]. Students are not merely expected to report data; they must learn to participate in a social and cognitive endeavor that requires them to synthesize observations with theoretical frameworks. However, a complicated interaction between conceptual, structural, and linguistic obstacles frequently impedes this transition from novice to expert scientific communicator.

Structural and Section-Specific Barriers. One of the most persistent difficulties for chemistry students is mastering the structure of scientific reports. The IMRAD model–Introduction, Methods, Results, and Discussion – appears straightforward, but each section performs a different rhetorical function. The introduction establishes context and purpose; the Methods section enables reproducibility; the Results section presents evidence; and the Discussion interprets that evidence and explains its significance. Students often blur these functions, especially when moving from high school laboratory worksheets to university-level scientific reporting [9], [13]. The major barriers to effective chemistry writing can be grouped into five broad categories: structure, scientific reasoning, language, chemistry-specific conventions, and referencing (Fig. 2). These categories provide a useful framework for understanding why students often struggle to transform laboratory work into coherent scientific reports.

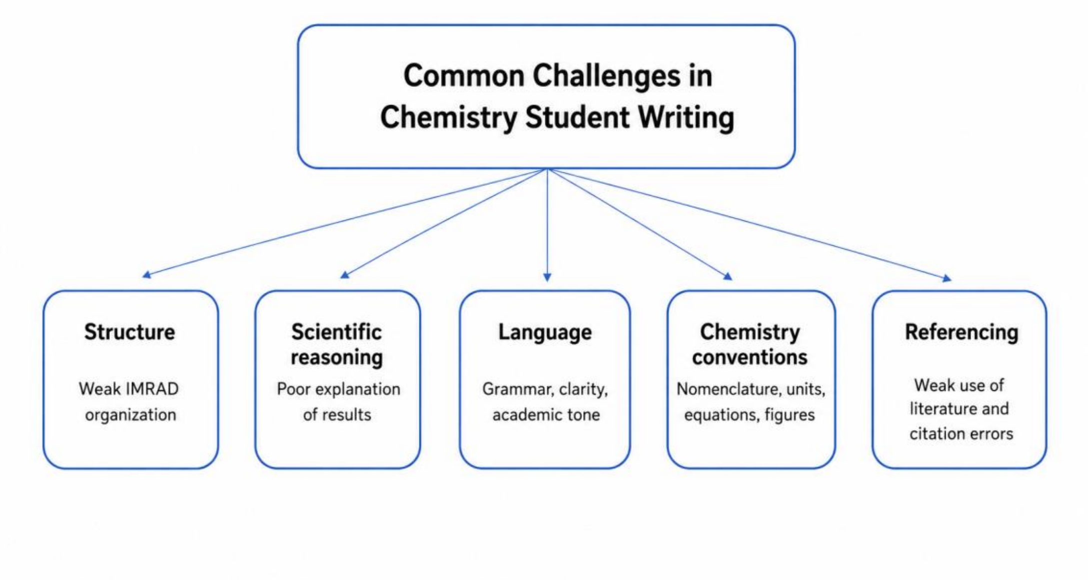

Figure 2. Common Challenges in Chemistry Student Writing

The Results and Discussion sections are frequently the most challenging. Students may make broad claims that lack data support or describe observations without explaining their relevance. In some cases, they present raw data without identifying trends, uncertainties, or relationships between variables. In other cases, they interpret results without acknowledging limitations, sources of error, or alternative explanations. Studies of undergraduate laboratory reports indicate that students often perceive interpretation-based sections harder to elaborate than descriptive sections because they require both chemical understanding and rhetorical judgment [13], [14].

Another structural challenge concerns the connection between sections. A strong report should follow a clear line of reasoning: the objective leads to the method, the method produces results, the results support the interpretation, and the interpretation leads to a conclusion. Novice writers may write each section as an isolated task, producing a report that lacks coherence. Explicit instruction is needed to help students see the report as a connected scientific argument rather than a collection of required headings.

Technical Fundamentals and Chemistry-Specific Style. Chemistry students commonly struggle with technical fundamentals such as hypothesis formulation, precision of language, grammar, mechanics, and audience awareness. A common problem is that students state a broad objective rather than a testable hypothesis. For example, "to investigate the reaction" is not equivalent to a hypothesis that predicts a measurable outcome under defined conditions. Teaching students to formulate hypotheses requires attention to variables, expected relationships, and chemical rationale.

Style is another major barrier. Scientific writing values clarity, concision, accuracy, and logical flow. Students may use informal expressions, vague statements, unnecessary repetition, or unsupported claims. They may also misuse chemical terminology or fail to distinguish between observation, inference, and conclusion. Chemistry-specific writing exercises can help students practice transforming informal descriptions into precise scientific statements [11]. For example, instead of writing "the solution changed a lot," students should be taught to write "the absorbance increased from 0.23 to 0.71 at 520 nm, indicating increased formation of the colored complex."

