Argument-Driven Inquiry: Using the Laboratory To Improve Undergraduates' Science Writing Skills through Meaningful Science Writing, Peer-Review, and Revision

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Argument-Driven Inquiry: Using the Laboratory To Improve Undergraduates' Science Writing Skills through Meaningful Science Writing, Peer-Review, and Revision

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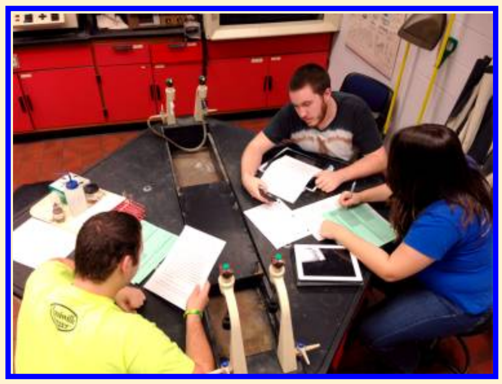
Supporting Information

ABSTRACT: This paper presents preliminary evidence supporting the use of peer review in undergraduate science as a means to improve student writing and to alleviate barriers, such as lost class time, by incorporation of the peer-review process into the laboratory component of the course. The study was conducted in a single section of an undergraduate general chemistry laboratory course offered at a large two-year community college located in the southeastern United States. The chemistry laboratory course was taught using Argument-Driven Inquiry, an instructional model that incorporates double-blind group peer review of student laboratory reports, and allows students to revise their reports based on the peer reviews. The reports written for each laboratory activity were used to examine changes in the students' writing skills over time and to identify aspects of science writing that were the most difficult for the undergraduates in this context. The reviews generated by the students were used to evaluate student engagement in the peer-review process. The results of a quantitative and qualitative analysis of the reports and reviews indicate that the participants made significant improvements in the their ability to write in science and were able to evaluate the quality of their peers' writing with a relatively high degree of accuracy, but also struggled with several aspects of science writing.



KEYWORDS: *First-Year Undergraduate/General, Chemical Education Research, Laboratory Instruction, Communication/Writing*

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■ INTRODUCTION

Undergraduate students in lower-division lab courses have few opportunities to write reports that describe the context, process, and outcome of an inquiry-based investigation. Current research also indicates that undergraduate students have few opportunities to conduct a formal review of other students' reports as part of their coursework.[1,2] It should therefore not be surprising to anyone that many students struggle to write in a scientific manner.[3−5] To address this problem, students need opportunities not only to practice meaningful science writing, but also to engage in peer review and revision. Research indicates that peer review is both a valid mechanism for evaluation and a valuable experience for students.[6] We have therefore developed an approach to lab instruction called Argument-Driven Inquiry (or ADI) that incorporates these key writing experiences into each lab activity without sacrificing course content or the development of inquiry abilities.[7,8] In the sections that follow, we will first provide an overview of the various stages of the approach. We will then provide some empirical support for it by sharing some findings from an exploratory study that we conducted to examine how students responded to the peer-review and revision process. Finally, we will conclude the article with our recommendations for course instructors interested in using this approach.

■ OVERVIEW OF THE ADI INSTRUCTIONAL MODEL

The ADI instructional model consists of seven steps (see Figure 1). An ADI lab investigation begins with the course instructor providing a research question for students to answer. Groups of three or four students are then expected to develop a method that they can use to gather the data needed to answer the question. Once the groups have collected their data, they are directed to develop a tentative argument (a claim that answers the research questions supported by evidence and rationale) on a 60×90 cm^2 whiteboard. The students are then given an opportunity to share and critique the merits of the various arguments and refine their own conclusions during an argumentation session.

