Special Series: Scientific Literacy

JMBE Journal of Microbiology & Biology Education

Annotations Serve as an On Ramp for Introductory Biology Students Learning to Read Primary Scientific Literature

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Learning to read primary scientific literature (PSL) is an important part of developing scientific literacy skills. First-year students entering college often have little previous exposure to PSL and therefore face initial barriers in learning how to engage with PSL. Annotations have been shown to be a useful tool in undergraduate education and have potential for guiding students in developing higher-level reading strategies. In this study, we collected both qualitative and quantitative data to test the hypothesis of whether annotated PSL aids in the development of reading strategies for novice students learning to read PSL. Our qualitative results showed that annotations help students (i) break down PSL into manageable pieces, (ii) summarize the text, (iii) identify key information, and (iv) distinguish between different sections of PSL. Quantitatively, we saw no significant influence of annotations on the development of reading strategies for students learning to read PSL. Overall, our study provides a window into better understanding of specific strategies that students employ in reading PSL. Collectively, we suggest incorporating annotated PSL with some scaffolding social activities as an effective strategy to bring novice readers up the on-ramp of scientific literacy.

KEYWORDS annotations, primary scientific literature, reading strategies, science literacy

INTRODUCTION

Improving students' scientific literacy has become a key emphasis in science education, and preparing future scientists to be able to read primary scientific literature (PSL) is critical for science literacy. Engaging with PSL allows students to experience how science is done through exposure to (i) experimental design, (ii) scientific language and the structure of scientific communication, (iii) critical assessment of data and conclusions, and (iv) continuity of the scientific research process (1). A growing body of literature shows that PSL is a valuable tool for science, technology, engineering, and math (STEM) education. Educational interventions using PSL include journal clubs, data and figure exploration, tutorials on how to read PSL, tailored assignments preparing students to discuss PSL, annotated PSL, and full courses being taught only with PSL (2–12). Therefore, PSL is an extremely versatile pedagogical tool for directly impacting students' science literacy (13).

Challenges to learning to read PSL

First-year students entering college often have little previous exposure to PSL and therefore face initial barriers in learning how to engage with PSL (14, 15). Although undergraduate university students tend to correctly interpret observation statements, statements of method, and predictions when they read science, they perform less well when reading requires integrating information from different sections of text and seeing the connections between them (16). In addition, reading comprehension depends on the background knowledge of the reader and requires the active construction of new meanings and contextualization, which is an additional challenge for novice STEM students with limited STEM knowledge (17).

Editor Jack Wang, The University of Queensland

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The authors declare no conflict of interest.

Received: 10 November 2022, Accepted: 16 February 2023, Published: 13 March 2023

Annotations and learning to read

Annotations are additional explanations or comments added to a text or diagram, and annotation tools have been adopted in teaching practices with a wide range of instructional activities (18–21). Annotations can be useful for undergraduate students to comprehend experimental protocols, pay better attention to details, and to effectively carry out research (22). Annotations can also be used to remove stumbling blocks to reading scientific text and possibly even to develop higher-level reading strategies.

Recently, studies have incorporated social or collaborative annotation technologies in scientific reading and case study activities in upper-level undergraduate courses (23, 24) and labs (22). In such studies, annotations supported student learning in the aspects of comprehension of course content, confirmation of ideas, engagement with diverse perspectives through collaborative activities, utilizing a guided instruction and grading rubric, and actively reflecting on the execution of lab protocols. However, research on understanding how annotations affect undergraduates' reading strategies and comprehension as they learn to read PSL in lower-level introductory courses is limited.

Annotated PSL

Annotated PSL is designed to help readers interpret complex science by overlaying additional information onto the original piece of PSL. Preserving the original text and its context is what makes annotated PSL unique and makes it distinct from adapted primary literature, an approach that rewrites PSL content (25). Science in the Classroom (SitC; www.scienceintheclassroom.org) is the premier example of annotated primary scientific literature and has been shown to have potential for classroom pedagogical use (26).

