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From Novice To Expert: An Assessment To Measure Strategies Students Implement While Learning To Read Primary Scientific Literature

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Primary Scientific Literature (PSL) has been used in undergraduate classrooms as a way to engage students with the research process and to increase science literacy. Most curricula lack any formal training for undergraduates to critically read PSL even though most undergraduate science courses require students to engage with PSL at some level. In addition, there are limited studies exploring the process by which expertise in reading PSL develops in undergraduates. In this study, we adapted behaviors that expert and novice PSL readers exhibit into a quantitative assessment tool, the PSL Reading Strategies Assessment, to evaluate undergraduates' development of reading strategies when learning to read PSL. Factor analysis and reliability measures were implemented to determine the structure of our assessment tool. Our results show the PSL Reading Strategies Assessment is sensitive enough to measure differences among student populations, suggesting that it can be used as a diagnostic tool to guide instructors and researchers as they change curricula, implement new teaching strategies, and strive to develop students' science literacy. Moreover, our data show that developing expert-like reading strategies in students learning to read PSL is not easy. Simply reading a PDF does little to promote the development of reading strategies in students learning to read PSL.

KEYWORDS expert, novice, primary scientific literature, reading strategies, science literacy

INTRODUCTION

The National Science Foundation (NSF), The National Association of Biology Teachers (NABT), and the American Association for the Advancement of Science (AAAS) have collectively emphasized the need for engaging students in scientific research. Primary scientific literature (PSL) can serve as a gateway to the research process. Through learning to read and deconstruct PSL, students can gain an understanding of how scientists design their experiments, analyze their data, and draw conclusions, fundamentally allowing students to experience how scientists progress from a problem to a set of data to a new conclusion. Increased scientific literacy is a natural outcome for students engaging with PSL (1).

In addition to increased science literacy, studies have shown increases in student effective and cognitive gains, increases in student interest in the course material, and increases in students' confidence in science communication (2–4). Moreover, educational interventions using PSL at the undergraduate level are well documented and include journal clubs (5, 6), variations of consider, read, elucidate the hypotheses, analyze and interpret the data, and think of the next experiment (C.R.E.A.T.E.) (2, 7–12), circular response (13), process-oriented guided inquiry learning (POGIL) activities (14), Jigsaw activities (15), Figure Facts (16), annotated articles (17), and comprehension exercises (18).

Despite the value of PSL in STEM education, most curricula lack any formal training for undergraduates to critically read. Considering that learning to read PSL is a long and continuing process for undergraduates, early exposure to PSL has been suggested by previous studies (1, 17, 19, 20). Instances of PSL being included in introductory classrooms are increasing and are likely to continue in this direction (19, 20). Therefore, it is becoming imperative that we develop and implement best practices for introducing novice students to PSL to better prepare them for the rest of their college careers and beyond.

There are limited studies exploring the process by which expertise in reading PSL develops in biologists as they progress

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through their career (21–23). A more thorough understanding of the development of expertise in the analysis of PSL, including how to measure the progression of becoming an expert, are needed. In general, expert PSL readers value different sections of PSL than novice readers (21, 22, 24). Novice readers tend to avoid figures and data (25) and place less value on interpreting methods and experimental results than expert readers (21).

Expert and novice readers likewise engage in different behaviors while reading PSL. A series of think-aloud interviews of biology faculty and undergraduates as they read PSL revealed faculty engaging in behaviors including reading the text more than once, summarizing or recapping the text, using reference points and prior knowledge, underlining key pieces of information, and taking notes as much as three times as that of novice readers (22). It is possible that this level of behavioral engagement is learned over time and contributes to the progression from novice to expert reader. Further exploration of this idea, including developing a way to measure the progression of this manner of behavioral engagement, would advance our understanding of how best to guide novice students as they learn to read PSL. For novice students learning to read PSL and develop science literacy skills, improving their underlying behaviors related to PSL may be as valuable as teaching them the mechanics of reading PSL.