Data presentation is equally important. Students often include tables or graphs without explaining why they are included. A figure should be cited, its main trend described, and its significance interpreted. Likewise, tables should be used when they make comparison easier, not when a sentence would be clearer. These conventions require repeated practice because they involve both writing skills and data interpretation.

Reading, Literature Use, and Citation Problems. Weak reading habits can limit writing development. Students who do not regularly read scientific articles may have difficulty recognizing how professional chemists organize arguments, cite evidence, describe methods, and discuss limitations. Exposure to published literature helps students internalize genre conventions and develop a sense of disciplinary voice. However, students also need guidance in how to read strategically. A research article can be intimidating because it contains dense terminology, complex figures, and unfamiliar methods.

Citation and information literacy are additional challenges. Students may rely on general websites rather than peer-reviewed sources, cite sources without integrating them into their argument, or misunderstand the difference between background information and evidence. In chemistry, information literacy includes the ability to search databases, evaluate the relevance of articles, read abstracts and figures efficiently, and cite sources accurately. Students' ability to locate, evaluate, and cite relevant sources improves with peer review and chemical literature courses [15].

Challenges for English as a Second Language and Graduate Students. Students writing in English as a Second Language face additional linguistic, cultural, and disciplinary barriers. These may include grammar, sentence structure, vocabulary, hedging, cohesion, and the conventions of academic tone. Doctoral students face challenges beyond just language accuracy. They must also learn how to position their research in the literature, construct an argument for novelty, and write for specific publication venues. Research on chemistry doctoral students identifies challenges in text organization, grammatical accuracy, general writing competence, institutional support, and the choice of dissemination medium [16].

Graduate students also face workload and time-management challenges. Writing a review article or manuscript requires processing large quantities of literature, organizing themes, identifying gaps, and synthesizing findings. Students may know how to summarize individual papers but struggle to build a coherent review narrative. Graduate-level writing courses help students develop both writing skills and scholarly independence by guiding them through the production of publishable review articles [17].

Table 2 - Common writing challenges in chemistry education and corresponding instructional supports

Challenge	Typical student difficulty	Likely consequence	Effective support
Report structure	Confusing the functions of Introduction, Methods, Results, and Discussion	Fragmented reports with weak argument flow	Explicit genre instruction and model analysis
Results and Discussion	Reporting data without interpretation or making claims without evidence	Weak chemical reasoning and unsupported conclusions	Guided questions, annotated examples, and revision
Technical style	Informal language, vague terms, grammar and mechanics errors	Reduced clarity and professional credibility	Chemistry-specific writing exercises
Data presentation	Poor integration of tables, figures, and spectra	Evidence is present but not used effectively	Figure-caption practice and data commentary
Literature use	Limited reading habits and weak citation integration	Poor context and weak justification of claims	Information-literacy instruction and peer review
ESL/graduate writing	Language barriers plus difficulty writing for publication	Slow manuscript development and low confidence	Writing groups, mentoring, and publication-oriented courses

Linguistic complexities further layer the obstacles for students studying chemistry in a second language. Even for those with strong general English skills, the specific register of scientific English presents unique hurdles. Students frequently struggle with the ambiguity of translated terminology, particularly with academic headings like 'Results' and 'Discussion,' which may not have direct, functionally equivalent translations in their native language.

Furthermore, the acquisition of specialized nomenclature–names of chemicals, apparatus, and analytical techniques–requires significant cognitive effort. Without explicit instruction, students may lack the descriptive precision necessary to document observations accurately, sometimes resorting to simplistic, non-scientific language (e.g., describing a 'turquoise' copper solution as 'fake blue'). This inability to access the appropriate lexicon limits their capacity to effectively communicate the "progress of thinking" behind their experimental findings.

Categorization of Writing Challenges. To better address these impediments, Table 2 synthesizes the common writing difficulties and their underlying drivers identified in undergraduate chemistry contexts.

Table 3 - Categorization of Common Writing Challenges in Undergraduate Chemistry

Category	Specific Challenge	Underlying Cause
Conceptual	The 'Reality Gap': Writing textbook theory rather than observed results [18].	Passive acceptance of paradigms; lack of experimental confidence [18].
Structural	Difficulty synthesizing 'Results and Discussion' and 'theoretical bibliographic' content [14].	Inadequate reading habits; limited exposure to academic literature [14].
Linguistic	Ambiguity in scientific nomenclature and terminology [19].	Second-language barriers; lack of familiarity with scientific register/precision [19].
Pedagogical	Inconsistency in report structure and expectation across modules [19].	Fragmented, course-by-course instruction lacking a coordinated approach [19].

By isolating these categories, educators can better tailor interventions to address not just the symptoms of poor writing but the foundational cognitive and pedagogical barriers that prevent students from achieving professional proficiency.