SitC, a collection of freely available annotated papers, aims to make primary scientific research literature more accessible to students and educators. SitC resources use the original text of research articles along with a "Learning Lens" overlay that is used to selectively highlight different parts of the text, e.g., Glossary, Previous work, Author's experiments, and Conclusions. Annotations contained within the Learning Lens were designed to be at the reading comprehension level of a first-year undergraduate student, and ongoing evaluation efforts have provided evidence that this goal is being met (27).

In this study, we investigated the impact of annotated PSL in introducing novice students to reading PSL. We compiled qualitative data on students' perception of both PSL and annotated PSL. We collected quantitative data on strategies students were using to read PSL as they interacted with annotated PSL over the course of a semester. We tested the hypothesis of whether annotated papers aid in the development of reading strategies for novice students learning to read PSL.

TABLE 1
Demographics for institutions and students involved in this study

Group and demographic	PSL1	PSL2	Control
Institution-wide			
Total no. of students	31,526	13,500	56,700
Students identifying as Hispanic/Latino	4%	3%	67%
Students identifying as African American/Black	5%	6%	12%
Students identifying as women	50%	61%	57%
Students involved in the study			
No. of students	62	272	41
% freshmen	80%	76%	88%
% with no prior experience with PSL	33%	29%	34%
% who had read <5 pieces of PSL prior to course	43%	43%	33%

METHODS

Participants

Data were collected from comparable General Biology I students during Fall 2021 at three different institutions: PSL1, PSL2, and control. It is important to note that these data were collected during the Fall of 2021, when all three institutions had returned to in-person learning. A pre- and post-course questionnaire (28) (see Appendix S1 in the supplemental material) was distributed to all students through Qualtrics (an online survey tool). The three institutions are part of an ongoing research collaboration examining PSL use in the classroom. Demographics for each of the institutions and for the students involved in this study are shown in Table 1. Collectively, the data showed that our overall student population was at the introductory level with little to no experience with reading PSL. Data shown in Table 1 represent students who enrolled in the course and do not represent only the students who completed the assessments. We do not have demographic data specific to students who completed the assessments.

Ethics statement. This study was deemed to be IRB exempt (IRB-20-0421-AM01).

PSL interventions

PSL1 and PSL2 participated in a PSL intervention with their students (the control group had no PSL included in their course) (Table 1). Details of the intervention are provided in Appendix S2. PSL used in the intervention was chosen based on course content, and students were engaged in learning the underlying biological concepts of each piece of PSL at the time they were assigned PSL readings.

PSL reading strategies

We measured the effect of the annotated PSL on student reading strategies by using a previously validated assessment that measures strategies students employ while learning to read PSL (28) (Appendix S1).

Descriptive statistics

SPSS was used for descriptive statistics and *t* tests. Paired *t* tests were employed to understand the changes between pre- and postcourse test scores of each dimension of the PSL reading strategies assessment, for all institutions, without directly comparing each institution's scores. The paired *t* test is a method used to determine if there is a significant change in the mean and it is therefore appropriate to use for pre- and postcourse testing (29).

Qualitative data analysis

Students' open-ended responses, collected only during the postcourse questionnaire (Appendix S1), were coded using both deductive and inductive coding techniques in order to both target specific constructs (reading strategies) while still leaving room for discovery (30). Deductive coding is a top-down approach using predetermined codes to analyze data. In our case, we used items from the PSL reading strategies assessment (Appendix S1).

We also performed inductive coding, a subset of thematic analysis (31). Per its definition, inductive coding is free from theoretical frameworks. Instead, inductive coding is completely driven by the participants' responses (31). Inductive coding was used to identify interesting codes that emerged from the open-ended responses. Four researchers read all of the open-ended responses and independently created lists of the perceptions, attitudes, and opinions that arose from participant responses. These lists were compared and discussed among the researchers, and a preliminary code book was developed consisting of short, descriptive phrases that could be used to describe particular perceptions, attitudes, or opinions expressed by participants. Using this team-generated code book, each open-ended question was independently coded by two researchers. All researchers then convened to discuss, further define, and reduce codes that were unclear. Analysis of coding considered only the presence or absence of specific codes within each open-ended response, not the frequency with which a single participant expressed a particular code. Responses corresponding to more than one code were coded to each code with which they corresponded. Kappa values measuring interrater reliability (the extent to which researchers assigned the same code to the same data) were over 0.85, which represented higher standards than recommended (0.65) (32). All qualitative analysis was completed using Nvivo software (NVivo version 12, QSR International).