In this study, we adapted the behavioral findings of Nelms and Segura-Totten (22) into a quantitative assessment tool as a way to evaluate biology undergraduates' reading strategies (behaviors) when learning to read PSL. We collected data concerning internal questionnaire structure (validity evidence) and relationships to external variables, and we tested the hypothesis of whether our instrument is sensitive enough to measure differences among diverse student populations. As such, our assessment can be used to measure the progression of novice readers' behavioral engagement in reading PSL and to determine which reading strategies they are developing.

METHODS

The PSL Reading Strategies Assessment

We adapted the behavioral findings of Nelms and Segura-Totten (22) into an 11-item quantitative assessment tool. Specifically, items were written using the working definition of behaviors within the "Thinking tools" theme (22). When the application of a thinking tool differed between experts and novices, we incorporated the description of the expert application in the item. For example, the "taking notes" thinking tool in Nelms and Segura-Totten (22) was converted into assessment items 4 and 5 (Table 1), since expert notes most often incorporated the analysis and evaluation of data in their notes (22). Other items were contextualized for undergraduate students by incorporating language that students in the Nelms and Segura-Totten (22) study used. For example, students mentioned for the "prior knowledge" thinking tool that knowledge gained in past courses helped them understand aspects of PSL. This was incorporated into item 7 of the assessment tool. We tested items with a focus group of undergraduate biology students for clarity and purpose. We chose a 5-point scale. In addition, we chose to include only positive statement items for 2 reasons: first, we feel that negatively worded questions or statements can be confusing to readers. If a respondent has to disagree in order to agree, we feel that the item is unclear. Second, and likely connected to confusing language in our experience, negatively worded items have tended to cluster as their own factor that have never met validity standards, resulting in their removal from the final assessment. Items are shown in Table 1.

TABLE 1
Original items in the PSL Reading Strategies Assessment[a]

Item	When reading a piece of Primary Scientific Literature, how often do you:
1	Reread portions of the text one or more times?
2	Summarize part of the text by restating it in your own words?
3	Create verbal summaries that included explanations of the text or conclusions based on the text?
4	Write down your thoughts about the analysis of a set of data/results?
5	Write down questions or thoughts about the validity of a set of data/results?
6	Write down important facts that you read in the text?
7	Use knowledge you gained in past classes to help you understand the text?
8	Underline the text?
9	Use the definition of a term provided to better understand the text?
10	Look up a word in the text that you don't know?
11	Look up a method in the text that you don't know?

[a]Items were measured using a 5 point Likert scale (1 = never; 2 = sometimes; 3 = about half the time; 4 = most of the time; 5 = always).

Participants

This study was deemed to be IRB exempt (IRB-20-0421-AM01). All data were collected from comparable Gen Bio 1 students during Fall 2020 at 3 different institutions. A pre- and post-course assessment was distributed to all students through Qualtrics (an online survey tool). The control group received no PSL intervention and is a public Carnegie R1-ranked urban university and Hispanic Serving Institution. PSL1 is a Carnegie R1-ranked land grant institution. PSL2 is a Carnegie R2-ranked state supported university serving a high population of students that are first generation college students. These institutions are part of an ongoing research collaboration examining PSL use in the classroom and demographics for each institution and for the students in this study are shown in Table 2. The control group was selected because the researcher affiliated

TABLE 2
Demographics for institutions and students involved in this study

	Control	PSL1	PSL2
Institution wide			
Total no. of students	42,000	24,500	13,500
Students identifying as Hispanic/Latino	67%	4%	3%
Students identifying as African American/Black	12%	5%	6%
Students identifying as women	57%	49%	61%
Students in this study (total students enrolled at each institution, a subset of these students completed the surveys)			
No. of total students (*n*)	147	105	306
Freshmen	77% (113)	82% (86)	77% (236)
No prior experience with PSL	27% (39)	34% (36)	32% (98)
Having read less than 5 pieces of PSL prior to this course	36% (53)	51% (54)	45% (138)

with this institution was not assigned to teach Gen Bio I and could not implement PSL with students. PSL1 and PSL2 only offered one section of Gen Bio, making it difficult to have a control and intervention group within each institution. Collectively, these data show that our overall student population is at the introductory level with little to no experience with reading PSL. Therefore, this is a perfect student population to work with as they likely have little to no prior knowledge of PSL reading strategies. It is important to note that these data were collected during the Fall of 2020, where all 3 institutions had COVID protocols in place requiring remote, online learning. Data shown in Table 2 represent students enrolled in the course and does not represent only the students who completed the assessments.