Effective Pedagogical Strategies

Scaffolding and Stepwise Writing Development. Scaffolding is one of the most effective approaches for helping chemistry students move from basic reporting to professional scientific writing. Instead of asking students to produce a complete journal-style report immediately, instructors can divide writing into smaller tasks and gradually increase complexity. Students may first practice writing figure captions, then experimentation procedures, results paragraphs, and finally full results and discussion sections. This approach reduces cognitive overload and allows students to focus on one writing skill at a time. A scaffolded approach allows students to develop writing competence gradually rather than being asked to produce a complete journal-style report at once. As illustrated in Fig. 3, writing instruction can begin with smaller tasks, such as caption writing and experimental sections, before progressing to Results, Discussion, full laboratory reports, and manuscript-style writing.

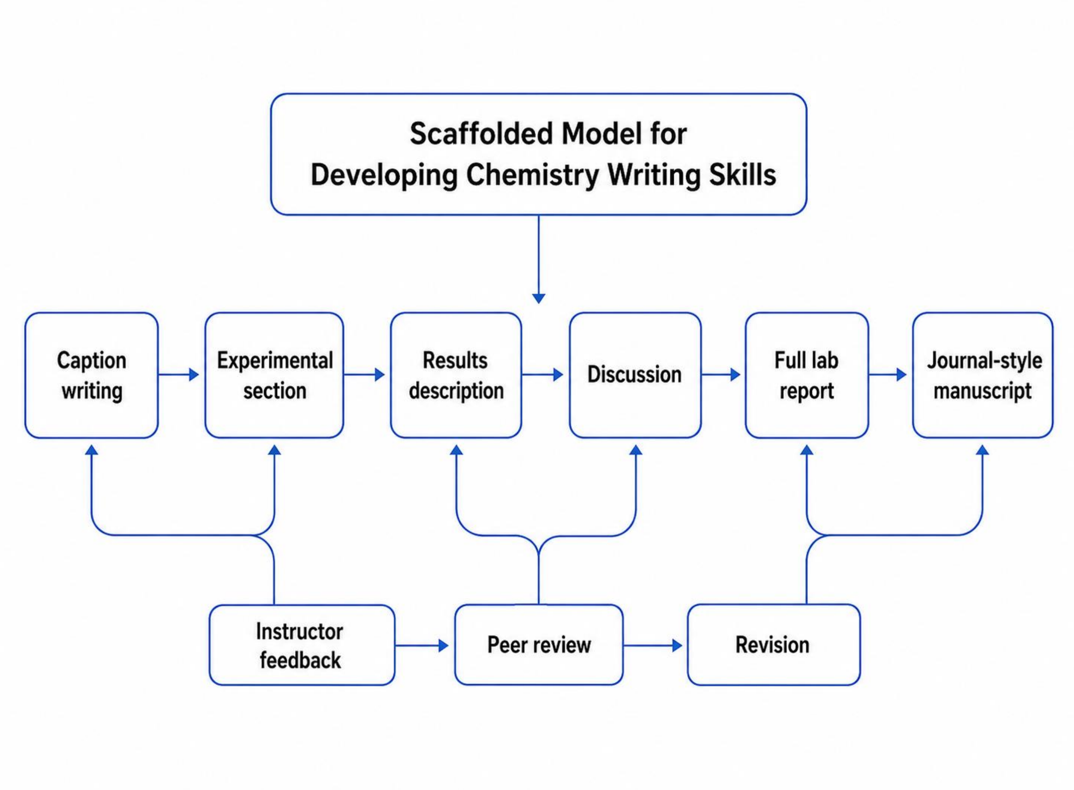

Figure 3. Scaffolded model for developing chemistry writing skills through progressive writing tasks, instructor feedback, peer review, and revision. The model shows how students can move from simple caption writing to full laboratory reports and journal-style manuscripts

A stepwise approach has been used successfully in organic chemistry courses, where students are guided from lower-level writing tasks toward Journal of Organic Chemistry-style reports [20]. The value of this method lies in its combination of imitation, practice, feedback, and revision. Students analyze authentic examples, identify the stylistic features of professional writing, and then apply those features in their reports. By the time they write a complete paper-style report, they have already practiced many of its components.

Short-term interventions can also be useful, especially in laboratory courses with limited time. We have demonstrated that co-created tutorials, reference guides, and targeted workshops on lab report writing can enhance student performance, even in resource-constrained environments [21]. Such interventions are most effective when they address specific weaknesses, such as writing a purpose statement, explaining a graph, or distinguishing results from discussion.

Writing-to-Learn Approaches. "Writing to Learn" emphasizes the role of writing in developing conceptual understanding. In chemistry, this approach can be used through short reflective prompts, claim-evidence-reasoning exercises, mechanism explanations, error analysis paragraphs, or written comparisons of experimental and theoretical results. These assignments do not need to be long to be effective. Their purpose is to make students articulate reasoning that might otherwise remain implicit.

Writing-to-learn activities are especially valuable because they help students connect symbolic, macroscopic, and particulate levels of chemical understanding. For example, students can be asked to explain why a color change corresponds to a change in concentration, why a peak shift in a spectrum supports a structural assignment, or why a deviation from expected yield may be chemically meaningful. Such writing tasks develop the interpretive skills needed for strong Results and Discussion sections [22].

