Argumentative Writing Workshop for Conceptual Learning and Weekly Writing for Knowledge Application in Undergraduate Chemistry Laboratories

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ABSTRACT

Pedagogical approaches for supporting students' argumentative writing in science laboratories have not been fully established. This paper examines the development of argumentative abilities in undergraduate students enrolled in chemistry laboratory courses that employed two teaching sequences: (1) an argumentative writing workshop for conceptual learning and (2) weekly laboratory report writing for application of knowledge gained in the workshop. The four workshop modules guided students through the process of identifying three key components of arguments (evidence, justifications and claims), selecting appropriate and inappropriate justifications, constructing justifications and conclusions, and analyzing experimental errors. Student performance in formulating scientific arguments was evaluated through instructors' assessment of evidence used in Results, justifications provided in Discussion and claims made in Conclusions of a laboratory report. Student performance improved from 60.9±3.4 to 91.5±8.0 in Introductory Chemistry I Lab and 60.7±5.2 to 91.7±5.4 in Introductory Chemistry II Lab. Students rated the helpfulness of the writing workshop [(3.6±0.1)/5.0], weekly writing [(4.1±0.3)/5.0] and instructors' feedback [(4.4 ± 0.5)/5.0] for both introductory and advanced chemistry laboratories positively. The format of this writing workshop can be used for online teaching or incorporated into any science laboratory course with the development of appropriate content modules.

GRAPHICAL ABSTRACT

KEYWORDS

Chemistry, Communication skills, Critical thinking skills, Data collection and analysis, Formative assessment, Inquiry skills, evaluation of data/arguments/claims, Lab reports

INTRODUCTION

Over the past three decades, research on promoting scientific arguments has progressed substantially in terms of pedagogical strategies, frameworks and assessments.(Erduran et al., 2015; Henderson et al., 2018; Sampson & Clark, 2008; Sibel Erduran & Jiménez-Aleixandre, 2007) In particular, a recent book edited by Erduran advances our knowledge of how argumentation can be integrated in chemistry education through curricula, teaching strategies, learning resources, assessment and professional development.(Mehmet Aydeniz et al., 2019) However, challenges still exist in developing argumentative abilities through instructional practices.(Henderson et al., 2018) Questions remain about how learning objectives in argumentation can be transformed and assessed for teaching and learning purposes in everyday chemistry classrooms.(Erduran, 2019)

The initiation of scientific methods can be traced back to the 1200s when Roger Bacon promoted inductive reasoning in science.(Whewell, 1858) This development continued during the 1500s and 1600s with Francis Bacon's skeptical methodology for science and inductive reasoning,(Bacon, 1620) along with René Descartes' deductive reasoning,(Descartes, 2014) as foundations of scientific thinking. There is a direct path from these historical developments to Toulmin's model of argumentative thinking, which has been widely disseminated since it was published decades ago.(Toulmin, 1958) This model proposes that three components – grounds (evidence/data), claim, and warrant (principles connecting grounds to the claim) – are necessary to support a good argument. Sampson and Clark examined the constraints of several frameworks designed to assess the quality of students' arguments by focusing on their structure, content, and justification.(Sampson & Clark, 2008) Among various analytical frameworks,(Henderson et al., 2018; Sampson & Clark, 2008) Zohar and Nemet's model evaluates the quality of written arguments based on the content of the justification.(Zohar & Nemet, 2002) Their approach identifies strong arguments as those that include multiple justifications – which must be relevant, specific and accurate – to support conclusions.

Scientific argumentation is now widely included in the standards of science education. In Europe, the Eurydice Network countries acknowledge teaching through argumentation and inquiry as skills and competencies necessary for science teachers.(EURYDICE, 2011) In 1996, the National Research Council (NRC) changed the emphasis from science as exploration and experiment to argument and explanation in order to promote inquiry.(*National Research Council, National Science Education Standards*, 1996) Arguments play a central role in the resolution of scientific controversies,(Taylor, 1996) as well as in science education, as they engage students in constructing their own knowledge and justifying claims.(Berland & McNeill, 2010) Compared to the version used in the 1990s, the new version of the U.S. Next Generation Science Standards (NGSS) for K-12 science education focuses more on deep understanding and application of content than on memorization.("National Research Council, Next Generation Science Standards," 2013) The NGSS identifies evidence-based argumentation as a key practice in learning science, encouraging students to generate evidence by investigation, to use models, and to construct arguments that explain evidence. To support the implementation of the NGSS, the National Science Teachers Association encourages teachers to demonstrate the ability to facilitate effective discourse and argumentation with and among students.(*National Science Teachers Association (NSTA), NSTA Position Statement: The Next Generation Science Standards*, 2016)