Students are then required to write an investigation report on their own as homework. The report is organized into three sections around three fundamental questions:

1. What were you trying to do and why?

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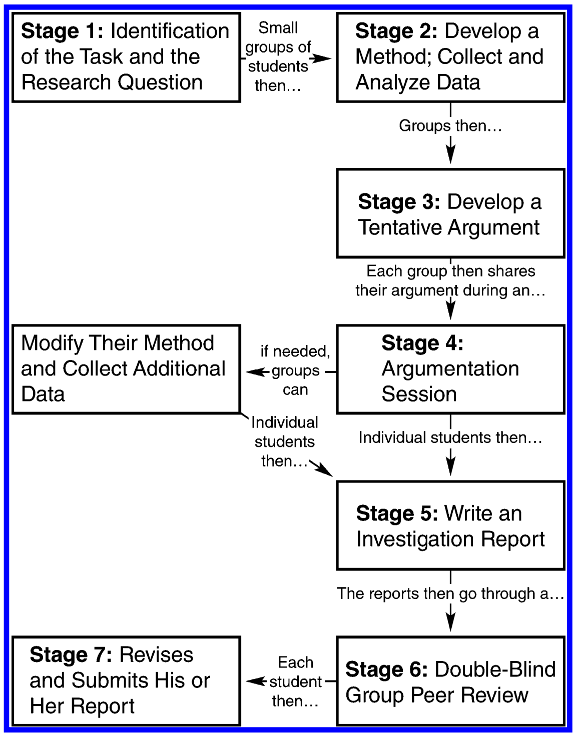

Figure 1. The seven steps of the ADI instructional model. Adapted from "Argument-Driven Inquiry: An Introduction to a New Instructional Model for Use in Undergraduate Chemistry Labs", by J. P. Walker, V. Sampson, and C. O. Zimmerman.[8].

2. What did you do and why?
3. What is your argument?

To help students learn how to communicate information in multiple modes, they are also encouraged to organize the data they gathered during the second step of the model into tables or graphs that they embed into the report and then reference in the body of the text. The three questions the students address as they write target the same information that is included in more traditional laboratory report formats (e.g., introduction, procedure, results, and discussion), but the questions are designed to help students understand the importance of argument in science, to elicit their awareness of the audience, and to help the make sense of the content (e.g., what they know, how they know, and why they believe it) as they write. Overall, the intent of this format is to bring the persuasive aspects of science writing to the foreground and to highlight the nonnarrative and multimodal (e.g., words, figures, tables) nature of scientific texts.

The students are required to submit four typed copies with only an identification number to the instructor at the beginning of the next session. The instructor then randomly distributes three or four sets of reports (i.e., the reports written by three or four different students) to each lab group along with a peer-review guide for each set of reports. The peer-review guide includes specific criteria to be used to evaluate the quality of an investigation report and space to provide feedback to the author. (For further details, see ref 8.) The lab groups review each report as a team and then decide whether it can be accepted as-is or whether it needs to be revised based on the criteria provided on the peer-review sheet. Students are required to make these decisions as a group because it gives them an opportunity to negotiate "what counts" as quality with each other and prevents students from simply checking off "good" for each criterion on the peer-review guide. Groups are also directed to provide explicit feedback to the author about what needs to be done in order to improve the quality of the report and the writing as part of their review. Overall, the intent of this step is to provide the students with the explicit and detailed feedback they need in order to improve, an opportunity to learn and adopt new criteria for evaluating science writing, and an opportunity to read the writing of others so they can see examples of better ways of presenting information in text. This step is intended to provide an opportunity for students to learn from their mistakes without imposing a grade-related penalty.

The final step of the ADI instructional model is to revise the report based on the results of the peer review. Authors who wrote papers that were not accepted by their peers are required to rewrite their reports based on the reviewers' comments and suggestions. The reports that are accepted by the reviewers may be submitted to the instructor at the end of this step (but all students are given the option to revise their report). Once completed, the revised reports (along with the original version of the report and the peer-review sheet) are submitted to the instructor for a final grade.

The last three stages of ADI are incorporated into the model to give students an opportunity to develop their science writing skills. The explicit focus on writing in science in this model is not a unique feature. In fact, many science educators teach science writing as part of a lab course or have even created stand-alone writing courses for science majors.[9−11] Many of these courses, however, are designed to teach science writing skills separate from the content and in a decontextualized manner (see Brillhart and Debs,[9] Flynn, McCulley, and Gratz,[10] and Powell,[11] as examples). ADI differs from these approaches because it was designed, in part, to teach content and science writing at the same time by requiring students to complete realistic writing tasks and engage in serious writing practices as part of each lab investigation. As a result, ADI can be described as a "writing to learn by learning to write" approach to teaching science writing skills.[12,13]

