JOURNAL OF CHEMICAL EDUCATION

Article

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Using a Progressive Paper To Develop Students' Writing Skills

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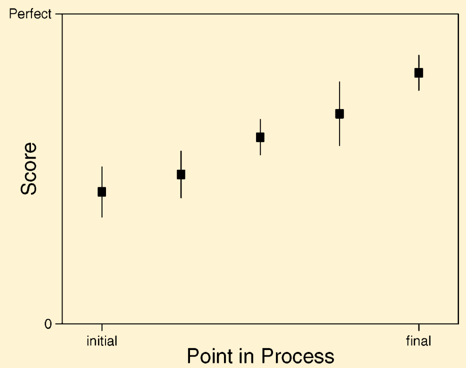
Supporting Information

ABSTRACT: This article describes the use of a progressive paper in a capstone course to develop students' writing skills. A progressive paper is one that students write one section at a time: as they add each new section, they go back and revise the previous parts based on actionable feedback from the instructor. In this course, the progressive paper takes the form of a laboratory report for a multistep synthesis. Students revise and update this paper throughout the semester. Each revision coincides with an additional step in the synthesis. This results in a complete journal-style article at the end of the semester. The students in this course show significant improvement in their writing skills throughout this process.



KEYWORDS: *Upper-Division Undergraduate, Curriculum, Laboratory Instruction, Communication/Writing, Problem Solving/Decision Making, NMR Spectroscopy*

■ INTRODUCTION

Developing effective communication skills is a common goal in undergraduate curricula. Many authors have discussed the importance of writing and how to develop writing skills in both general education classes and within the major.[1] In chemistry, writing in the discipline is widely considered an important part of the undergraduate curriculum[2] and it is embedded into many chemistry courses in a variety of forms.[3−24]

It is also common for chemistry departments to have a capstone course that requires students to integrate what they have learned throughout the undergraduate curriculum.[25−27] Advanced Synthesis and Spectroscopy is the capstone course for chemistry majors at Widener University. In this class, students conduct a multistep synthesis and use a variety of spectroscopic techniques to characterize the product from each step in the synthesis. The class also emphasizes writing, which is implemented using a progressive paper structured in parallel with the multistep synthesis. This progressive paper engages students in the writing process, furthers their understanding of the scientific writing process, and significantly improves student writing.

■ WRITING A PROGRESSIVE PAPER

In a progressive writing assignment, students write their paper in sections. For each section, the instructor provides detailed feedback, which the students use to revise and extend the paper. Ideally, each section is connected to the course content so that the paper unfolds along with the course. At the end of the semester, the student has written an extensive paper that has been revised multiple times.

This assignment design is significantly different from the standard college paper. When students submit a single draft of a paper for grading, feedback from the instructor can be ignored without any consequences for the student. Instructors often address this dilemma by having students submit a rough draft for comments and then a final version, giving students one opportunity to make changes. A progressive paper assignment increases the number of revisions and models the process frequently used for professional writing: manuscripts undergo multiple revisions and authors receive feedback from colleagues and reviewers that result in additional revisions. At the end of the semester, students have produced a substantial academic paper following much the same process as a writer in the discipline. The assignment design for a progressive paper is also consistent with literature from psychology on the development of expertise in writing and in other fields.[28] Kellogg and Raulerson[29] make the following recommendations for developing writing proficiency:

> *Skill development involves (1) exertion to improve performance, (2) intrinsic motivation to engage in the task, (3) practice tasks that are within reach of the individual's current level of ability, (4) feedback that provides knowledge of results, and (5) high levels of repetition over a period of several years.*