Scientific writing develops critical thinking skills.(Klein, 2004; Tsui, 2002) Ennis defines critical thinking as reasonable reflective thinking focusing on deciding what to believe or do.(Ennis, Summer 2011; Ennis, 1987) One of the key concepts in Ennis' view is the ability to judge the quality of an argument, including its reasons, assumptions, evidence, and degree of support for the conclusion. Walker et al. developed an instructional model of Argument-Driven Inquiry (ADI) emphasizing the role of argument in chemistry laboratories.(Victor Sampson et al., 2009; Walker et al., 2011) Using the ADI model, students follow an authentic research process from task identification, data generation, argument production and discussion to scientific report writing, peer-review and revision. ADI was shown to improve students' ability to use evidence and reasoning to support a conclusion.(Eymur, 2018; Joi Phelps Walker et al., 2012) Our recent work showed that students' argumentative abilities could be promoted through the use of guiding questions.(Gao et al., 2021) Success in laboratory writing is also attained with the use of the science writing heuristic (SWH) approach. SWH emphasizes knowledge construction, promotes classroom discussion, and facilitates laboratory writing via inquiry questions, individual writing, and collaborative learning as a group.(Haozhi Xu & Talanquer, 2013; Jason R. Poock et al., 2007; Tanya Gupta et al., 2015) Gupta et al. reported that first-year general chemistry students who were instructed using the SWH approach scored significantly higher on various critical thinking traits than first- and fourth-year chemistry students who received traditional laboratory instruction.(Tanya Gupta et al., 2015) Xu and Talanquer examined the effect of inquiry levels on students' written reflection of their laboratory work and found that inquiry-based instruction shifted writing from factual to procedural and metacognitive knowledge.(Haozhi Xu & Talanquer, 2013) Hyatt and coworkers provided writing strategies for revision and correction of common errors seen in undergraduates' writing documents.(Hyatt et al., 2017)

The development of research and writing skills through chemistry curricula has attracted increasing attention for the past two decades,(Cynthia L. Nicotera et al., 2001; Jeffrey Kovac & Sherwood, 2001; Kaya Forest & Rayne, 2009; Louis J. Liotta & Almeida, 2005; Oliver-Hoyo, 2003) in both introductory chemistry(Carmel et al., 2019; Kaya Forest & Rayne, 2009; Oliver-Hoyo, 2003) and organic chemistry courses.(Cynthia L. Nicotera et al., 2001; Louis J. Liotta & Almeida, 2005) Nonetheless, explicit guidance on promoting critical thinking has not been fully developed in laboratory courses although laboratories are recognized as the natural model for initiating inquiry(Schwab, 1960) and doing chemistry,(Seery, 2020) and post-laboratory reports are regularly used to assess student performance in critical thinking.

When properly designed, laboratories have the potential to enhance students' understanding of the nature of science through inquiry, metacognition and argumentation.(Hofstein et al., 2019) To engage undergraduates in constructing scientific arguments, we used an argumentative writing workshop for conceptual learning, along with weekly laboratory report writing to engage students in knowledge application. Our efforts focus on how to present the three key components of an argument in a laboratory report, namely evidence in the Results section, justifications in the Discussion section and claims in the Conclusion(s) section. The pedagogical effectiveness of this strategy is assessed by instructors' direct measure and students' perception.