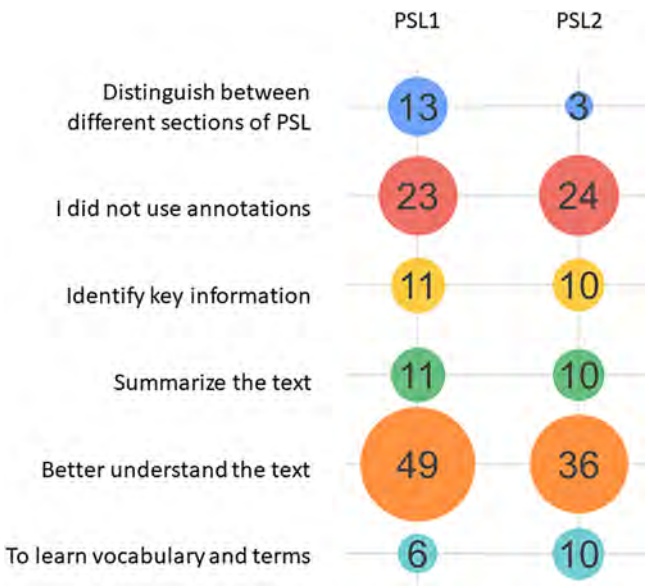

FIG 1. How students described their use of the annotations. Inductive coding of short answer responses provided by participants in response to the question "How did you use the annotations?" is shown. The *y* axis shows codes connected to participant responses that were found in the data set, and the *x* axis indicates the institution participants were from. The data are shown graphically, with the area of each circle being representative of the percentage of participant responses connecting to each code (the exact percentage is noted within each circle). Some responses correspond to more than one code. The complete code book is found in Appendix S3 in the supplemental material. $n = 53$ for PSL1 and $n = 67$ for PSL2.

RESULTS

Annotations help students break down PSL into manageable pieces

We asked students "How did you use the annotations?" Inductive coding revealed that students described how annotations helped them better understand the text, including how annotations helped to summarize the text (Fig. 1). Example student responses are shown in Appendix S3 and included the following:

> I used them to break down the article to get a better understanding.
> I usually hover over annotations provided to see what kind of information they give.
> Sometimes it is really helpful in summing up what I read or it provides a little more background that makes the sentence more creditable.

We also noted that students mentioned how annotations helped them to distinguish between different sections of PSL, which was relevant to this study in particular, as we used *Science* articles where different sections were not clearly defined. These data suggested that one value of annotations is helping students learn how different sections of PSL contain different types of information, as shown in student responses (Appendix S3):

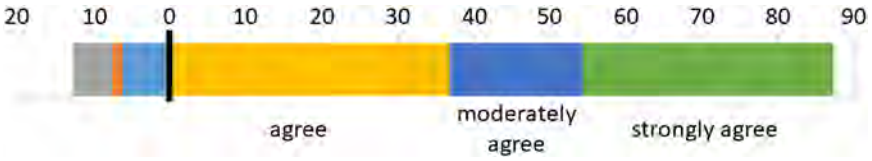

FIG 2. Students found annotations to be helpful. Students ($n = 157$) were asked during the postcourse questionnaire only "Did the annotations make it easier to read PSL?" using a 6-point Likert scale question. Bars represent the percentages of students that selected a particular choice. Gray, strongly disagree; orange, moderately disagree; light blue, disagree; yellow, agree; dark blue, moderlately agree; green, strongly agree.

When determining what section of the text I need to be looking in.
I did use them when I could not find a certain section within the article.