During the semester when students are taking this course, the progressive paper addresses all of these criteria. The instructors provide abundant feedback, and over the semester, students repeatedly rewrite and revise their paper. The exertion and motivation come from holding students to high expectations, making them accountable for meeting those expectations, and providing concrete and sustained feedback to the writing they produce at each stage of the process. Breaking the

dx.doi.org/10.1021/ed300312q | J. Chem. Educ. XXXX, XXX, XXX−XXX

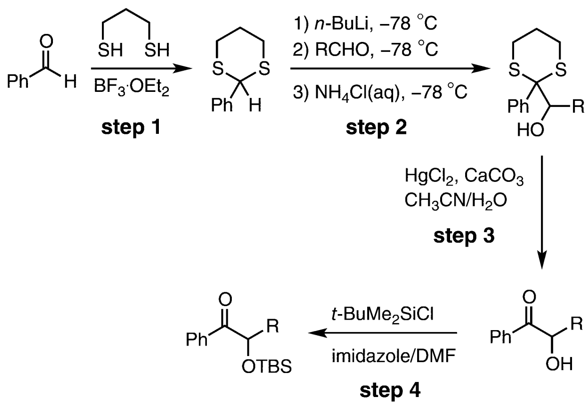
paper into parts and spreading it out over the entire semester keeps the tasks manageable while also giving students the opportunity to learn through repetition.

COURSE DESIGN FOR ADVANCED SYNTHESIS AND SPECTROSCOPY

Students in Advanced Synthesis and Spectroscopy write a progressive paper that is tied to a multistep synthesis. The course includes a one-credit lecture integrated with a two-credit lab. Two instructors, one with a background in organic chemistry and the other with a background in spectroscopy, team-teach the course. The students are senior chemistry majors and the class typically has three to four students each year. The students who take this course generally have a wide range of academic abilities and career goals. They have gone on to graduate work, professional school, and industry. The small class size makes it possible for the instructors to provide intensive, individualized feedback for over 100 pages of written work from each student. It should be noted that instructors interested in using progressive papers for larger courses should carefully consider the length of the assignments and the number of revisions. Having five revisions of a paper in a larger course would require using shorter assignments or some type of peer-review process to keep the grading manageable.

Scheme 1[30] shows the synthetic pathway used for the initial course. This four-step synthesis allows each student in the class

Scheme 1. Synthesis Scheme[a]



[a]A variety of aliphatic aldehydes have been successfully used during step 2.

to use a different aldehyde so that after the second step they all have different products. The students write a progressive paper that consists of five writing assignments tied to the synthetic steps. For each revision of the paper, students add the experimental section and the results and discussion section for another step of the synthesis. They also extensively revise and update the previous sections based on the instructor feedback and any additional spectroscopic data they collect on the previous materials. The final laboratory report is a complete journal-style article that includes an abstract, introduction, experimental, and discussion sections that describe the entire synthesis and the characterization of all materials. Students follow a departmental writing guideline, based on the *ACS Style Guide*,[31] which outlines expectations for student papers. A copy of the departmental writing guidelines is included in the Supporting Information.

With each revision of the paper, students receive extensive feedback on their writing and their experimental results. Much of the feedback is focused on the mechanics of structuring a scientific paper and effectively presenting experimental evidence. In the first few drafts, students receive comments about using figure captions, designing effective tables, font size, formatting figures, writing style, grammar, usage, proper citations, and the role of each section in the paper. As these mechanics of the paper improve, the comments focus more on using active voice, proper verb tense, and integration of results to more effectively support claims. Students also receive a significant amount of feedback to keep the focus on their claims by cutting extraneous information.

In addition to feedback on how to write clearly, the instructors also comment on weaknesses in the spectroscopic evidence. Students are directed to conduct additional experiments to provide more effective evidence for supporting their claims. This feedback provides the structure for the course, guiding student progress in lab. The first week in lab, students are told to characterize their starting materials. Because students use IR and ^{1}H NMR in earlier courses, they start with these techniques and the first draft of the paper includes the results and discussion for characterizing the starting materials. The feedback from the instructor indicates that ^{13}C NMR data are needed to prove the structure of the starting materials. After receiving this feedback students learn about ^{13}C NMR data acquisition, data processing, and interpretation so that in the next draft of the paper they can add ^{13}C NMR to the results and discussion for both the starting materials and the product of the first step. Using the ^{13}C NMR spectrum in the paper also helps students shift from assigning peaks to using the spectroscopic evidence to prove the structure. With each step of the synthesis, the product becomes more complex; students either discover for themselves that they need to conduct additional spectroscopic experiments, or the instructors identify these experiments in the feedback for the papers.

