Writing Scaffolding Introduction and Effectiveness Across Chemistry Curriculum

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Abstract: Scientific writing is essential for students' future success in STEM careers, yet many chemistry and other science majors receive little formal instruction in writing. Scientific writing is a critical skill for student success in STEM fields, yet formal instruction in writing remains limited across many chemistry programs. To address this gap, a comprehensive writing support system—referred to here as "writing scaffolding"—was instituted department-wide throughout the entire chemistry curriculum, spanning from students' first year through graduation and aligning with the degree plan as students progress through their coursework. In this context, "writing scaffolding" refers to an integrated, multi-course strategy that introduces, reinforces, and assesses scientific writing through structured support at each curricular level. This initiative includes three key components: an introductory course schedule, a shared departmental writing style guide, and standardized rubrics for major writing sections. The formal rollout began with instructors taking responsibility for introducing different components of scientific writing (such as abstracts, introductions, and discussions) and modeling disciplinary norms for structure and tone. Students receive multiple rounds of feedback on newly introduced sections, while

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earlier writing skills are reinforced in later courses. This study assessed the effectiveness of the scaffolding effort midway through implementation, focusing on writing outcomes in Quantitative Chemical Analysis. Student work from before and after implementation was blindly reevaluated in triplicate by faculty using the new rubrics. Rubric criteria included clarity of writing, appropriate structure, use of scientific tone, and integration of data. Statistical analysis of the scores was used to determine the impact of the writing scaffolding. Results showed a modest improvement, with average scores increasing from 6.7 ± 1.4 (n=65) to 8.1 ± 1.0 (n=48) on a 10-point scale following implementation. The most notable improvements were in structural organization and clarity of discussion sections.

Introduction

Writing is a fundamental part of scientific literacy, which encompasses the ability to read, write, and speak about scientific concepts in an informed, critical, and communicative way (Howell and Brossard, 2021; Shaffer et al., 2019). In chemistry education, however, writing instruction is often underemphasized in favor of content mastery and theoretical understanding (Durst and Newell, 1989). Developing students' linguistic and rhetorical skills—particularly through reading and writing scientific texts—can support deeper comprehension and critical engagement with scientific material (Glynn and Muth, 1994). Effective strategies to improve student writing in chemistry have included peer instruction (Golde et al., 2006), progressive writing assignments,(van de Pol et al., 2010) and single-course scaffolding with peer review (Weaver et al., 2014). More comprehensive approaches that scaffold writing across the curriculum have shown promise in chemistry and other STEM disciplines (Cohen and Williams, 2019; Klein and Aller, 1998; Whitaker and Reimer, 2019).

Beyond academia, employers consistently rank communication and critical thinking among the top skills they seek in college graduates (Ater Kranov and Khalaf, 2016; Morreale et al., 2017; Stevens, 2005; Stevens et al., 2019). These abilities are closely tied to scientific writing, which requires clarity, logical reasoning, and the ability to synthesize and present information (Paul and Elder, 2020). Yet, instruction in writing and peer review is often unstructured, inconsistently implemented, or overlooked entirely in STEM curriculum (Cho and Schunn, 2007; Kramer et al., 2022; Puntambekar and Hubscher, 2005). Kramer emphasizes the importance of timing and structure in peer review, showing that students' perception of authority and their capacity for critical thinking evolve over time. Structured feedback is more impactful when paired with intentional, developmentally appropriate writing assignments (Kramer et al., 2022).

In response to these needs, the Department of Chemistry at the University of Central Oklahoma (UCO) launched a curriculum-wide scientific writing scaffolding initiative. The program was designed to embed scientific writing instruction consistently and progressively across the chemistry major. Instructors were responsible for introducing, modeling, and assessing different sections of scholarly writing—such as abstracts, methods, results, and discussions—throughout the curriculum. A universal set of rubrics was developed to assess each section, helping to standardize expectations and reduce inconsistencies in grading and feedback across courses (Cockett and Jackson, 2018; Finkenstaedt-Quinn et al., 2019; Weaver et al., 2014).

An introduction timeline to academic writing has been established to align with the most common student path through the chemistry curriculum. This timeline is designed to have students producing full, journal-style reports by their fifth semester in the department. Courses involved in the scaffolding are required for the chemistry major and include both traditional content/lab pairings—such as General Chemistry, Organic Chemistry, and Physical Chemistry—as well as department-specific offerings like Professionalism in Chemistry, Directed Research, and Capstone.