METHOD DESCRIPTION

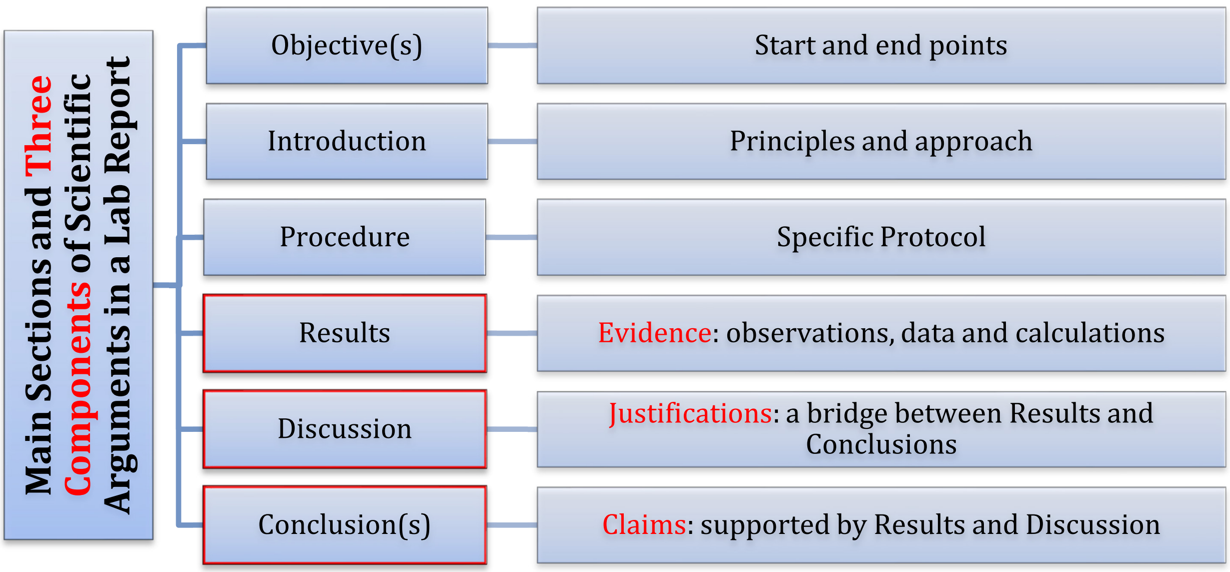
Argumentative Writing Workshop for conceptual learning

At the very first laboratory each semester, we briefly discuss what belongs in the traditional sections of a laboratory report and introduce the idea of scientific argument. While there's a rationale for holding an Argumentative Writing Workshop during the very first laboratory session as a means for preventing trainees from making errors,(Carroll, 1990) we typically conduct the Argumentative Writing Workshop during the third or fourth week, once students have completed one or two experiments and received extensive comments on these laboratory reports. This timing allows students to improve the evidence, justifications, and claims included in the early laboratory reports through revision and resubmission. Learning from mistakes has a positive impact on the motivation to learn.(Lin-Siegler et al., 2016)

The workshop begins with a discussion of laboratory report sections and the three components of scientific argument (Scheme 1). Our introductory presentation focuses on the following ideas:

- To successfully complete an experiment, students need to understand its objectives and principles, which are typically discussed during short pre-lab lectures. The experimental objectives should be stated at the beginning of a laboratory report as well as reflected in the conclusions.
- The principles of and approach to the experiment, along with any relevant chemical reactions, belong in the Introduction section.
- It is important for students to describe their actual protocol in the Procedure section rather than simply copying material from a laboratory manual.
- The final three sections – Results, Discussion and Conclusion(s) – call for more than description; they require argumentative thinking and writing. Students should use the Results section to present experimental evidence (observations, data and calculations) in a way that can be easily

understood. They should qualitatively and/or quantitatively analyze their results to support the justifications in the Discussion section. The Conclusion(s) section should be a summary of their findings, based on their results and discussion.



Scheme 1. Laboratory report sections and scientific argument

Following this presentation, we facilitate cooperative discussions in small groups using modules appropriate for lower or upper division laboratories. Those modules are described below (Table 1 and student handout in Supporting Information).

Table 1. Four instructional modules used in Argumentative Writing Workshop*

Modules	*Description*
Module I – Identify evidence, justifications and claims, or faults and omissions in others' writing	I-1. Identify evidence, justifications and claims in a news story or article. I-2. Evaluate what is missing, inadequate, misplaced or unnecessary in sample lab reports.
Module II – Select the appropriate & inappropriate justification statements provided in the Discussion section.	II-1. Explain the effect of O_2 flow on shape and color of Bunsen burner flame. II-2. Explain the difference in basicity between NaOH and $NH_3{\cdot}H_2O$ solutions. II-3. Explain why HCl is a stronger acid than CH_3COOH. II-4. Explain the difference in pH between two salts: Na_2CO_3 and NH_4Cl.
Module III – Write the Discussion and Conclusion sections.	III-1. Identify the periodic trends of atomic radii. III-2. Determine molar volume of O_2 generated from H_2O_2 decomposition and understand experimental errors – classroom demonstration.
Module IV – Analyze experimental errors.	Analyze and compare experimental errors in the determination of CO_2 molar volume at STP.