On subsequent drafts, students follow a similar process as they continue to refine their evidence with additional spectroscopic data and add steps in the synthesis. By the final revision of the paper, students are using IR, ^{1}H NMR, ^{13}C NMR, DEPT, COSY, HETCOR, and mass spectrometry to determine the structure of the final product. As they revise and rework each section of the paper, the students learn to synthesize the information from different spectroscopic experiments to effectively prove the structure of each material; concomitantly, they learn what additional experiments are necessary to make an effective argument about their findings. Table 1 shows how this feedback is integrated into the course. This process lets the feedback from the paper guide the spectroscopy used for characterization, and introduces the topics for lecture. This course design integrates the lecture and laboratory components of the course as each new spectroscopic technique discussed in lecture solves a problem students have encountered in the laboratory. Students use this to resolve weaknesses in their discussion and improve the papers. The Supporting Information provides copies of all five drafts of a paper, including comments for one student in order to provide examples of the type of comments students receive.

GRADING

Students submit each paper electronically. The two faculty members teaching the course provide extensive feedback using the comment feature in word-processing software. After

Table 1. Course Outline

Week	Laboratory	Lecture Topics	Paper and Assignments	Feedback
1	Characterize reactants	Designing a synthesis		
2	Interpretation of data	Advanced NMR processing	Draft 1: IR, ^{1}H NMR of starting materials	Add ^{13}C NMR and prove structure
3	Step 1 of synthesis	^{13}C NMR Interpretation		
4	Purify step 1		Problem set: Unknown NMR spectra	
5	Characterize step 1	Synthesis mechanisms		
6	Step 2 of synthesis		Draft 2: Revise, add ^{13}C NMR and step 1 and 2 procedure	Add DEPT
7	Purify step 2	DEPT interpretation	Problem set: Unknown DEPT spectra	
8	Characterize step 2			
9	Step 3 of synthesis	Chemical shift and symmetry	Draft 3: Revise above, add DEPT and step 3 procedure	Add 2D NMR
10	Purify step 3	2D NMR		
11	Characterize step 3	NMR decoupling and relaxation	Draft 4: Revise above, add COSY and HETCOR	Add mass spectrometry
12	Step 4 of synthesis	Mass spec interpretation	Problem set: Unknown mass spectra	
13	Purify and characterize step 4		Synthesis problem set	
14		Oral presentations	Draft 5: Revise above, add MS, abstract, intro and step 4	

commenting on the laboratory report, each instructor scores the paper using a rubric developed by the chemistry department. The seven criteria for this rubric are listed in Table 2, with the weighting used for determining the student scores presented in this paper. Students are evaluated on a five-point scale ranging from developmental (1) to masterful (5), and this scale is applied to each of the seven criteria. The first two items are related to the claim the student makes in the laboratory report: does the student make an arguable claim and reach a reasonable conclusion? The next two items address the evidence the student uses to support the claim: is the evidence relevant and does the student synthesize different ideas to effectively present this evidence? Items five and six relate to audience awareness: is the organizational pattern effective and does the student use appropriate style and mechanics? The final item is specific to writing in chemistry: does the student effectively use structures, tables, and figures?

After each instructor has made comments and scored the paper, the instructors meet to discuss each laboratory report and determine the student grade. For each laboratory report, the student receives two sets of scores. One score is the grade for the assignment based on the instructors' expectations at that point in the course. The second score represents the grade that the work would receive if the draft were submitted as the final laboratory report. For example, on the first draft a student will receive a good grade for evidence if they assign all the peaks in the ^{1}H spectrum and can explain the chemical shift, integration, and splitting. For the final draft, however, students will need to integrate this information with additional spectra to prove the structure. On the final draft a student who only assigns peaks in the spectra to the structure will receive a very low score. This dual scoring system allows student work to be graded based on realistic expectations as their writing develops during the course, but also clearly communicates how expectations will increase for the final laboratory report.