Each course introduces specific sections of scientific writing, with expectations building as students advance. Early courses focus on writing basic abstracts, tables, and results sections, while upper-division courses emphasize full-length scientific papers, literature searches, and oral/poster presentations. Students receive guided feedback and complete multiple rounds of revision, in line with departmental guidelines. Instructors may structure this as three rounds of feedback on a single assignment or one round of feedback across three separate assignments.

All writing assignments are scored using department-wide rubrics developed collaboratively by faculty and vetted by the curriculum committee. These rubrics have helped standardize instruction, reduce variability across instructors, and minimize student confusion around expectations. Table 1 outlines the scaffolding sequence and identifies the writing components introduced in each course.

Individual chemistry courses are listed along with the writing sections introduced in each. These sections were emphasized throughout the semester with multiple rounds of feedback. Sections from previous semesters were also included, though they may not have undergone the same level of feedback in those courses.

A pilot of this program began the semester before full departmental implementation with two sections of General Chemistry I Laboratory. Full implementation of the writing scaffolding program began in the following semester. After three years, all required courses in the chemistry major were participating in the initiative, and students were consistently producing journal-style writing and oral presentations by their junior year.

While this scaffolding structure was carried through to students' final year—including senior projects such as Capstone and Directed Research—quantitative evaluation of senior-lev-

Table 1. Individual chemistry courses are found within each cell above. Writing sections listed under the course are those which are introduced in the curriculum for that course. Courses continue to practice skills taught in prior semesters in the table.

1st Semester	General Chemistry 1 Lab *Abstract *Calculations/Tables		
2nd Semester	General Chemistry 2 Lab *Results *Procedures		Professionalism in Chemistry 1 *Literature Search
3rd Semester	Quantitative Analysis *Equation Editor *Discussion *Conclusions *Proper Lab Notebook *Oral Presentation	Organic 1 Lab *Methods *Chem Draw/ Biovia *Mechanisms *Discussions *Proper Lab Notebook	
4th Semester	Instrumental Analysis *Introduction *Methods	Organic 2 Lab *Introductions *Conclusions	Professionalism in Chemistry 2 *Citations *Poster Presentations
5th Semester	Experimental Physical Chemistry Lab *Electronic Notebook *Full Reports	Experimental Biochemistry Lab *Full Reports	Inorganic Chemistry Lab *Full Reports
6th Semester	Directed Research *Full Report *Oral Presentations	Capstone *Full Report *Oral Presentation	

el writing has proven difficult due to variability in project formats and the relatively small number of students completing each course in a given year. However, faculty have noted a clear improvement in the overall quality and clarity of student writing in these upper-division experiences. Anecdotally, the department believes that students are graduating with stronger writing skills, better rhetorical awareness, and greater confidence in scientific communication.

This study presents a mid-program assessment of the initiative, focusing on writing outcomes in Quantitative Chemical Analysis (CHEM 2104). The goal was to determine whether the scaffolded writing instruction had a measurable impact on student writing and to identify specific areas of strength or continued need.

Methods

This project evaluated the effectiveness of a department-wide writing scaffolding initiative by analyzing student laboratory reports from the Quantitative Chemical Analysis Laboratory course. While the scaffolding process was already embedded across the curriculum, this study focused specifically on measuring its impact on students' writing performance.

Lab reports submitted prior to the implementation of the scaffolded writing approach were compared with those submitted post-implementation. Because electronic submission of lab reports has been standard for several years, a substantial archive of student work was available for analysis. These archived reports were deidentified and randomly mixed with current reports written under the scaffolding model to eliminate potential reviewer bias. All feedback was scored using department-approved rubrics, and reports were anonymized prior to evaluation. This project was reviewed and approved by the University of Central Oklahoma Institutional Review Board (IRB) as IRB Exempt, ensuring compliance with ethical standards for research involving student work.

A total of 136 lab reports were included in the study. Each report was scored independently by either three ($n = 74$) or four ($n = 62$) randomly selected reviewers. Reviewers consisted of UCO Chemistry Department faculty members trained in using the department's universal rubrics.

Each report was evaluated using a detailed rubric that included ten subscores, each rated on a 1–5 scale, with 5 being the highest. The rubric grouped scoring criteria into three primary sections:

- Abstract: including Purpose, General Methodology, and Major Results;
- Results and Discussion: including Results Presentation, Data Tables, Discussion of Logic Behind Calculations, and Discussion of Data Quality/Error Analysis;
- Formatting: including Appropriate Length, Formatting, and Spelling and Grammar.