■ CAN ADI HELP STUDENTS WRITE BETTER IN SCIENCE? INITIAL FINDINGS FROM AN EXPLORATORY STUDY

We conducted a small study in a single section of a general chemistry lab course offered at a community college to examine the potential of ADI as a way to help undergraduates learn how to write in science as part of a pilot project.[14] The students in this course completed six ADI investigations and wrote five different reports (four of which were peer reviewed). A quantitative analysis of the initial and final draft of the reports and peer-review guides collected during the original study indicated that the reports written by the students improved significantly as a result of the peer-review process and the students' overall scores on both the initial and final version of the reports improved over the course of a semester (see ref 14). That analysis demonstrates how undergraduates' science writing skills can improve over the course of a semester when a course instructor uses the ADI instructional model, and provides some evidence that undergraduates can, when they review a report as a group and use a guide, provide an accurate evaluation of their peers' writing. In this article, we share the results of a secondary analysis of the data we collected during the original study in order to compare the gains made by the stronger and weaker writers in the course. We also examined

Table 1. General Description of the ADI Investigations Used in the Study

ADI Investigation	Concept	Guiding Question	Nature of Inquiry Activity
1	Physical Properties	Are the samples provided made of the same material?	Given three objects, students determine density using multiple methods for determining volume.
2	Molecular Formulas	What is the identity of the unknown hydrate?	Given an unknown hydrate, students evaporate water to determine the percent water and identify the hydrate.
3	Solutions	How could you prepare more of this dye?	Given a solution prepared with a combination of food dyes, students use spectroscopy to identify the solutes and generate calibration curves to determine the solute concentration.
4	Limiting Reagents	What is the optimum mole ratio for a chemical reaction?	By collecting the carbon dioxide gas generated with different mole ratios of sodium bicarbonate and acetic acid, students identify the optimum mole ratio for the reaction.
6	Chemical Reactions	How could you isolate 0.5 g of product?	Given two types of reactions (redox and precipitation), the students prepare two types of product then compare yields of product and issues associated with each reaction and product recovery.

Table 2. Overall Scores for Strong and Weak Writers for the Initial and Final Version of Each Report

	Scores for Strong Writers (N = 8)			Scores for Weak Writers (N = 8)				
Reports	Median	Mean	SD	Median	Mean	SD	z Values	p Values
1: Initial	20.00	19.89	1.90	15.00	13.00	3.28	−3.59	<0.001[a]
1: Final	23.00	23.67	2.18	20.00	20.11	3.41	−2.41	0.01[a]
2: Initial	19.00	19.11	1.83	18.00	16.89	2.85	−1.84	0.07
2: Final	22.00	22.89	2.32	20.00	21.00	2.87	−1.43	0.16
3: Initial	21.00	21.11	2.03	19.00	17.78	4.15	−2.29	0.02[a]
3: Final	24.00	23.78	1.64	22.00	21.89	3.48	−1.16	0.26
4: Initial	22.00	21.78	1.64	22.00	20.22	3.23	−0.72	0.47
4: Final	25.00	24.78	2.22	25.00	23.89	3.72	−0.22	0.86
6: Initial	25.00	26.11	3.02	23.00	24.44	4.04	−1.19	0.26

[a]Significant at the 0.05 level.

students' views of this type of instruction. The research questions that guided this follow-up study were:

1. Do the science writing skills of both strong and weak writers improve over time in response to the Argument-Driven Inquiry instructional model, and, if so, do both types of writers make similar gains over the course of a semester?
2. Do students see value in the various components of the Argument-Driven Inquiry instructional model as way to help them learn how to write better in science?

■ THE SECONDARY STUDY

A total of 18 undergraduate students (38% female, 46% underrepresented minority, 11% ESL, 22% enrolled in another writing course such as "writing about literature" or "college composition") were enrolled in the lab course and agreed to participate in the study. These students attended a 2-h lab session each week. These undergraduates completed six Argument-Driven Inquiry investigations during the 15-week semester and each investigation took two to three class sessions to complete (see Table 1). Only four of the six investigations, however, included all seven stages of ADI instructional model. The course instructor did not require the students to write an investigation report for ADI Investigation 5 (owing to a time limitation) and there was no peer review and revision of the report written for ADI 6 because the instructor used it as the final for the course. The students worked in a team of three or four members during each ADI investigation.