Peer Review and Revision. Peer review is a high-impact strategy because it exposes students to multiple examples of writing and encourages them to evaluate scientific arguments. When students review peers' reports, they learn to identify unclear claims, missing evidence, weak figure references, and unsupported conclusions. This evaluative activity can enhance their writing skills by helping them comprehend the criteria used to judge scientific writing [23].

Calibrated Peer Review (CPR) is one structured model that uses rubrics and calibration samples to train students to evaluate writing quality. In biochemistry courses, CPR-generated feedback has been associated with improvements in abstract writing quality, and it can reduce the feedback burden on instructors while still providing students with meaningful formative evaluation [24]. Similarly, argument-driven inquiry uses peer review and revision in laboratory settings to help students develop stronger scientific arguments [25].

For peer review to be effective, students need clear rubrics and training. Without guidance, peer comments may focus only on grammar or superficial features. A strong peer-review process should ask students to evaluate whether the objective is clear, whether the method is reproducible, whether figures are interpreted, whether claims are supported by evidence, and whether citations are used appropriately. Revision should be required after peer review, as the learning benefit comes from applying comments, not just receiving them.

Interactive and Multi-Modal Learning. Large-enrollment chemistry courses often make individualized writing feedback difficult. Interactive video workshops offer a practical solution by delivering consistent instruction on writing fundamentals to many students at once. Such workshops can cover audience awareness, sentence-level clarity, argument construction, data commentary, and common errors in lab reports. Studies indicate that interactive video workshops can improve undergraduate scientific writing proficiency and help students produce higher-quality laboratory reports [9].

Multi-modal instruction is particularly suitable for chemistry because students must coordinate text, equations, graphs, molecular structures, and experimental data. Video modules can show students how to revise a poor Results paragraph, how to write a figure caption, or how to connect a spectrum to a structural claim. These resources can be reused across courses and provide consistency in departmental writing instruction.

Review Article Writing at the Graduate Level. At the graduate level, reviewing article writing can serve as both a writing exercise and a professional development experience. Writing a review requires students to search literature systematically, identify themes, compare findings, evaluate methodological differences, and construct a narrative about the state of a field. Graduate students report that this process is time-consuming, but it broadens their knowledge base and strengthens their ability to synthesize information.

A review-writing course can be structured around stages: topic selection, literature mapping, annotated bibliography, outline development, thematic synthesis, drafting, peer review, revision, and journal targeting. This sequence mirrors the actual process of scholarly publication and helps students understand writing as an iterative research activity rather than a final administrative step.

Curriculum-Level Integration of Writing Instruction. The literature suggests that writing instruction is most effective when it is integrated across the curriculum rather than concentrating in a single course. A departmental approach can ensure that students encounter writing expectations repeatedly and progressively. Introductory courses can emphasize observation, data description, and basic report structure. Intermediate courses can focus on methods, figure captions, and results sections. Advanced laboratory and research courses can require full manuscript-style reports, literature reviews, and oral or poster presentations [5], [26]. Writing instruction should be distributed across the chemistry curriculum rather than limited to a single laboratory course. As shown in Fig. 4, students can progressively develop from basic observation and laboratory notebook writing in the first year to full IMRAD reports, literature reviews, research proposals, and publishable manuscripts at advanced levels.

This progression helps students see writing as a normal part of chemical practice. It also prevents the common problem in which each instructor assumes that students learned writing elsewhere. A shared departmental framework can define expectations for each level, coordinate rubrics, and reduce inconsistency among courses. Such coordination is particularly important for programs that serve students with diverse preparation levels and language backgrounds.