In addition to the ten section scores, each report also received one overall score rated on a 1–10 scale, with 10 being the highest.

Each report received quadruplicate scoring wherever possible, aligning with best practices in multi-rater reliability (Rosenthal and Rosnow, 2008). Scores for each section were averaged, and both subsection scores and overall scores were analyzed statistically. Independent samples t-tests assuming unequal variances were used to compare mean scores before and after implementation of the writing scaffolding. Cohen's d was calculated to determine effect sizes, with p-values < 0.05 considered statistically significant and $d > 0.8$ considered a large effect. All statistical analysis was conducted using R version 4.2.0.

Results and Discussion

To assess the effectiveness of the department-wide scientific writing scaffolding initiative, student lab reports from the Quantitative Chemical Analysis course were evaluated using a standardized rubric. These reports, collected before (n = 62) and after (n = 74) the implementation of the scaffolding program, were assessed across ten rubric categories and an overall score. Summary statistics are presented in Table 2, and boxplots for subscores and overall scores are shown in Figures 1 and 2.

Table 2. Comparison of mean lab report scores before and after implementation of the department-wide writing scaffolding program. Scores represent averages across ten rubric categories (each rated on a 1–5 scale) and one overall score (rated on a 1–10 scale). Statistically significant improvements were observed in all categories post-implementation, with large effect sizes in most cases (Cohen's d > 0.8).

Category	Before (n = 62) mean (sd)	After (n = 74) mean (sd)	t	p-value	effect size
Purpose	3.76 (0.62)	4.25 (0.40)	5.38	<0.001	0.94
General Methodology	3.53 (0.75)	4.05 (0.50)	4.66	<0.001	0.82
Major Results	3.63 (0.76)	4.10 (0.45)	4.28	<0.001	0.75
Results	3.37 (0.64)	4.14 (0.43)	8.12	<0.001	1.42
Data Tables	3.63 (0.64)	4.33 (0.37)	7.50	<0.001	1.32
Discussion of Logic	3.14 (0.72)	4.19 (0.46)	9.88	<0.001	1.73
Discussion of Data Quality	3.04 (0.76)	3.94 (0.51)	7.85	<0.001	1.37
Appropriate Length	3.36 (0.70)	4.48 (0.28)	11.83	<0.001	2.10
Appropriate Formatting	3.54 (0.55)	4.30 (0.36)	9.27	<0.001	1.62
Spelling & Grammar	3.69 (0.47)	4.09 (0.43)	5.14	<0.001	0.89
Overall Score	6.74 (1.07)	8.02 (0.74)	7.96	<0.001	1.39

b. ACS scores

	Before (n = 103) mean (sd)	After (n = 82) mean (sd)	t	p-value	effect size
ACS Scores	23.8 (5.85)	24.4 (6.72)	0.61	0.543	0.09

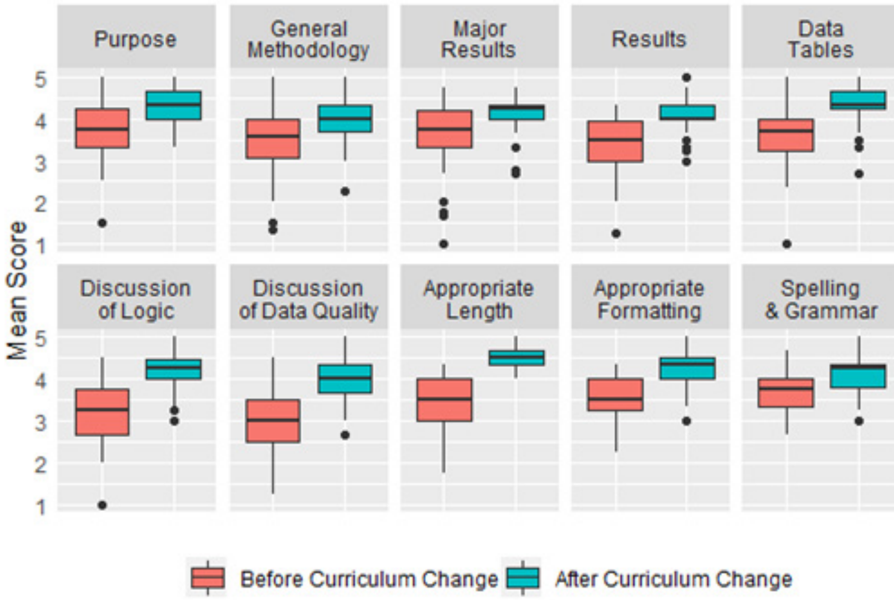

Figure 1. Boxplots of sub scores for each of the categories scored on a 1-5 scale with 5 being the highest.