We made copies of the initial and final version of each report after the course instructor collected them. We then used a rubric to score the overall quality of the investigation reports. The rubric focused on four different aspects of science writing. These aspects include the students' ability to:

1. Communicate the goal of their investigation
2. Describe the method used and why it was used
3. Provide an accurate explanation and support it with appropriate evidence
4. Use appropriate writing mechanics

he scores earned on each aspect of science writing were then combined to assign an overall score of the report. As a result, the overall score could range from 0 to 36, with higher scores representing higher-quality science writing. Two graduate students, who did not know when the reports were written during the semester or the identity of the student who wrote the report at the time, scored all the reports. The inter-rater reliability of the scores, as measured by Cohen's κ, was 0.86.

We also administered a Student Assessment of Their Learning Gains (SALG) survey at the end of the semester to determine how much the students valued the various activities and tasks that we built into the ADI instructional model (e.g., the feedback they received from their peers, an opportunity to read good examples of reports, etc.) as a way to improve their ability to write in science. A SALG survey[15] gives students an opportunity to rate how much an aspect of a course helped them to learn a new concept or skill using a five-point Likert scale (0 = "Not at all"; 4 = "Helped a great deal"). We also included some items that were not associated with the writing that takes place during an ADI lab activity, such as the grading system and opportunities to work with peers outside of class, in the SALG as a baseline measure. We administered the questionnaire as an optional online survey at the end of the semester. A total of 13 students chose to complete the survey (72% of the participants). All of these students completed the 14 Likert-scale items and 7 responded to an open-ended item at the end of the survey, which gave them an opportunity to make any additional comments about the writing they did during the course.

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RESULTS

Gains Made by Strong and Weak Writers

We used a median split on the initial version of Report 1 in order to classify each student as an either a strong or weak writer based on his or her performance on the initial report. We then compared the overall scores of the strong writers on the initial version of Reports 1−4 and the initial (and only version) of Report 6 to the scores of the weak writers. The median scores for these two groups of students on Reports 1−6 are provided in Table 2 and illustrated in Figure 2.

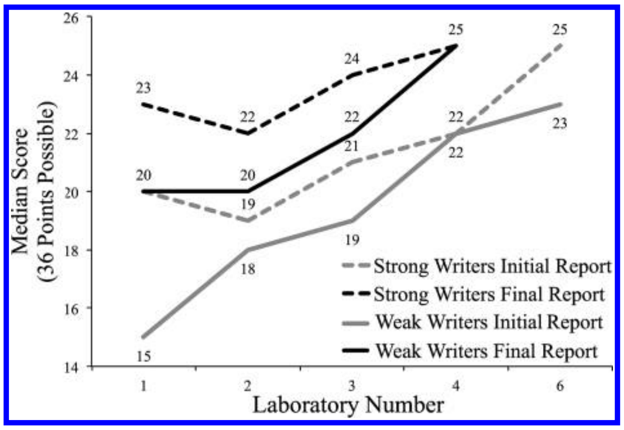

Figure 2. Differences in the median score for strong and weak writers on Reports 1−6.

There was a five-point difference between the median score of the strong writers and the weak writers on Report 1. The difference between the median score for the two groups of writers for Report 2 was only one point (due to the stronger writers making no gain and the weaker writers making a three-point gain), and on Report 3 it was two points. On Report 4, there was no difference in the median score for the two groups. On Report 6, there was only a two-point difference between the median score of the strong and weak writers. The results of a series of Mann−Whitney U tests indicated that the differences between the median scores of these two groups of students were significant for the initial lab Reports 1 and 3 but not for lab Reports 2, 4, and 6. In addition, two paired Wilcoxon Signed Ranks tests indicated that both the strong writers, $z = -2.63$, $p = 0.008$, and the weak writers, $z = -2.68$, $p = 0.007$, had significantly higher scores on lab Report 6 when compared to the initial report for lab Report 1. These results suggest that both groups of students improved in their ability to write in science over the course of semester and, perhaps more importantly, that the achievement gap between the strong and weak writers was eliminated.