PSL interventions

PSL1 and PSL2 participated in a PSL intervention with their students. Details of the intervention are provided in Appendix 1. Briefly, an identical introductory lecture introducing PSL was given at the start of the semester. Students were then assigned 3 pieces of PSL to read over the course of the semester. PSL1 students engaged with PSL mostly on their own while PSL2 students engaged with PSL in peer groups and with teacher's assistants (TAs). Both sets of students completed corresponding inquiry worksheets related to the PSL being read. The interventions were designed by the research team and have not been previously tested. PSL used in the intervention was chosen based on course content.

Descriptive statistics

M*plus* (26) was used for factor analysis and IBM SPSS Statistics (Version 26) (27) was used for descriptive statistics and paired *t*-tests. Before factor analysis, descriptive statistics and correlations between items were examined. A complete overview of these analyses are shown in Appendix 2. These results show that the data set was appropriate for factor analysis (28).

Dimensionality of the assessment

To collect validity evidence concerning internal structure, factor analysis was performed. Considering that these data were collected with a newly developed assessment instrument and a new student population, Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA) were conducted on the same data ($n = 322$) set using M*plus*. Because there is minimal previous research on how expertise in reading PSL develops, we had no hypothesis about the dimensionality of the PSL Reading Strategies Assessment other than to assume the items would correlate.

Exploratory factor analysis

Further details on exploratory factor analysis (EFA) methods are found in Appendix 3. An oblique rotation was chosen. Factor correlations were used to evaluate the fit of the data to the model as well as the fit of individual items to the scales.

Confirmatory factor analysis

Further details on confirmatory factor analysis (CFA) methods are found in Appendix 4. Once the scales were created using the EFA approach, CFA was conducted to investigate and construct the validity of the assessment.

Reliability

The reliability of the assessment was determined based on the Cronbach's alpha, which measures the internal consistency of scale items (29). This is the preferred measure of reliability in our study because of its reliance on Likert-based questions. The Cronbach's alpha needed to be greater than 0.7, to reach the

TABLE 3
Post-EFA items with corresponding factor names[a]

Item no.	Description	Factor
2	Summarize part of the text by restating it in your own words?	1. SUMMARIZING the text
3	Create verbal summaries that included explanations of the text or conclusions based on the text?	
4	Write down your thoughts about the analysis of a set of data/results?	2. WRITING notes from the text
5	Write down questions or thoughts about the validity of a set of data/results?	
6	Write down important facts that you read in the text?	
9	Use the definition of a term provided to better understand the text?	3. FINDING additional information
10	Look up a word in the text that you don't know?	
11	Look up a method in the text that you don't know?	

[a]Items 1, 7, and 8 were dropped after EFA analysis and the remaining factors were named according to the strategies they encompassed.

desired threshold for reliability (30). Composite reliability (30) as the reliability and internal consistency of latent constructs was then set at a measure of 0.6 (31).

Measuring changes in pre- and post-PSL Reading Strategies Assessment scores between different groups of students

Paired *t*-tests were employed to understand the changes between pre- and post-test scores of each dimension of the 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 is therefore appropriate to use for pre- and post-testing (32). In this study, paired *t*-tests were used to determine the change in mean for 3 pairs of pre- and post-test factors determined through factor analysis.