EVALUATION OF THE PROGRESSIVE PAPER

The original intent of the dual scoring system was to clearly communicate the instructors' expectations for the final draft without discouraging the students. This grading system provides a grade that is consistent with the expectations for the quality of writing in each draft, while emphasizing that students have to go beyond simply addressing the comments from the instructors and making minor corrections for each draft. To receive a good grade on the final paper, students need to revise and restructure their report.

The second score, which is based on expectations for the quality of the student writing at the end of the course, also provides an opportunity to examine how student writing improves with each step of the progressive paper. Both authors use this scoring rubric for grading and assessment in a variety of courses and have used a similar rubric for round-robin assessment of effective communication in student papers from general education courses. The authors have made a conscious effort to have consistent expectations for this score so that comparisons between drafts are meaningful. Although the results shown here are not from an external evaluation, and therefore do not meet the criteria for a peer-reviewed study, they do help to illustrate how student writing improves in this course. Based on this score, every student who has taken this class shows improvement in their writing.

Figure 1 shows the average student scores for the five revisions of the laboratory report submitted by 10 students who completed the course in fall 2008, 2009, and 2011 (the course was not offered in 2010). Although chemistry students at Widener are required to do a significant amount of writing, it is clear from the first draft that at the start of the semester these seniors have not mastered the conventions for writing a scientific paper. Student writing improves with each additional draft of the laboratory report. After five revisions, all students in the class reached a competent level (3 out of 5) on the overall paper. Six of the 10 students had a final score of 4 or higher on the final draft. The average student score increased by 2.0 on the 5-point scale. The smallest overall improvement was 0.8, by a student who put in minimal effort until the final draft. The largest overall improvement was 2.7, by a student who made steady improvement across all five drafts. Only one student did not show any improvement after the fourth draft: this student's fourth draft scored 4.6, the highest score in the group. The trends for each subscore in the grading rubric are similar to the overall scores.

The student scores were also analyzed using a one-way, repeated measures ANOVA. The repeated measures ANOVA is an omnibus test that allows simultaneous comparison of all five

Table 2. Grading Criteria for Widener University Department of Chemistry Writing Rubric

Criteria (Weight)	Evaluation of Material Merits a Rating Equivalent to		
	Masterful (5)	Competent (3)	Developmental (1)
Claim (10%)	Writer presents an arguable claim, grounded in deep understanding of the discipline and reflecting critical and original thought.	Writer presents an intelligible claim, evidencing basic understanding of the discipline and some critical thought.	Writer presents a shaky or simplistic claim, which seems to reflect weak grasp of the discipline.
Conclusion (10%)	Writer reaches reasonable and interesting conclusions based on claims and evidence.	Writer reaches conclusions that are, for the most part, solid.	Writer reaches tenuous, illogical, or irrelevant conclusions.
Evidence (30%)	Writer provides appropriate, relevant evidence, chosen to further claims and establish credibility, and evaluated and analyzed according to writer's purpose and context.	Writer provides some evidence that, while not fully analyzed, is mostly relevant.	Writer provides no evidence, or evidence presented has little to do with the purported claim.
Synthesis (10%)	Writer demonstrates an awareness of disciplinary contributions and synthesizes the ideas of others with his or her own.	Writer demonstrates some awareness of disciplinary contributions, although synthesis may be lacking.	Writer offers little or no synthesis of information or research with the writer's own ideas.
Audience (10%)	Writer constructs and maintains an organizational pattern that facilitates reader understanding of the argument and information presented.	Writer constructs an organizational pattern that allows for general understanding, although components of the structure may be weak or ill sustained.	Writer constructs a disjointed or flimsy organizational pattern that fails to lead the reader effectively through the text.
Style and Mechanics (10%)	Writer employs style and mechanics suited to the genre of academic writing and the specifics of the discipline, including appropriate word choice, usage, and documentation.	Writer follows the expectations of academic writing, although there may be flaws in diction, usage, or documentation.	Writer employs style and mechanics inconsistent with the expectations of academic writing: misuse of diction, poor usage, flawed documentation.
Figures and Tables (20%)	•Structures are drawn using a chemical drawing program with correct bond lengths and angles.	•Structures have incorrect angles or are not well labeled.	•Structures are not present, are hand drawn, or are not original.
	•Tables contain appropriate information and are aesthetically pleasing.	•Tables are not properly formatted (unnecessary spacing, etc.).	•Tables do not contain the appropriate information.
	•Figures are clear and original if possible; reproduced figures are minimal and properly referenced.	•Figures are not numbered and captioned.	•Figures are not legible or used a screen shot.