We also analyzed the scores on the final version of reports 1−4 to examine how student performance changed over time and to determine if the peer-review process was beneficial for both groups of students. The median scores for these two groups of students on the final versions of report one through four are provided in Table 2 and illustrated in Figure 2. There was a three-point difference between the median score of the strong writers and the weak writers on the final version of the first report. The difference between the median score for the two groups of writers for the final version of the second report was only 1 point and on the third report it was 2 points. On the final version of the fourth report, there was no difference in the median score for the two groups at all. The results of a series of Mann−Whitney U tests indicated that the differences between the median scores of these two groups of students was significant for the final report for lab one but not for labs two, three and four (see Table 2). In addition, a series of Wilcoxon Signed Ranks tests indicated that the strong writers and the weak writers scored significantly higher on the final version of each report (see Table 3). These results indicate that the final reports written by both groups of students improved over time and the peer review process was beneficial for both the strong and weak writers.

Students' Views of Argument-Driven Inquiry Instruction

We examined the students' responses to the Student Assessment of Their Learning Gains (SALG) survey to determine how students viewed this type of instruction. Table 4 provides the mean rating for each item. The mean rating for 11 of the 14 items was 2.00 or higher (it helped some, or more). The two aspects of the course that the participants perceived as being the most valuable in terms of learning to write better in science (mean rating >3.00) were (i) an opportunity to revise their reports ($M = 3.29$) and (ii) the chance to read good examples of reports ($M = 3.07$). The three aspects of the course that the students' perceived as being the least helpful (mean rating <2.00), in contrast, were (i) the instructions they received about how to write a report ($M = 1.86$), (ii) the grading system used ($M = 1.64$), and (iii) an opportunity to work with peers outside of class ($M = 1.50$). Two of these aspects (working with peers outside of class and the grading system) were course aspects unrelated to ADI.

We also examined the comments the students made about the writing they did in the course in response to the open-

Table 3. Change in Score on the Initial and Final Version of Reports 1−4 Made by Strong and Weak Writers

		Initial Report Scores		Final Report Scores			
Group	Lab	Median	SD	Median	SD	z Values	p Values
Strong Writers (N = 8)	1	20.00	1.90	23.00	2.18	−2.67	0.008[a]
	2	19.00	1.83	22.00	2.32	−2.56	0.01[a]
	3	21.00	2.03	24.00	1.64	−2.56	0.01[a]
	4	22.00	1.64	25.00	2.22	−2.54	0.01[a]
Weak Writers (N = 8)	1	15.00	3.28	20.00	3.41	−2.67	0.008[a]
	2	18.00	2.85	20.00	2.87	−2.54	0.01[a]
	3	19.00	4.15	22.00	3.48	−2.53	0.01[a]
	4	22.00	3.23	25.00	3.72	−2.72	0.007[a]

[a]Significant at the 0.05 level.

Table 4. Mean Ranking of the Perceived Value of Each Aspect of the Course

	How Much Did the Following Aspects of the Course Help You To Write Better?	Rating[a] Mean[b]	SD
1	The number of the reports you wrote.	2.64	1.28
2	The feedback you received from the teacher.	2.64	1.15
3	The feedback you received from your classmates.	2.79	0.98
4	Reading good reports written by your classmates.	3.07	0.83
5	Reading bad reports written by your classmates.	2.50	0.86
6	Critiquing reports written by your classmates.	2.64	0.75
7	Revising your reports.	3.29	0.99
8	Having detailed instructions about what to include in the reports.	1.86	1.17
9	Knowing the criteria that are used to score the reports.	2.57	1.45
10	Having the same rubric used on all reports.	2.57	1.22
11	The grading system.	1.64	1.28
12	Quality of contact with the teacher.	2.36	0.63
13	Working with classmates outside of class.	1.50	1.70
14	Working with classmates outside of class.	2.36	0.75

[a]Scale for ranking: 0.00, It did not help at all; 1.00, It helped very little; 2.00, It helped some; 3.00, It helped a lot; 4.00, It helped a great deal. [b]$N = 13$.

ended item. Five of the seven comments that were made by the students were positive in nature. These comments included:

Reading a good report by one of my peers helped to better mine the most, BY FAR. [emphasis in the original]

The writing process helps you understand the entire concept of the lab.