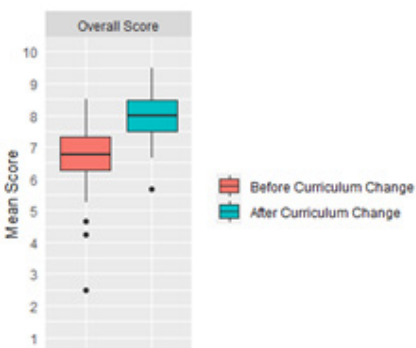

Figure 2. Boxplots of overall scores

The analysis revealed statistically significant improvements across all rubric categories. Post-scaffolding reports scored significantly higher in all ten subscores and in the overall score ($p < 0.001$ for all comparisons). Effect sizes (Cohen's d) were large for all but one category, suggesting the improvements were not only statistically significant but also educationally meaningful.

One of the most striking trends was the marked improvement in writing elements requiring higher-order cognitive skills. The Discussion of Logic (effect size $d = 1.73$), Appropriate Formatting ($d = 1.62$), and Discussion of Data Quality ($d = 1.37$) categories all showed large gains. These areas are often the most challenging for students and typically benefit the most from repeated exposure, guided practice, and targeted feedback—all key features of the scaffolding model. Students seemed to gain a better grasp of how to explain their reasoning and address sources of error, indicating a deeper understanding of experimental context and implications.

The Appropriate Length category showed the single largest effect size ($d = 2.10$), suggesting students became much more adept at adhering to structural expectations. This likely reflects the influence of department-wide formatting norms and clear expectations reinforced consistently across courses. Similarly, improvements in Spelling and Grammar ($d = 0.89$) and Major Results ($d = 0.75$), though less dramatic, still point to improved clarity and communication over time.

The overall score increased from a mean

of 6.74 (±1.07) before the curriculum change to 8.02 (±0.74) after implementation, with a large effect size (d = 1.39). These findings suggest that the writing scaffolding program has had a broad and positive impact on student writing competency, particularly in their ability to structure and articulate scientific arguments.

In contrast, the analysis of ACS Analytical Exam scores did not show a statistically significant difference between the pre- and post-scaffolding groups (Table 2b; Figure 3). The average scores rose slightly from 23.8 (±5.85) to 24.4 (±6.72), but the effect size was negligible ($d = 0.09$, $p = 0.543$). This outcome is not unexpected, as the ACS exam emphasizes chemistry content knowledge rather than communication skills. The lack of change in ACS performance reinforces that gains observed in writing were likely due to the scaffolding initiative rather than a broader shift in overall academic performance.

Although formal data collection in senior-level courses was limited, anecdotal feedback from faculty indicates that writing quality in capstone and research-based courses has improved. In Capstone for Chemistry and Directed Research courses, faculty have noted that students enter with stronger foundational skills, are better prepared to articulate their work in writing, and require less remedial instruction in basic formatting and structure. The variability of senior projects—ranging from experimental reports to community outreach projects to literature reviews—made systematic rubric scoring difficult. However, the department's collective impression is that the scaffolding program has led to greater consistency and confidence in student writing at the senior level.

These anecdotal observations align well with broader research on disciplinary writing development. Studies have shown that peer review and structured writing interventions benefit students differently depending on their academic maturity (Kramer et al., 2022). Lower-division students tend to show the greatest gains in writing mechanics, while upper-division students develop more advanced skills such as synthesis and critical evaluation. Our results from the Quantitative Chemical Analysis course reflect this pattern, with middle-stage students showing significant growth in both foundational and analytical writing dimensions

Overall, this project supports the value of a consistent, department-wide writing scaffold. By explicitly introducing different sections of scientific writing across multiple courses, using shared rubrics, and requiring multiple rounds of revision, students are better equipped to engage in scientific communication. Importantly, this approach appears to be effective without negatively impacting other learning goals, such as content knowledge.

Looking forward, the department plans to continue refining rubric language, encouraging faculty development around writing instruction, and exploring ways to extend more structured peer review into upper-division courses. With time and consistent application, the scaffolding initiative is expected to further close the gap between novice and expert writers, ultimately producing graduates who can communicate their scientific knowledge with clarity and professionalism.

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