We next asked students, regardless of whether they used the annotations, if the annotations made it easier to read PSL. We asked this during the postcourse questionnaire only (Appendix S1). Quantitatively, we saw an overwhelming positive response to annotations being helpful (Fig. 2). Qualitatively, through inductive analysis, we again saw students describe how annotations helped them better understand the text (Fig. 3). We also saw students describing how the annotations helped them focus, identify key information, and distinguish between different sections of PSL. These data suggested that annotations helped students to center themselves when reading PSL, as shown in the following student responses (Appendix S4):

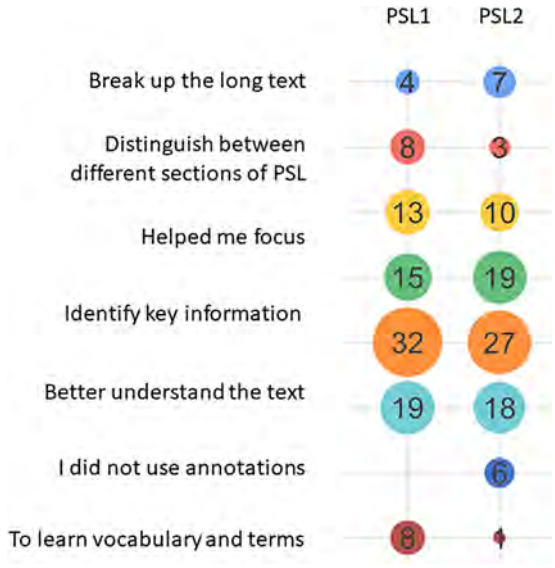

FIG 3. Students described whether the annotations made it easier to read PSL. Inductive coding of short answer responses provided by participants were in response to the question "Did the annotations make it easier to read PSL?" The *y* axis shows codes connected to participant responses that were found in the data set, and the *x* axis indicates which institution participants were from. The data are shown graphically, with the area of each circle being representative of the percentage of participant responses connecting to each code (the exact percentage is noted within each circle). Some short answer responses corresponded to more than one code. The complete code book is found in Appendix S4. $n = 53$ for PSL1 and $n = 67$ for PSL2.

The annotations guide me to focus a little more on what is highlighted because those are the points that the author really wants you to understand.
My reasoning is because I often found myself lost in the material, so annotations helped to guide me through it rather than get stuck in it.

Annotated papers did not significantly influence student strategy development for reading PSL

We used the PSL reading strategies assessment to measure changes in student reading strategies while engaging with annotated PSL. Paired *t* tests showed significant differences ($P < 0.05$) in student responses for increased summarizing for control and PSL2, decreased note writing for PSL1, and decreased finding additional information for PSL1 and PSL2 (Fig. 4). While these results were unexpected, they can be explained with the corresponding qualitative data.

We asked students "When reading primary scientific literature, do you often find yourself confused or lost? Please explain." We coded these data deductively using the PSL reading strategies assessment as codes (Fig. 5). We saw surprising consistency in student responses across institutions, regardless of whether the annotated PSL was read. When students described what they do when they are lost and confused, we saw connections to "Look up a method in the text that you don't know" and "Look up a word in the text that you don't know," even though we saw a decrease in these collective skills (finding additional information) quantitatively (Fig. 4). Students in the control group mentioned summarizing, which may help to explain the increase we saw in summarizing quantitatively with this group who read no annotated PSL. We also saw students describing additional reading strategies that corresponded to expert-like behavior, such as "reread portions of the text one or more times" and "use knowledge from past classes" (33). Examples of student responses are shown in Appendix S5.

We next asked "When reading PSL, what do you do to better understand the material?" We coded these data deductively using the PSL reading strategies assessment as codes. Again, we saw unexpected consistency in student responses across institutions, regardless of whether annotated PSL was read (Fig. 6). We saw very few responses connected to "writing notes," which may explain the decrease in quantitative data we saw (Fig. 4). We saw the most connections to "additional information," which disagreed with the quantitative changes we saw (Fig. 4).