dx.doi.org/10.1021/ed300312q | J. Chem. Educ. XXXX, XXX, XXX−XXX

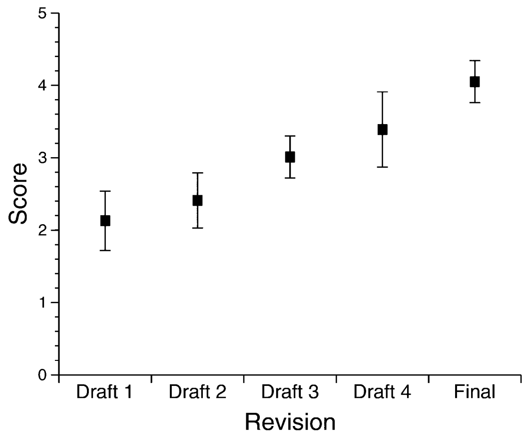


Figure 1. Student overall scores from 1 (developmental) to 5 (masterful) on each revision of the paper. For each draft, the figure shows the average score ±95% confidence interval (N = 10).

means, taking into account the sample size and standard deviation while maintaining the error at 0.05. This analysis shows a statistically significant effect from the five drafts: $F(4,36) = 37.36$; $p < 0.001$; $\eta p^2 = 0.81$. Table 3 presents adjusted p-values using a Bonferroni correction; adjusted p-values were calculated in order to compensate for multiple comparisons and to minimize Type 1 error. This table shows that draft five is the only revision that has a statistically significant effect when compared to the prior draft. However, it also shows that there is always a statistically significant effect after two revisions: draft 1 to 3, draft 2 to 4, and draft 3 to 5.

Table 3. Adjusted p-Values for Significance of Posthoc, Pair-Wise Comparison[a]

From	To Draft 2	To Draft 3	To Draft 4	To Draft 5
Draft 1	1.000	<0.001	0.003	<0.001
Draft 2	—	0.054	0.034	<0.001
Draft 3	—	—	0.557	<0.001
Draft 4	—	—	—	0.004

[a]Results are based on estimated marginal means and adjusted using Bonferroni correction for multiple comparisons between drafts for the 10 different students (N = 10). Values less than 0.05 are statistically significant. Mauchly's test of sphericity was completed and showed that sphericity could be assumed (Mauchly's $W = 0.155$, $p = 0.137$).

It is clear from the information in Figure 1 and Table 3 that having students revise a paper five times over the course of a semester results in significant improvement of student writing. Table 3 shows that even with the fifth draft students are continuing to show statistically significant improvement.

■ STUDENT COMMENTS

The multiple revisions required for the laboratory report and the nature of the feedback that students receive in this course is atypical. Student feedback and course evaluations indicate that they value this experience. Given the volume of writing, it is surprising that there has been no resistance from the students. In 2012 a follow-up survey was sent to the 10 students who completed the course. This survey asked students the value they place on each skill in the rubric (Table 2) on a four-point scale from "not at all important" to "extremely important". The four students who responded were overwhelmingly positive in their assessments. None of the items were ranked as having "little importance" or as being "not at all important". All four students ranked the use of evidence and style and mechanics as "extremely important". Three out of the four students ranked the items on claims, conclusions, organization, figures, and tables as "extremely important". Two of the students ranked the synthesis of ideas as "extremely important". The following comment is from this follow-up survey:

> *I look back at my first draft and am impressed with the progress that I made. I know I didn't always see the positive as I worked countless hours writing each report, but looking over the entire course I have really improved and have tremendously enjoyed my experience in this class.*

■ INSTRUCTOR REFLECTIONS

In 2008 this course was offered for the first time and we had no idea how the course design would impact student writing. The original design with reviewer feedback was meant to engage students in the class and to help clarify the connection between lecture and lab. Along the way it became clear that this course design also resulted in substantial improvement in student writing. Now that we have been through this process with three cohorts of students, it is clear that writing a progressive paper is a valuable experience for students.