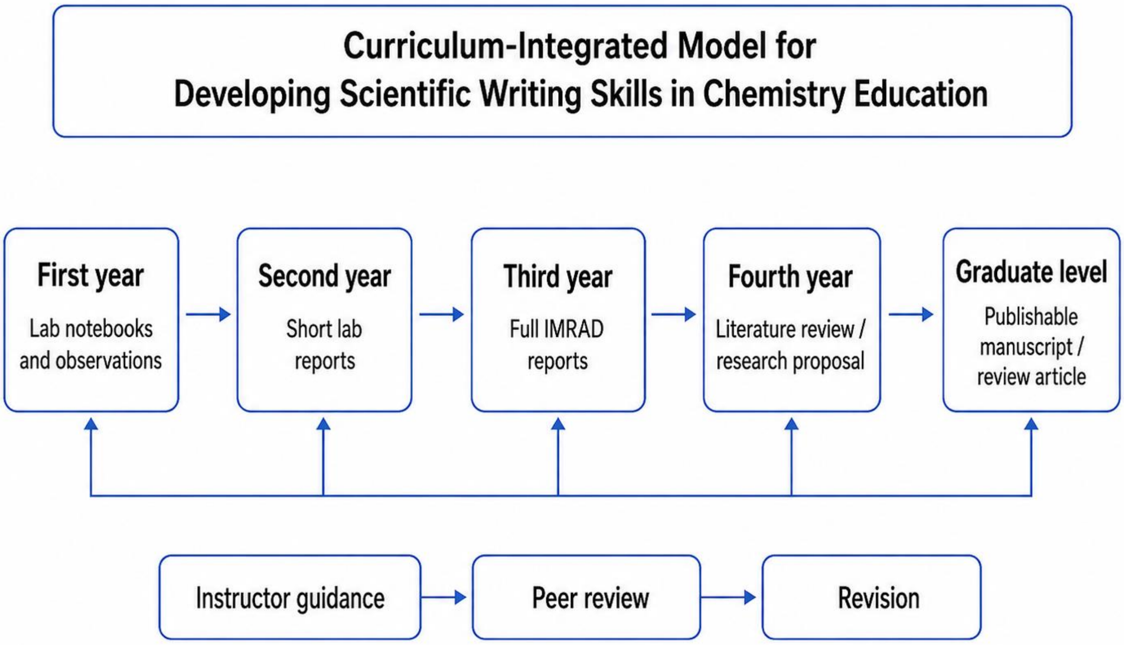

Figure 4. Curriculum-Integrated Model for Developing Scientific Writing Skills

Writing instruction should also be aligned with assessment. If students are graded only on correct answers or final numerical results, they may not value communication. Rubrics should therefore include criteria such as clarity of objective, appropriateness of evidence, interpretation of results, use of figures and tables, citation quality, and professional style. This communicates that writing is part of scientific performance, not merely formatting.

Table 4 - Suggested progression of chemistry writing instruction across the curriculum

Curriculum level	**Primary writing goals**	**Example assignments**	**Recommended feedback**
Introductory chemistry	Observation, accuracy, basic structure	Short lab reports, data descriptions, figure captions	Checklist and brief instructor comments
Organic/analytical laboratory	Methods, evidence, and section coherence	Experimental sections, Results paragraphs, journal-style mini reports	Rubric-based feedback and revision
Upper-level laboratory	Scientific argument and literature integration	Full IMRAD reports, literature-supported Discussion sections	Peer review plus instructor conferences
Research/graduate level	Publication-oriented communication	Review articles, manuscripts, proposals, conference abstracts	Mentoring, writing groups, and iterative revision

Discussion. ***Impact of Writing Interventions.*** The reviewed studies indicate that chemistry students can improve substantially when writing instruction is explicit, scaffolded, and connected to disciplinary practice. Students do not automatically acquire scientific writing conventions simply by completing laboratory reports. They need to see models, discuss criteria, receive feedback, and revise. The most successful interventions combine these elements and treat writing as a repeated process rather than a one-time assignment.

Department-wide initiatives are especially promising. Comprehensive approaches involving coordinated writing instruction, teaching assistant training, writing-intensive laboratory components, and consistent assessment have shown positive effects on student communication skills [1], [2]. Such approaches also benefit instructors because they create shared expectations and reusable resources. Rather than each instructor designing writing support independently, departments can develop common guides, rubrics, video modules, and peer-review protocols.

The evidence also shows that writing development is linked to information literacy. Students who can locate, read, and assess chemical literature are better equipped to craft meaningful introductions and discussions. Conversely, students with weak literature skills may produce reports that describe procedures but fail to connect findings to broader chemical knowledge. Peer review, literature search assignments, and review article projects can therefore strengthen both writing and research competence [15], [17].

However, writing interventions must be realistic. Chemistry courses are often content-heavy, and instructors may have limited time for extensive writing feedback. For this reason, efficient strategies are needed. Rubrics, peer review, calibrated examples, short, targeted tasks, and reusable video workshops can make writing instruction feasible without overwhelming instructors. The goal is not to turn every chemistry course into a composition course, but to embed writing tasks that directly support chemical reasoning.

Practical Recommendations for Chemistry Instructors. First, instructors should make the purpose of each report section explicit. Students should know that the introduction justifies the experiment, the Methods section supports reproducibility, the Results section presents evidence, and the discussion section explains what the evidence means. Providing annotated examples can help students see these functions in practice.

Second, instructors should assign smaller writing tasks before full reports. Figure captions, claims supported by data, short discussion paragraphs, and error-analysis explanations are useful preparatory exercises. These tasks are easier to grade and can target specific weaknesses.

Third, writing rubrics should focus on scientific reasoning as well as language accuracy. Grammar matters, but a grammatically correct report can still be scientifically weak if it lacks interpretation. Rubrics should therefore assess evidence, logic, data commentary, section coherence, citation use, and chemical accuracy.

Fourth, peer review should be structured and required before final submission. Students should be trained with examples and rubrics so that their comments address scientific content, not only surface-level errors. Requiring revision after peer review increases the instructional value of the process.

Fifth, departments should support ESL and graduate students through writing groups, manuscript workshops, and mentoring. These students often need support not only with language but also with publication strategy, literature synthesis, and disciplinary argumentation [16], [17].