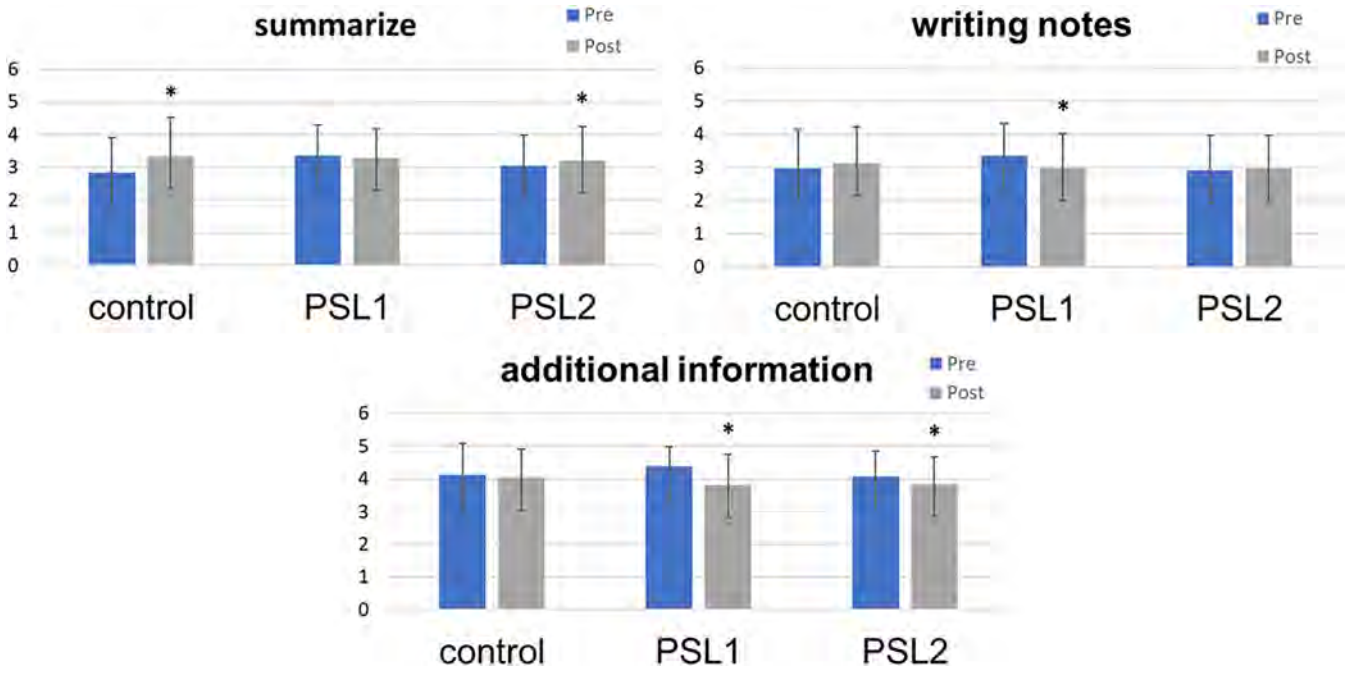

FIG 4. Pre- and postcourse comparisons for each institution in each subscale of the PSL reading strategies assessment. The Likert scale we used, scale of 1 to 5, is shown on the *y* axis with the three subscales of the assessment shown along the *x* axis. Asterisks indicate significant ($P < 0.05$) differences in student scores between groups. $n = 34$ for control, $n = 31$ for PSL1, $n = 166$ for PSL2.

Examples of student responses to this question are shown in Appendix S6.

To determine if students were able to translate annotations into strategies, we asked students how they would annotate in the future. Very few responses corresponded to the PSL reading strategies of summarizing, writing notes, and additional information (Fig. 7). We did see responses indicating that students would annotate in general, and the lack of direct connections to PSL reading strategies may have been because students did not get specific enough in their responses. Students also described additional strategies that corresponded to expert-like behavior, such as "highlight important parts of the text" (33). Examples of student responses are shown in Appendix S7.