I improved each time because I learned how to write better based on the previous reports.

Peer review is very helpful.

Writing the lab reports has made me a better writer.

These types of comments, although rather brief, once again suggest that the students in this study valued the activities that we incorporated into the ADI instructional model. The second comment also demonstrates how a realistic writing task, which emphasizes the development of ideas and the improvement of argument and not just the mechanics of writing, can help a student understand the content. There were, however, two comments that highlighted some reservations these students had about this type of instruction. These comments included:

I did not find some of the peer reviews very helpful due to the feedback I was getting, it almost seemed like some students would just "try" to review my paper because it was an assignment and not help me by giving sufficient feedback.

I didn't care for it [the writing] too much. It seemed like the entire class struggled as well.

The first comment is especially informative given our previous analysis of the comments students included on the peer-review sheets.[14] In the original study, we documented how the students were able to identify weakness and omissions in the reports with a high degree of fidelity, but they did not provide each other with enough genuine feedback when they identified an error. This issue seems to have contributed to the students rating the feedback they received from their peers as being less valuable ($M = 2.79$) than an opportunity to read an example of a well-written report ($M = 3.07$). It is important to note, however, that these students still rated the peer feedback as being more valuable ($M = 2.79$) than the feedback they received from the course instructor ($M = 2.64$). Overall, these observations suggest that the students perceive the peer-review and revision components of the instructional model as valuable.

■ DISCUSSION AND IMPLICATIONS

The results of our secondary analysis of the data collected during the original study demonstrate that undergraduates can learn how to write better in science when a course instructor uses the ADI instructional model regardless of a student's initial skill level. It is important to note, however, that our original study was exploratory in nature, did not include a comparison group, and was based on a small sample. The results presented here therefore might not generalize to the larger undergraduate population. The results of our secondary analysis suggest that the undergraduates in the original study valued the various components of ADI as a way to improve their ability to write in science. It is important to note, however, that this claim is based on student self-report data. Yet, because the SALG questionnaire was used to examine the students' views about what they valued about the intervention instead of what students learned in response to the intervention, we argue that this claim is warranted.

We argue that the mechanisms embedded within the ADI instructional model can help students learn to write in science during a lab course as they learn about important content and develop the skills they need to engage in a scientific inquiry. This type of focus on scientific writing is important because students, especially science majors, need to be able to communicate through writing in a manner that is consistent with the norms of science. Yet many science instructors do not want to focus on scientific writing in an undergraduate lab course because of the sheer volume of the papers that they will need to read and the amount of feedback they will need to give to students. The ADI approach, however, shifts the burden of providing feedback on the reports to the students and actually decreases the number of assignments instructors need to grade. These findings also are important for practical reasons. Faculty are not likely to implement a new instructional approach when they know students will view it unfavorably or complain about it because it might result in a poor course evaluation. Faculty are also often reluctant to implement a new instruction approach if it does not help all students improve.

The results of this secondary analysis support the substantial literature that indicates learning how to write in science is difficult for many students[3,4] and learning new skills is often influenced by the attitudes and motivation of the learner.[16,17] We conjecture that the ADI model can help undergraduates learn to write better in science because of the underlying mechanism that has been built into it. This mechanism consists of four basic components. First, ADI provides an opportunity for undergraduates to complete a realistic writing task in science and engages them in the serious writing practices of science (such as peer review and the revision of a manuscript). This focus on the serious writing practices of science provides students with a reason to learn how to write in a manner that reflects the disciplinary norms of science. Second, the peer-review stage of ADI provides students with an opportunity to read examples of reports written by other students, which supplies them with a model of "what counts" as a high-quality

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report. Third, the peer-review guides provide the students with detailed information about what should be included in a report (i.e., scaffolding) and the feedback they receive on the peer-review guide provides them information about how to improve (i.e., coaching). Finally, and perhaps most importantly, ADI encourages students to use the feedback they receive to improve the quality of their writing because the students are required to revise their initial reports before submitting them to the course instructor for evaluation.

■ ASSOCIATED CONTENT

Supporting Information

Peer-review guide; instructor scoring rubric. This material is available via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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