Future Directions. Future research should examine how digital tools, artificial intelligence, collaborative platforms, and automated feedback systems can support chemistry writing without replacing human judgment. These tools may help students identify grammar errors, improve readability, or organize references, but they cannot fully evaluate chemical reasoning, experimental validity, or the appropriateness of interpretation. Therefore, digital tools should be integrated carefully, with attention to academic integrity and disciplinary accuracy.

Another important direction is the development of writing support for multilingual chemistry students. More research is needed on how students negotiate language, disciplinary conventions, and cultural expectations in scientific writing. Writing centers, chemistry departments, and graduate supervisors can collaborate to create discipline-specific support rather than relying solely on general academic writing services.

Finally, more longitudinal research is needed. Many studies evaluate improvement within a single course, but writing development occurs over years. Future studies should track student progress across multiple courses and examine how early writing instruction affects later research participation, graduate success, and publication readiness.

Conclusion. Chemistry students should systematically develop their scientific writing skills throughout the curriculum. Students commonly face challenges related to report structure, results and discussion writing, hypothesis formulation, chemistry-specific style, data presentation, literature use, and language barriers. You can address these difficulties by using scaffolded assignments, writing-to-learn activities, peer review, interactive workshops, information-literacy instruction, and graduate-level review article writing.

The most effective approaches are explicit, iterative, and discipline-specific. When writing instruction is coordinated across chemistry courses, students are more likely to develop the ability to communicate experimental results clearly and to participate confidently in the scientific community. Chemistry programs should therefore treat writing not as a peripheral requirement but as an essential component of scientific training.

Funding. No specific funding was reported for this review paper.

Conflicts of Interest. The author declares no conflict of interest.

Conclusion and Recommendations for Departmental Frameworks. The evidence reviewed in this paper confirms that scientific writing is an inseparable component of chemical practice, essential for the development of scientific literacy and professional identity. However, the efficacy of instruction depends heavily on pedagogical structure. The literature consistently highlights that fragmented, course-specific assignments are insufficient for long-term improvement. Instead, departments must adopt sustainable, vertically integrated frameworks that transition students from nominal chemical literacy to the multi-dimensional understanding required for professional research and practice.

Central to these frameworks are three evidence-based pillars: early intervention, iterative feedback, and rigorous peer review.

The Pillars of Sustainable Writing Pedagogy

1. **Iterative Feedback and Scaffolding:** Moving beyond static assignments, pedagogical models such as the "progressive paper” where students revise sections based on actionable, prescriptive feedback–have proven highly effective. Feedback must address the synthesis of content, structural form, and contextual application to produce meaningful qualitative changes in student writing.

2. **Institutionalized Peer Review:** Peer review serves as more than an editing tool; it is a mechanism for developing student objectivity and self-examination. When integrated directly into laboratory curricula–such as through Argument-Driven Inquiry–peer review allows students to treat writing as an authentic scientific practice rather than an academic exercise. This process prepares students for the collaborative nature of professional science.

3. **Context-Driven Instruction:** To foster deep epistemic understanding, writing tasks must be grounded in information literacy and critical review. By moving toward a curriculum that treats writing as a scaffolded skill–developed from introductory courses through capstone research–departments can ensure that graduates are equipped to communicate complex scientific phenomena effectively.

To assist departments in transitioning toward these models, the following strategic framework is recommended based on the synthesis of current educational research.

Table 5- Strategic Intervention Framework for Chemistry Departments

Strategic Intervention	Pedagogical Focus	Expected Outcome
Departmental Integration	Moving from course-based to uniform, scalable curricula (e.g., video workshops).	Consistent writing standards and reduced faculty barriers.
Iterative Peer Review	Double-blind group reviews integrated into lab modules.	Enhanced objectivity, critical thinking, and communication skills.
Progressive Scaffolding	Incremental writing assignments (e.g., progressive papers) with feedback loops.	Longitudinal improvement in report structure and data synthesis.
Professional Alignment	Incorporating research proposals, literature reviews, and oral presentations.	Direct preparation for capstone research and chemical industry careers.
Literacy Development	Evaluating sources and developing arguments based on chemical concepts.	Advancement from functional to multi-dimensional chemical literacy.

As chemistry curricula evolve, the priority must be to create environments where writing is recognized as a vital scientific competency. By embedding these strategies into the undergraduate experience, chemistry departments can ensure that students move beyond the basic ability to record observations, ultimately gaining the capacity to articulate complex arguments, contribute to scientific discourse, and succeed in the professional chemical sciences.

References:

1. Marteel-Parrish A.E., Lipchock J.M. Preparing Chemistry Majors for the 21st Century through a Comprehensive One-Semester Course Focused on Professional Preparation, Contemporary Issues, Scientific Communication, and Research Skills // Journal of Chemical Education. – 2018. – Vol. 95, No. 1. – P. 68-75. – DOI: 10.1021/acs.jchemed.7b00439.