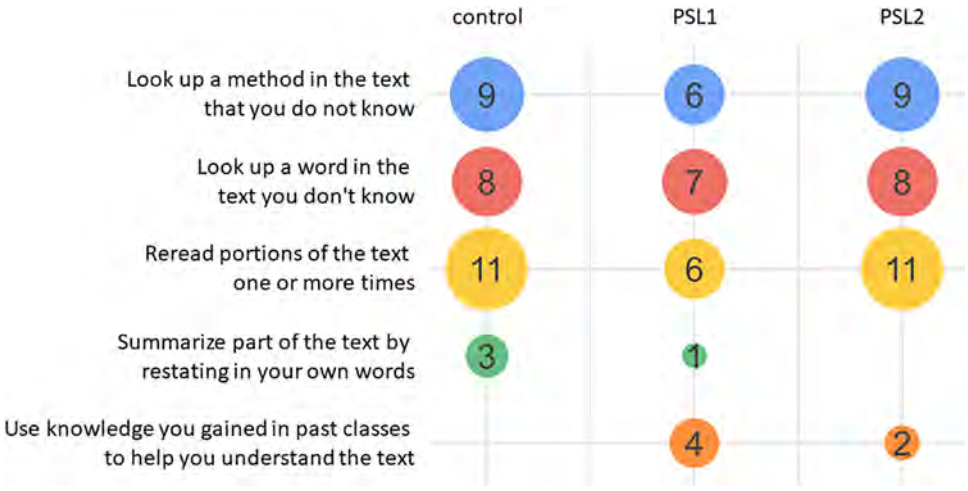

FIG 5. Students described whether they were confused or lost while reading PSL. Deductive coding of short answer responses provided by participants further described their use of reading strategies in response to the question "When reading primary scientific literature, do you often find yourself confused or lost? Please explain." The *y* axis shows deductive codes (PSL reading strategies assessment [Appendix S1]) connected to participant responses that were found in the data set, and the *x* axis indicates which institution participants were from. The data are shown graphically, with the area of each circle being representative of the percentage of participant responses connecting to each code (the exact percentage is noted within each circle). Some short answer responses corresponded to more than one code. $n = 74$ for control, $n = 53$ for PSL1, $n = 67$ for PSL2.