* See student handout and instructors' notes in Supporting Information.

The four workshop modules in Table 1 were designed to isolate specific skills for concentrated practice and to gradually release learning responsibility to students for more efficient learning.(Ambrose et al., 2010) In Module I-1, students highlight evidence, justifications and claims. Any scientific news article with these three identifiable components may be used. Students are given time to read and use different color highlighters to identify evidence, justifications and claims. They then share their findings in a class discussion. Table 2 is a summary of typical student comments for "Acidic Seas: How Carbon Dioxide Is Changing the Oceans?".(Hale, 2018) In Module I-2, excerpts of student work are used by groups to correct material placed in the wrong section, casual writing styles, missing background information, and other errors. Both activities in Module I involve analyzing the arguments of others as a step toward creating one's own arguments.

Table 2. Three components in the article of "Acidic Seas: How Carbon Dioxide Is Changing the Oceans?"

Results (Evidence)	*Discussion (Justifications)*	*Conclusions (Claims)*
• Oceans have become warmer. • Corals have lost color. • Ocean pH has decreased from 8.2 to 8.1.	• Greenhouse effect: CO_2 causes IR light to remain in the atmosphere. • Corals and shellfish cannot survive at acidic pH because $CaCO_3$ in shells slowly dissolve in acids. • Dissolved CO_2 generates acidity by chemical reactions of $CO_2 + H_2O \leftrightarrow H_2CO_3$, $H_2CO_3 \leftrightarrow H^+ + HCO_3^-$, and $HCO_3^- \leftrightarrow 2H^+ + CO_3^{2-}$.	CO_2 increases ocean temperature and decreases ocean pH, endangering ocean life.

Module II is designed for students to choose appropriate justifications based on information given in the Results, Discussion and Conclusion sections. Justifications provided may be appropriate and supportive of conclusions, or they may be irrelevant, theoretically correct but not part of the results observed, or may demonstrate chemistry misconceptions (see Instructors' Notes for specific examples in Supporting Information). For instance, in Module II–2, pH values were determined for solutions of 0.0010 M NaOH and $NH_3{\cdot}H_2O$ and found to be 11.02 and 10.12, respectively. Complete dissociation of the strong base NaOH leads to more OH^- released, thus a higher pH than that of the weak base $NH_3{\cdot}H_2O$ at the same concentration. Giving the dissociation reaction $NaOH \xrightarrow{100\%} Na^+ + OH^-$ is an appropriate justification because it provides a theoretical explanation, while the statement "The reaction of NaOH with HCl releases heat" is correct but irrelevant. Module II – 3 illustrates that HCl is a stronger acid than CH_3COOH by showing the pH of two solutions of the same concentration.

Although the statement "H_2 gas was produced when dropping a piece of copper metal into the solution of 0.00010 M HCl, while no reaction was observed when adding copper into CH_3COOH solution" is correct, it is not an acceptable justification because no reaction with metals was observed in the procedure described.

Module III is designed for students to construct justifications in the Discussion section and claims in the Conclusion section based on information given in the Objectives and Results sections. For instance, atomic radii in the periodic table are provided in Module III–1, so students can summarize trends they observe. Module III-2 employs a classroom demonstration of H_2O_2 decomposition ($2\ H_2O_2 \xrightarrow{Catalyst} 2\ H_2O + O_2$). Data on the mass of H_2O_2 and volume of O_2 are collected with student participation. Instructors use this module to demonstrate how to do an experiment, analyze results, and write a laboratory report. The activity fosters argumentative writing through subsequent group discussion of the information students included in their Results, Discussion and Conclusion(s) sections.