We have made a number of observations as instructors working closely with students on developing their writing that might be useful to anyone who uses a progressive paper for teaching.

The dual grading system provides students with a strong incentive to work hard at improving their writing. By the second draft, most students pay attention to this score and are motivated when they see it improve with each draft.

It always surprises the students that, just like real reviewers, the instructors do not always agree on what should be changed. This provides a valuable opportunity to talk about the importance of audience awareness in effective communication.

Focusing the editorial feedback on how to structure evidence to support a claim helps show students why scientific articles have a specific structure and style. This gives an explanation for why scientists use references, why tables are organized particular ways, and when figures are useful. Students seem more receptive to learning about writing style when it is in the context of feedback about how to make their writing more effective, rather than when someone tells them to follow a specific style guide.

Having students go through five drafts lets instructors identify weaknesses in student writing without telling the students how to fix something. Students can try different ways of presenting their evidence and the faculty can provide feedback on how effectively this works. For example, students go back and forth with spectra presented as figures or as tables. Usually, they start with just the figures, then they use both figures and tables for everything, then they remove all the figures, and finally they present a balance of the two, depending on which one is most effective for supporting their claim. As a result, students learn the advantages and disadvantages of both figures and tables. Students develop the judgment needed to be an intentional writer, to facilitate reader understanding, and to anticipate readers' needs as part of effective communication.

The way students write has changed over the years. While working on this manuscript, the authors started asking students about how they write papers. The resulting conversations helped to clarify the source of many of the common weaknesses in student papers. From these discussions, the days of collecting note cards, making an outline, writing a draft, editing, and then typing are long gone. Spending time talking with students about how they write has helped to inform our teaching.

Students do not start by deciding the claim of a paper, then compiling evidence to support the claim, looking for external sources of information, developing an outline, revising, and rewriting. Usually, they just sit down and start typing. Without a structure for developing a paper, it is no surprise that student work is often disorganized and disjointed.

As a result of informal conversations about this project with other faculty, two colleagues in the English Department at Widener University implemented a form of a progressive paper in their courses. In both of these English courses, the students demonstrated improvement in their writing and both of these colleagues intend to continue using this assignment design in the future.

CONCLUSIONS

Although the progressive writing assignment requires substantial commitment on the part of students and faculty, its use engages the students in the writing process and furthers their understanding of the scientific writing process while developing the skills necessary to write scientific papers. This approach allows students to explore and develop their writing style in a manner that encourages them to consider the audience in the organization and presentation of material. The use of a dual-scoring system, coupled with detailed comments on the multiple drafts, allowed the instructors to grade the current draft and set expectations for future drafts. The increased engagement of the students in the writing process through a progressive writing assignment results in statistically significant improvement in student writing. Although the authors implemented the progressive report using a multistep synthetic sequence over the course of the semester, the assignment design could be implemented with many multiweek laboratory experiments throughout the curriculum.

ASSOCIATED CONTENT

Supporting Information

Department writing guidelines; drafts 1, 2, 3, 4, and 5 for a sample student. This material is available via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

ACKNOWLEDGMENTS

The authors would like to thank the students for their hard work and dedication to this course, especially the student who graciously agreed to provide drafts with feedback included as Supporting Information. Members of the College of Arts and Sciences Assessment and General Education Committee helped develop the effective communications rubric. Karen Rose helped with the statistical analysis. The reviewers offered extensive feedback on this manuscript, feedback that reminds us that constructive criticism can be difficult to hear, yet that we can all improve our writing. The Widener University Institutional Review Board reviewed this project.

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