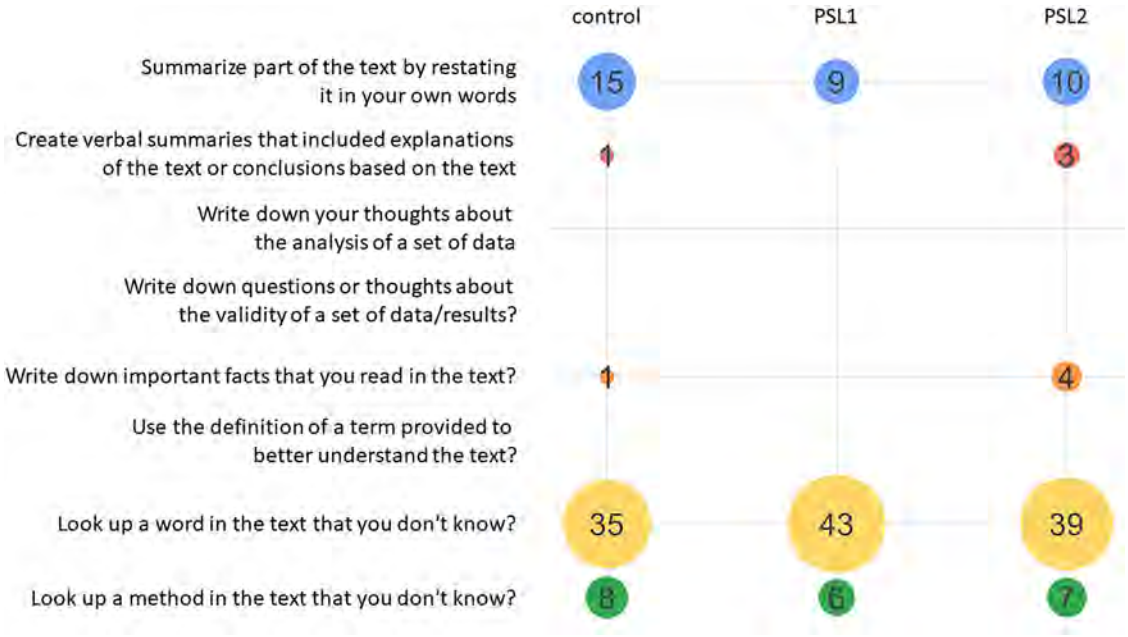

FIG 6. Students described strategies they used to better understand the material. Deductive coding of short answer responses provided by participants further described their use of reading strategies in response to the question "When reading PSL, what types of things do you do to better understand the material?" The *y* axis shows deductive codes (PSL reading strategies assessment [Appendix S1]) connected to participant responses that were found in the data set, and the *x* axis indicates which institution participants were from. The data are shown graphically, with the area of each circle being representative of the percentage of participant responses connecting to each code (the exact percentage is noted within each circle). Some responses corresponded to more than one code. $n = 74$ for control, $n = 53$ for PSL1, and $n = 67$ for PSL2.

DISCUSSION

Annotated PSL can serve as an on ramp for novice PSL readers by highlighting different sections of PSL and helping students to focus on the important parts of PSL. We report here quantitative data suggesting that annotations do not significantly influence the development of reading strategies of novice PSL readers. However, corresponding student short-answer responses indicated that there is more to the story and that students are developing strategies. We confirmed that annotated PSL can be added to the growing number of PSL-based interventions that impact students' science literacy (13).

Annotated papers have benefits for students learning to read PSL

The benefits of annotated PSL were more foundational than we had anticipated. Overall, students reported annotations being useful (Fig. 2). Annotations were found to help students at a more basic level of learning how to distinguish between sections of PSL and on how to break down PSL into manageable pieces (Fig. 1 and Fig. 3). For the students in this study, this level of introductory overview was a necessary place for novice readers to start engaging with PSL. Annotations are valuable for students learning to integrate information from different sections of text and seeing the connections between them (16). In other words, annotations may act as a catalyst in the development of scientific literacy.

Do annotated papers help to develop reading strategies in novice PSL readers?

Our results for this research question were somewhat unclear. Quantitatively, there were no meaningful changes in reading strategies. We saw a significant increase in "summarizing" for the control group that read no PSL, and never saw an annotation, suggesting that learning to summarize content may simply be a function of participating in an introductory biology course or that this is a general reading strategy that students bring with them to college (Fig. 4). The significant increase in summarizing exhibited by PSL2, who read PSL in groups and discussed PSL content with student peers, teaching assistants (TAs), and the instructor, may be explained in the same way as the control results. Additionally, the gains seen with PSL2 could also be an artifact of working together in groups, where summarizing takes place automatically (Fig. 4). This finding is consistent with previous studies in the applications of social annotation tools showing that peer interactions along with challenging tasks, such as reading PSL, can promote student learning gains (22, 23). Additionally, students participating in a course that paired annotated PSL with group discussions showed increases in students' scientific literacy skills (34).

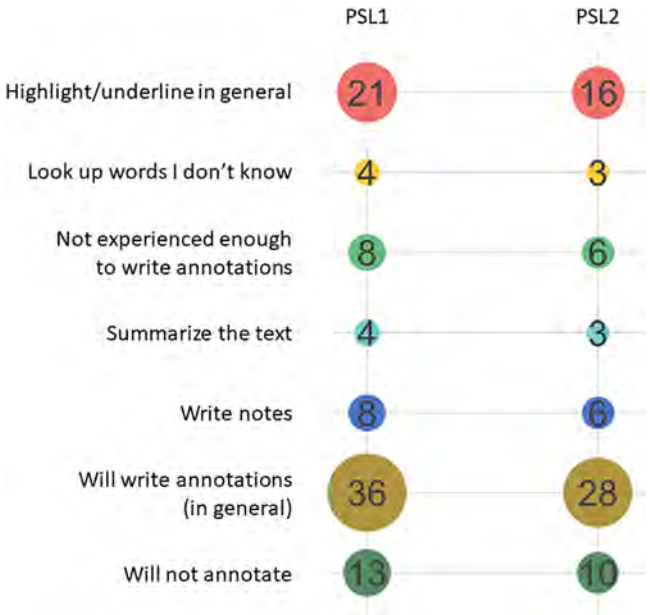

FIG 7. Students described whether they would annotate in the future. Inductive coding was used for short answer responses provided by participants in response to the question "How will you annotate in the future?" The *y* axis shows codes connected to participant responses that were found in the data set, and the *x* axis indicates which institution participants were from. The data are shown graphically, with the area of each circle being representative of the percentage of participant responses connecting to each code (the exact percentage is noted within each circle). Some responses corresponded to more than one code. The complete code book is found in Appendix S8. $n = 53$ for PSL1 and $n = 67$ for PSL2.