2. de Oliveira J.R.S., Queiroz S.L. Scientific Communication in Undergraduate Chemistry Courses: A Review // Química Nova. – 2015. – DOI: 10.5935/0100-4042.20150019.

3. Cardellini L. Chemistry: Why the Subject is Difficult? // Educación Química. – 2012. – Vol. 23. – P. 305-310. – DOI: 10.1016/S0187-893X(17)30158-1.

4. Cooper M.M., Klymkowsky M.W. Chemistry, Life, the Universe, and Everything: A New Approach to General Chemistry, and a Model for Curriculum Reform // Journal of Chemical Education. – 2013. – Vol. 90, No. 9. – P. 1116-1122. – DOI: 10.1021/ed300456y.

5. Stewart A.F., Williams A., Lofgreen J.E., Edgar L.J., Hoch L.B., Dicks A.P. Chemistry Writing Instruction and Training: Implementing a Comprehensive Approach to Improving Student Communication Skills // Journal of Chemical Education. – 2016. – Vol. 93, No. 1. – P. 86-92. – DOI: 10.1021/acs.jchemed.5b00373.

6. Fanguy M., Wang H.H., Lee K. Critical Review of Instructional Approaches to Graduate-Level Research Writing in Science, Technology, Engineering, and Mathematics // Review of Education. – 2025. – Vol. 13, No. 2. – DOI: 10.1002/rev3.70080.

7. Klein G.C., Carney J.M. Comprehensive Approach to the Development of Communication and Critical Thinking: Bookend Courses for Third- and Fourth-Year Chemistry Majors // Journal of Chemical Education. – 2014. – Vol. 91, No. 10. – P. 1649-1654. – DOI: 10.1021/ed400595j.

8. Jones M.L.B., Seybold P.G. Combining Chemical Information Literacy, Communication Skills, Career Preparation, Ethics, and Peer Review in a Team-Taught Chemistry Course // Journal of Chemical Education. – 2016. – Vol. 93, No. 3. – P. 439-443. – DOI: 10.1021/acs.jchemed.5b00416.

9. Morgan M.M., Murray G., Sala A.J., Johnson E.C., Wagner E.P. Cultivating Undergraduate Scientific Writing Proficiency through Interactive Video Workshops // Journal of Chemical Education. – 2025. – Vol. 102, No. 2. – P. 630-638. – DOI: 10.1021/acs.jchemed.4c01099.

10. O'Donnell J.L., Karr J.W., Lipinski B.M., Frederickson D. Developing Undergraduate Students' Critical Thinking Skills in a Chemical Communications Course and Beyond // ACS Symposium Series. – Washington, DC: American Chemical Society, 2019. – P. 41-55. – DOI: 10.1021/bk-2019-1327.ch004.

11. Robinson M.S., Stoller F.L., Horn B., Grabe W. Teaching and Applying Chemistry-Specific Writing Skills Using a Simple, Adaptable Exercise // Journal of Chemical Education. – 2009. – Vol. 86, No. 1. – P. 45. – DOI: 10.1021/ed086p45.

12. Deng Y., Kelly G.J., Xiao L. The Development of Chinese Undergraduate Students' Competence of Scientific Writing in the Context of an Advanced Organic Chemistry Experiment Course // Chemistry Education Research and Practice. – 2019. – Vol. 20, No. 1. – P. 270-287. – DOI: 10.1039/C8RP00171E.

13. Yamaguchi K.K. de L., Yamaguchi H.K. de L., Silva J.D.S.E. Evaluating of Difficulties of Undergraduate on the Report of Chemistry Lab Experimental // Figshare. – 2021. – DOI: 10.6084/m9.figshare.14278924.

14. Yamaguchi K.K. de L., Yamaguchi H., Silva J. da S. e. Avaliação das Dificuldades dos Estudantes de Graduação na Elaboração de Relatórios de Química Experimental // Química Nova. – 2020. – Vol. 43. – P. 636-641. – DOI: 10.21577/0100-4042.20170501.

15. Zwicky D., Hands M.D. The Effect of Peer Review on Information Literacy Outcomes in a Chemical Literature Course // Journal of Chemical Education. – 2016. – Vol. 93, No. 3. – P. 477-481. – DOI: 10.1021/acs.jchemed.5b00413.

16. Ead H.A., Fahmy H.M., Elbadry A. Academic Writing Challenges Faced by Chemistry Doctoral Students: A Self-Study Informed by Three Writing Theories // International Journal of Education and Learning. – 2023. – Vol. 5, No. 2. – P. 113-123. – DOI: 10.31763/IJELE.V5I2.1248.

17. Ogunsolu O.O., Wang J.C., Hanson K. Writing a Review Article: A Graduate Level Writing Class // Journal of Chemical Education. – 2018. – Vol. 95, No. 5. – P. 810-816. – DOI: 10.1021/acs.jchemed.7b00838.

18. Mammino L. Being Consistent with Reality: A Great Challenge for Chemistry Laboratory Reports // Unisa Institutional Repository (University of South Africa). – 2016. – Available: http://hdl.handle.net/10500/22881.