Module IV is designed to engage students in quantitative measurements and error analysis. We emphasize that calculating statistical quantities - mean, standard deviation, relative standard deviation, bias and relative bias – is the basis for connecting their data and observation (evidence) to the justification of experimental errors.(Gao & Lloyd, 2020)

It is worth noting that our writing workshop was initially developed based on a college-wide writing workshop program designed by the Director of the Writing Center. The Chemistry laboratory writing workshop has evolved since its inception with the use of a sequence of activities focusing on specific skills. Faculty attention to writing activities that are grounded in collaboration across departments at the college created a synergy that influenced this work.

Weekly laboratory report writing for knowledge application

Weekly writing provides students with an opportunity to apply what they have learned in the Argumentative Writing Workshop to their laboratory reports. Through conversations with colleagues at the Writing Center and Writing Across the Curriculum program, we have gained an understanding of the value of drafts and revisions in developing writing ability. Grading revised laboratory reports is time consuming for instructors but results in a rapid improvement in laboratory report quality and is cited by students as a positive aspect of the laboratory course (See assessments below.). The weekly lab reports evaluated in this study have been required in prior semesters. However, several changes were made to focus on argumentative writing. Prior to this study, students and instructors both generally focused on data sheets and calculations in their lab reports. We set the tone for attention to writing by providing explicit objectives and applying appropriately rigorous grading standards in early laboratories. Grading rubrics were developed and provided prior to each session, helping students to understand what each lab report should contain and helping instructors to offer consistent and specific feedback. Instructors provided extensive comments, especially in the Results, Discussion and Conclusion sections, to support students in developing effective evidence, reasoning, and claims in these sections. The submission of revised drafts, based on instructors' comments, emphasized our focus on argumentative writing. We have found that rubrics make grading faster and more consistent. It is certainly true that grading revised lab reports is time consuming and may not be practical for large laboratory classes, but even if used for a few labs each semester, it can foster improved writing. More importantly, it will convey the message that instructors place value not just on what the data are but on how students' reasoning is presented and supported by evidence.

Students often fail to see how different sections of a laboratory report are related to one another. For instance, they might correctly describe how to weigh solid chemicals on a balance in the Procedure section, but not include the mass of the weighing paper (tared to zero or the actual mass) in the Results section. The calculations are then done with missing data/evidence. Many students are also confused as to what should be addressed in each section. They explain principles, which belong to the Introduction, but not results in the Discussion section, claim an unknown concentration being determined without reporting the actual value in the Conclusion section, or conclude every laboratory report with "the goal was reached", "the skills were improved", "human error explains the discrepancies", etc. We emphasize that conclusions must follow from evidence in the Results, justifications must be included in the Discussion, and error analysis must be appropriate for the activity. Students enrolled in Introductory I and II Labs (up to 24 students per class), Analytical Chemistry Lab (10-20 students per class) and Instrumental Analysis Lab (5-10 students per class) had the opportunity to revise and resubmit their laboratory reports. Instructors' policies varied, but generally students were allowed a single resubmission for each laboratory or a few (usually 2-4) resubmissions during the semester on specific laboratories or at students' choice.

DISCUSSION AND ASSESSMENT

Argumentative workshop for conceptual learning

Rivard indicated in his 1994 review that students' awareness of their thinking processes was not improved through the quantity of writing.(Rivard, 1994) They need guidance and support to engage in effective argumentative writing.(Carl Bereiter & Scardamalia, 1987) Many students struggle to present appropriate information to support their conclusions even when their experiment is successful. It was encouraging for us to read feedback about the writing workshop. Below are some student responses to the post-course survey question, "What strategies from the Writing Workshop have you used (if any)?".

- "Determined the 3 major parts of a lab which include claim, evidence, and conclusion"
- "From the writing workshop, I was able to distinguish the differences between the content of the discussion and conclusion, and how to properly write each one."
- "How to condense my information to only the important stuff"
- "Getting straight to the point, but also having details to further explain my thoughts making the writing more concise with less words"

Students were asked to evaluate the helpfulness of this workshop on a scale of 1 to 5 with 1 being the worst and 5 the best. They rated the helpfulness to be 3.7 and 3.6 out of 5 in Introductory Chemistry I and II Labs, respectively (Figure 1).