PSL2 students were required to summarize and answer questions prior to class and reviewed and revised their answers together in small groups. Therefore, PSL2 students were actively using the skill of summarizing, and similar increases found in the control group did not negate the work of students in PSL2. In fact, qualitative data would further support students doing both, summarizing with course work (evidenced by the control) and also adding on to those skills with the annotated PSL.

We saw significant decreases in "finding additional information" for both PSL1 and PSL2. This may have been the result of the annotations providing additional information for the students at the click of a button, which may have had the unintended effect of allowing students to think additional information would always be present. However, these quantitative data disagreed with what the qualitative data showed us. Figures 5 and 6 both suggest that students were looking up additional information when reading PSL. The qualitative data here are important, as the findings describe what information the students are looking up, such as vocabulary words and methods, which is an appropriate action for a first-semester student's reading level and science background. Students looking up a word may be the first step in the development of their reading strategies and could serve as a stepping stone to the next step of summarizing. Thus, these data may hint at a stepwise or layered strategy in reading PSL.

The qualitative data also showed that students were rereading the text, which suggested they may be struggling with the mechanics of reading. This may also have led to a decrease in the need to look up information, evidenced by the quantitative results (Fig. 4). Rereading the text has been previously shown to be a reading strategy employed by expert PSL readers (33).

These data can be collectively explained by the idea that students need very structured guidance when learning strategies for reading PSL. This is consistent with the finding of Cafferty (24), who used a guided rubric for assessment in parallel with annotations. As described above, students likely were summarizing and looking up additional information, yet they did not automatically consider this to be a reading strategy. Instead, they may have considered this to be another assignment for the course. One clear result from these contradicting data is that simply providing students with annotations alone is not enough guidance for developing a reading strategy. Specific and targeted instruction connecting the purpose of annotations, and the content contained with annotations, to specific strategies for learning to read PSL was missing from our PSL teaching implementations.

These results are also similar to what we previously reported with students participating in the same course under the same interventions who read a PDF version of the same papers. In that study, where no annotations were available, we saw the same increases in summarizing for PSL2 which, again, may have been an artifact of working in groups and with TAs (28). We also saw the same decreases for PSL1 and PSL2 for additional information. Taken together, these data suggest that the inclusion of annotations provided no additional benefit with regard to learning reading strategies.

CONCLUSION

Why then should annotated PSL be included as part of undergraduate courses? Our data showed that annotations, while not enough to encourage the development of reading strategies, do serve as an on-ramp for students learning to read PSL. These results agree with other studies showing that introductory students find annotations useful, especially for vocabulary and graph interpretation (26). Our data also provided a window into better understanding barriers that remain for students, such as the need to reread the text and look up vocabulary words and methods. We also are beginning to understand the sequence with which novice students start to develop reading strategies. For example, annotations may help students overcome the initial step of reading PSL, conceptual understanding, that in turn may further help students to improve their summarizing skills. The qualitative data from this study also showed that students recognize the utility of annotations for future work. We acknowledge that we worked in large, intro biology courses, and future studies should investigate whether the use of annotated PSL would produce similar data from smaller class sizes. Overall, we suggest incorporating annotated PSL with some

scaffolding social activities, such as group interactions and peer mentoring, as an effective strategy for bringing novice readers up the on-ramp to scientific literacy. This suggestion is supported by our data showing that PSL2, who participated in small group discussions, exhibited an increase in summarizing compared to PSL1, who worked independently.

SUPPLEMENTAL MATERIAL

Supplemental material is available online only.

SUPPLEMENTAL FILE 1, DOCX file, 0.1 MB.

ACKNOWLEDGMENTS

This work was supported a Pearson 2020 Biology Leadership Conference Catalytic Grant. We thank all our students for sharing their time, enthusiasm, and data with us.

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