19. Hyde J., Wright J.S., Xie A. Progression from Chinese High School onto a TransNational Chinese-UK University Joint BSc Degree in Chemistry: An International Study Focussing on Laboratory Practical Skills // Chemistry Education Research and Practice. – 2024. – Vol. 25, No. 1. – P. 151-170. – DOI: 10.1039/D3RP00099K.

20. Wackerly J.W. Stepwise Approach to Writing Journal-Style Lab Reports in the Organic Chemistry Course Sequence // Journal of Chemical Education. – 2018. – Vol. 95, No. 1. – P. 76-83. – DOI: 10.1021/acs.jchemed.6b00630.

21. Doménech N.G., Arjona A.S., Prochukhan N., Scully N., O'Donoghue J. How to Write a Scientific Lab Report: A Short-Term Intervention for Improving Chemistry Writing Skills // Journal of Chemical Education. – 2024. – Vol. 101, No. 3. – P. 903-909. – DOI: 10.1021/acs.jchemed.3c00651.

22. Sherwood D.W., Kovac J. Writing in Chemistry: An Effective Learning Tool // Journal of Chemical Education. – 1999. – Vol. 76, No. 10. – P. 1399. – DOI: 10.1021/ed076p1399.

23. Finkenstaedt-Quinn S.A., Milne S., Petterson M.N., Chen J., Shultz G.V. Student Experiences with Peer Review and Revision for Writing-to-Learn in a Chemistry Course Context // Written Communication. – 2024. – Vol. 41, No. 4. – P. 632-663. – DOI: 10.1177/07410883241263542.

24. Hartberg Y., Gunersel A.B., Simpson N.J., Balester V. Development of Student Writing in Biochemistry Using Calibrated Peer Review // Journal of the Scholarship of Teaching and Learning. – 2008. – Available: https://scholarworks.iu.edu/journals/index.php/josotl/article/view/1693.

25. Walker J.P., Sampson V. Argument-Driven Inquiry: Using the Laboratory to Improve Undergraduates' Science Writing Skills through Meaningful Science Writing, Peer Review, and Revision // Journal of Chemical Education. – 2013. – Vol. 90, No. 10. – P. 1269-1274. – DOI: 10.1021/ed300656p.

26. Whelan R.J., Zare R.N. Teaching Effective Communication in a Writing-Intensive Analytical Chemistry Course // Journal of Chemical Education. – 2003. – Vol. 80, No. 8. – P. 904. – DOI: 10.1021/ed080p904.

МРНТИ 34.01.45 https://doi.org/10.51889/3005-6217.2026.88.2.003

Садирдин А.*[1], Бекенова Н.[1]

[1]*Казахский национальный педагогический университет имени Абая, г. Алматы, Казахстан*

**e-mail:* aruuu.sadirdin@gmail.com

МЕТАКОГНИТИВНЫЕ СТРАТЕГИИ КАК МЕТОД ФОРМИРОВАНИЯ НАУЧНОГО СТИЛЯ МЫШЛЕНИЯ СТАРШЕКЛАССНИКОВ ПРИ ИЗУЧЕНИИ БИОЛОГИИ

Аннотация

Модернизация образовательной системы Республики Казахстан диктует необходимость перехода от трансляции готовых знаний к формированию научного мировоззрения. В условиях преподавания биологии в старших классах средней школы №135 г. Алматы это требует внедрения инструментов, развивающих стиль научного мышления. Метакогнитивные стратегии позволяют учащимся распознавать и корректировать свои когнитивные процессы, что важно для глубокого понимания естественнонаучной картины мира. Исследование основано на фундаментальных работах Дж. Флейвелла (Концепция метапознания), Дж. Новака (Метод отображения понятий), также на идеи Л.С. Выготского о развитии высших психических функций и рефлексов. В контексте казахстанского образования рассматриваются принципы функциональной грамотности и обновленного содержания обучения. В ходе опытно-экспериментальной работы внедрен комплекс метакогнитивных средств, в том числе «Метакогнитивные контрольные листы», которые учащиеся используют до, во время и после выполнения лабораторных и практических работ. Эти листы позволяют учащимся самостоятельно планировать исследования, прогнозировать результаты и рефлексивно оценивать свои собственные стратегии мышления. Также использовались методы концептуального картирования и анализа проблемных биологических ситуаций. Тестирование этих методов показало качественный рост научного стиля мышления: учащиеся стали более эффективно выявлять причинно-следственные связи и более сознательно применять теоретические знания для решения практических задач. Внедрение метакогнитивных контрольных листов способствовало превращению пассивного усвоения материала в активное формирование научного мировоззрения, что подтверждается результатами педагогической диагностики и повышенным интересом к научно исследовательской деятельности.

Ключевые слова: метакогнитивные стратегии, научное мировоззрение, научный стиль мышления, биологическое образование, старшеклассники, листы метакогнитивного контроля