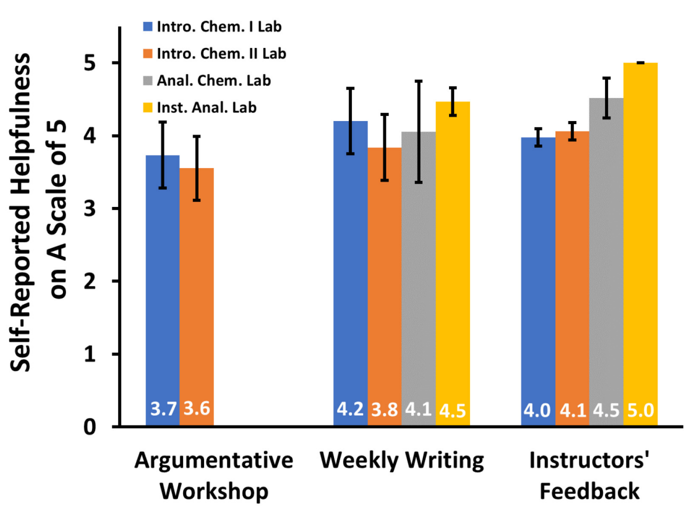


Figure 1. Student self-reported helpfulness of argumentative writing workshop, weekly writing and instructors' feedback between fall 2017 and spring 2020 from Introductory Chemistry I (blue bars, n = 117) and II (orange bars, n = 48) Labs, Analytical Chemistry Lab (gray bars, n = 13) and Instrumental Analysis Lab (n = 11) for the post-course survey questions: (1) How much did the argumentative writing workshop help your learning? (2) How much did the writing assignments/laboratory report writing help your learning? (3) How much did the instructor's feedback on your work help your learning?

Weekly writing for knowledge application

The importance of feedback has been widely addressed.(John Hattie & Timperley, 2007; Philip C. Abrami et al., 2015) Specific feedback can only occur with assessment, while assessment without timely feedback contributes little to learning.(Arthur W. Chickering & Gamson, 1987) Students received prompt and frequent feedback on each laboratory report that included specific suggestions for improvement. As shown in Figure 1, students found the weekly writing and instructors' feedback helpful for all laboratories (3.8-5.0 out of 5). They rated the overall helpfulness of the writing workshop, weekly writing and instructors' feedback for both lower and upper division chemistry laboratories to be 3.6 ± 0.1, 4.1 ± 0.3 and 4.4 ± 0.5 on a five-point Likert scale, respectively.

Student performance on the three key sections of laboratory reports was evaluated based on correctness, completeness, and clarity. There was no widespread data collection in the laboratories prior to this project. Figure 2 shows that many students were under-prepared for argumentative skills at the beginning of the semester, as indicated by their overall low grades on the Results, Discussion and Conclusion sections, 57.2-64.0% and 55.8-66.3% for Introductory Chemistry I and II Labs, respectively. Their performance improved by the end of the semester, with average scores increasing to 83.1-99.0% and 88.4-98.0% for the two courses above, respectively. Overall, student performance on these three sections improved during the semester from 60.9 ± 3.4 to 91.5 ± 8.0 in Introductory Chemistry I Lab and 60.7 ± 5.2 to 91.7 ± 5.4 in Introductory Chemistry II Lab based on the data extracted from Figure 2. Our observation is consistent with a prior study by Taylor et al., which found statistically significant correlations between students' achievement and the frequency with which they were asked to draw conclusions from experiments.(Joseph A. Taylor et al., 2006) While it might be expected that students in Introductory Chemistry II would begin at a higher level than those in Introductory Chemistry I, a similar performance pattern was observed between Figure 2A and 2B, which might result from the dynamic changes in student enrollment (~ 75% student continuation from Introductory Chemistry I to II Labs) or the different workshop modules and teaching approaches used.