RESULTS

Internal structure of the PSL Reading Strategies Assessment: EFA

EFA is a statistical method used to identify the underlying relationships between measured variables, which, in our study, is the relationship between assessment items. EFA can be used to explore patterns underlying a data set and elucidate how different items and constructs relate to one another. EFA is suitable during early stages of instrument development and can identify items that do not empirically belong (33). Data was cleaned to include only data from students completing both the pre-and post-survey (control $n = 75$; PSL 1 $n = 41$; PSL2 $n = 206$; total $n = 322$), and the pre-data set was used here. The result of the initial analysis of EFA on the items in Table 1 revealed a probable three-factor solution with Oblique (Geomin) Rotation using maximum-likelihood with robust standard errors (MLR) (24). Additional EFA results are found in Appendix 5. Based on this, the first EFA output revealed that among 11 items, 3 items loaded in factor 1, 4 items loaded in factor 2, and 4 items loaded in factor 3. Also, none of the test one-, two-, three- or four-factor models resulted in a good fit (three-factor solution: chi-square= 74.04 $P < 0.05$, RMSEA = 0.078, TLI = 0.910, SRMR = 0.029) Therefore, item 1, item 7, and item 8 from Table 1 were removed to see improvement of the model fit.

The result of second run of the EFA (using the same pre-data) revealed a probable three-factor model. Items were then organized into 3 factor categories: summarizing, taking notes, and additional information. The eigenvalues are 3.639, 1.445, and 1.087 for the first, second, and the third factor, respectively. No other factors had eigenvalues > 1. The second calculation of EFA resulted in a good fit with three-factor model (chi-square = 4.897, $P = 0.673$, RMSEA = 0.000, TLI = 1, SRMSR = 0.007). The second EFA output showed that 2 items loaded in factor 1 (renamed as summarizing the text) (Appendix 5 and Table 3), 3 items loaded in factor 2 (renamed as writing notes from the text) (Appendix 5 and Table 3), and 3 items loaded in factor 3 (renamed as finding additional information) (Appendix 5 and Table 3). It is more common for a scale to have at least 3 items (24). However, there are situations in which it is preferable to have only 2, if the variables are highly correlated with one another, but uncorrelated with other variables (34). This allows for the factors to reflect the narrowness of the construct itself. We now have a structure for our assessment that we will test using confirmatory factor analysis using post-data.

Internal structure of the PSL Reading Strategies Assessment: confirmatory factor analysis

CFA is used to confirm a previously stated theoretical model (33). Essentially, we are confirming our EFA results. CFA was conducted using post-data from all 3 institutions ($n = 322$). As shown in Fig. 1, the reading strategies were considered as

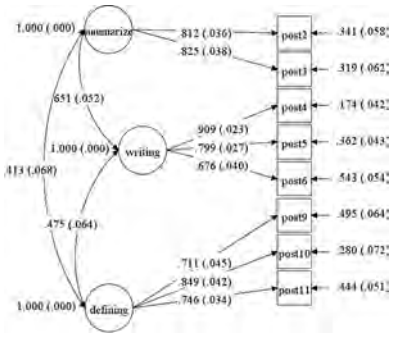

FIG 1. CFA Model for the PSL Reading Strategies Assessment.

latent variables in CFA. The result of CFA showed that the model that previously identified by EFA is satisfactory ($\chi^2_{(17)}$ = 60.892, $P < 0.01$), The root mean square error of approximation (RMSEA) index was 0.09 (0.066, 0.114 90% C.I.). The comparative fit index (CFI) was 0.948, the Tucker-Lewis Index (TLI) was 0.915, and Standardized Root Mean Square Residual was 0.057. All the fit indices lie within the acceptable fit thresholds. Hence, we conclude that the proposed model has an acceptable fit with the data.

Reliability analysis

Internal consistency is measured by determining whether the same results are obtained from different parts of the questionnaire designed to evaluate the same item. Cronbach's alpha will be calculated to assess the reliability and internal consistency of the questionnaires (33). A reliability test for both the pre- and post-data sets was conducted. The study used Cronbach's alphas and composite reliabilities (CR) to test the scale's stability and internal consistency, with values higher than 0.70 considered good. The Cronbach's alphas for the three factors of the EFA model were 0.748, 0.838, and 0.819 (Table 4). The Cronbach's alphas for the 3 factors for the CFA model were 0.802, 0.830, and 0.801. The composite reliability coefficients were 0.802, 0.841, and 0.779. With the values all higher than the minimally acceptable value of 0.7, it can be assumed that the EFA and CFA models for the PSL Reading Strategies Assessment have satisfactory reliabilities.

Changes in PSL Reading Strategies Assessment scores

Once the structure of the assessment was determined, we investigated whether the instrument was sensitive enough to measure changes across different populations of students. Data from students who completed both the pre- and post-assessment were analyzed (control $n = 75$; PSL 1 $n = 41$; PSL2 $n = 206$) (Table 5). The paired t test was utilized to evaluate differences between pre- and post-scores of each dimension of the PSL Reading Strategies Assessment. The average score of each factor was used to compare pre- and post-test. This was determined by using the Likert scale items as continuous variables (35). Ordinal data can be treated as continuous if it is scaled, as in the case of a Likert scale because there is an underlying continuum measurement (35). The variables factor 1 "summarizing," factor 2 "writing notes", and factor 3 "additional information" were evaluated for the significance of the change, through both compared means and paired t test. For the control group, we saw no significant changes. For PSL1, "additional information" significantly decreased over time. For PSL2 "summarizing" significantly increased and additional information significantly decreased (Table 5).

DISCUSSION

We designed and validated a quantitative assessment measuring 3 factors of strategies (behaviors) novices and experts employ at varying frequencies while reading PSL. One of the goals of this study was to contribute to the understanding of how expertise in reading PSL develops in biology undergraduates. Our assessment is a novel tool that instructors can use to learn more about the processes by which students learn to develop strategies for reading PSL and developing science literacy skills. Additionally, we believe that using our 11-item assessment in different student populations and different approaches for reading PSL will yield information on how these behaviors vary throughout a college student's experience.

The PSL Reading Strategies Assessment is comprised of three separate yet related factors

Factor analysis of the original 11 items (Table 1) resulted in a three-factor, 8-item final assessment (Fig. 1 and Table 3). The 3 factors of summarizing the text, writing notes from the text, and finding additional information are in alignment with expert-like behavior for reading PSL (22).

TABLE 4
Cronbach's alphas and composite reliability coefficients of the EFA model and the CFA model

Factor	Cronbach's alpha for the three factors of the EFA model	Cronbach's alpha for the three factors of the CFA model	Composite reliability coefficients
1: summarizing the text	0.748	0.802	0.802
2: writing notes from the text	0.838	0.830	0.841
3: finding additional information	0.819	0.801	0.801

TABLE 5
Paired *t*-test results[a]

	Pre-test (m, sd)	Post-test (m, sd)	Change	*n*	*t*	*P*
Control				**75**		
Summarizing	3.3 (1.053)	3.16 (1.056)	Decrease		1.101	0.137
Taking notes	2.793 (1.152)	2.827 (1.056)	Increase		−0.280	0.390
Additional information	4.084 (0.983)	4.107 (0.840)	Increase		−0.216	0.415
PSL 1				41		
Summarizing	2.951 (0.907)	3.07 (1.052)	Increase		−0.808	0.212
Taking notes	2.74 (1.156)	2.585 (1.03)	Decrease		0.957	0.172
Additional information	**3.927 (0.953)**[b]	**3.325 (1.139)**	**Decrease**		**2.978**	**0.002****
PSL 2				206		
Summarizing	**3.262 (0.986)**	**3.45 (1.038)**	**Increase**		**−2.34**	**0.01****
Taking notes	3.12 (1.015)	3.21 (1.081)	Increase		−1.19	0.118
Additional information	**4.17 (0.805)**	**3.937 (0.942)**	**Decrease**		**3.38**	**<0.001****

[a]Comparisons of each dimension of the PSL Reading Strategies assessment for the three institutions before and after intervention.
[b]Bolded items showed significant changes.