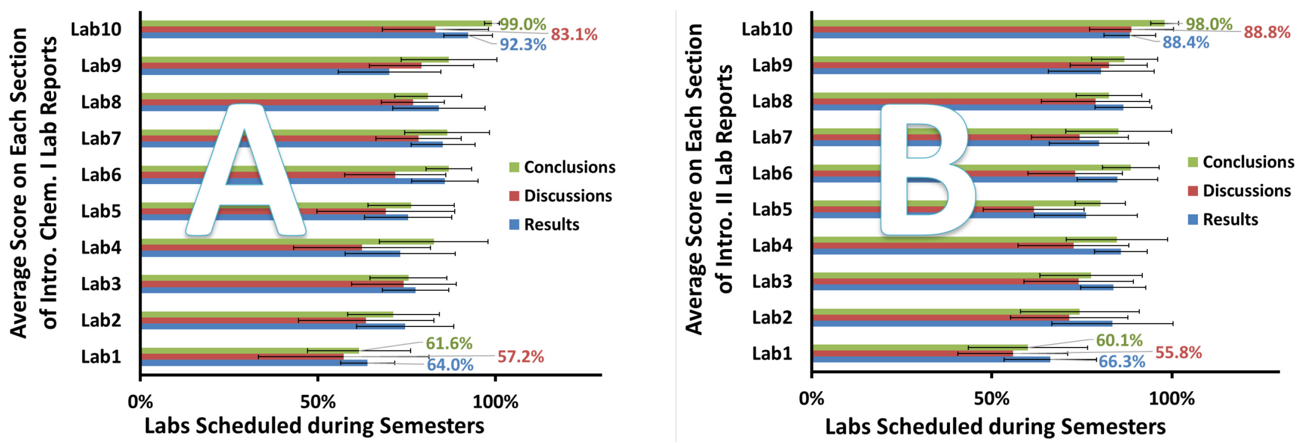


Figure 2. Grade distribution on each section collected from the beginning (Lab 1) to the end (Lab 10) of the semesters between fall 2016 and spring 2020 in Introductory Chemistry I (graph A: n = 186) and II (graph B: n = 94) Labs

An accurate self-assessment of one's knowledge leads to more effective use of feedback, improved time management, and appropriate goal setting.(Hacker et al., 2000) To further demonstrate pedagogical effectiveness from students' viewpoints, pre- and post-course surveys were distributed to track students' perception of mastering knowledge. Their self-reported understanding of scientific arguments increased on average from 3.2/5 to 4.0/5, 4.0/5 to 4.4/5, 4.1/5 to 4.5/5 and 3.7/5 to 4.7/5 for the Introductory Chemistry I and II Labs, Analytical Chemistry Lab, and Instrumental Analysis Lab, respectively, indicating that students gained confidence in their mastery of knowledge (Table 3). The better perceived understanding of scientific arguments from Introductory Chemistry II Lab and Analytical Chemistry Lab might be associated with the workshop training and weekly writing practices students obtained in their previous classes. However, it is worth noting that the emphasis of argumentative training varies in different courses. Students enrolled in Analytical Chemistry Courses focus more on error analysis while first-year students begin with the basic components of an argument. At a small liberal arts college with 80% of graduates being transfer students, our class enrollments change dynamically. Approximately 75% of students in Introductory Chemistry I Lab continue on to Introductory Chemistry II Lab, 30% from Introductory Chemistry Lab continue on to Analytical Chemistry Lab, and ~60% from Analytical Chemistry Lab continue on to Instrumental Analysis Lab. The lower perception of mastering knowledge in Instrumental Analysis Lab could be the result of the large percentage of transfer students who were exposed to different curricula (3.7/5 in

Table 3). In addition, the results should be considered preliminary since scientific argument was not included in the curricula of laboratory courses prior to this study.

Table 3. Students' self-reported understanding of scientific arguments

Courses	*Pre-Lab Responses*	*Post-Lab Responses*
Introductory Chemistry I Lab	3.2/5 (n = 102)	4.0/5 (n = 33)
Introductory Chemistry II Lab	4.0/5 (n = 102)	4.4/5 (n = 48)
Analytical Chemistry Lab	4.1/5 (n = 13)	4.5/5 (n = 13)
Instrumental Analysis Lab	3.7/5 (n = 11)	4.7/5 (n = 11)

CONCLUSIONS

Explicit teaching of scientific argumentation was achieved through an Argumentative Writing Workshop that provided conceptual training for constructing a strong laboratory report, weekly lab report writing, and instructors' frequent feedback. Students' overall performance in presenting evidence in Results, justifications in Discussion and claims in Conclusion(s) was improved. Students expressed a positive perception of the writing workshop, weekly writing activities and instructors' feedback in both lower and upper division chemistry laboratories.

ASSOCIATED CONTENT

Supporting Information

Student workshop handout and instructors' notes, pre- and post-survey questionnaires, and grading rubric

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