The PSL Reading Strategies Assessment is sensitive enough to measure differences among student populations

Our assessment is sensitive enough to measure differences among student populations. PSL1 students read PSL on their own for homework and completed the guided reading questions (Appendix 1). For these students, we see a significant decrease in their likelihood to look up additional information (Table 5).

We see significant changes in both directions for PSL2 students who discussed PSL in class, both in small groups with oversight from TAs, completed the guided reading questions, and engaged in a whole class discussion with the instructor (Appendix 1). We see the same significant decrease in their likelihood to look up additional information as we see with the PSL1 students. In addition, PSL2 students increased their likelihood of summarizing (Table 5).

Simply reading a PDF does little to promote development of reading strategies in students learning to read PSL

Our study shows 1 instance of an increase in expert-like reading strategies in students: PSL2 students, working in groups with TAs on guided inquiry worksheets, showed an increase in their tendency to summarize the text as they read. This may be an artifact of working in groups and having to discuss the content of the PSL with their peers and TAs, which is a type of summarizing. Expert studies show that practicing a skill is essential to achieve expertise, and the students working in groups may have had more practice at summarizing (36, 37). In contrast, PSL1 students mostly worked alone and may have had less opportunities to practice summarizing. This suggests that, for novice students, learning to read PSL in a guided group setting, as opposed to individually, positively impacts students likelihood to summarize and should be further advocated as a best practice in PSL pedagogy.

Both student groups saw a decrease in their likelihood to look up additional information. One possible reason for this are the guided questions that accompanied each piece of PSL (Appendix 1). These guided questions did require students to look up additional information however it is possible that students saw this more as an assignment and less as a method for learning a reading strategy. A second possible explanation is that the content of each piece of PSL aligned with the content being taught in the course. If the content in the lecture overlapped enough with the PSL students may have had enough background content fresh in their mind and didn't see the need to look up additional information. As students progress through the semester, they likely acquire more background information, further diminishing their need to look up additional information.

As described above, students were likely summarizing and looking up additional information, yet they did not connect these behaviors to reading strategies. This may be an artifact of the self-reported nature of our assessment and that future studies may include faculty observations of students with a version of our assessment for a more direct measure. However, what is more likely is that students need very structured guidance when learning strategies for reading PSL. Targeted instruction specifically connecting behaviors and strategies was missing from our PSL teaching implementations.

What types of targeted instruction would be enough to increase expert-like behaviors? Most likely, students will need to engage with PSL to a greater extent than simply reading a PDF. Previous examples of increased engagement with PSL include the use of pre-assignments (38) and corresponding worksheets (19, 39). The common student behavior in these 3 examples leading to successful engagement is "generating notes and/or summaries of the content contained

within PSL in their own words," which was also found to be a factor in our Reading Strategies Assessment. The discussion sessions the PSL2 students had with their peers, TAs, and instructors seemed to initiate students moving toward more expert-like behaviors, suggesting that the addition of discussion exercises among supportive networks could lead to positive changes.

Limitations of this study

It is important to mention that Nelms and Segura-Totten (22) was a small-N study, which could affect the generalizability of their results. However, a study on the challenges and motivations of undergraduates reading PSL supported key conclusions of this study (18), which lends validity to its findings. Further, the fact that our assessment could measure differences between student populations as well as directional changes of items supports the claim that the behaviors reported in Nelms and Segura-Totten (22) are indeed important in the reading of PSL. Since the field of how expertise in reading PSL develops in biology undergraduates is still fledging, and as more knowledge is gained, we will continue to test and modify our assessment to reflect current knowledge. Additionally, use of this assessment in different student populations will contribute to the understanding of how expertise in reading PSL develops in biology undergraduates.

Use of the Reading Strategies Assessment in practice

Collectively, our data show that developing expert-like reading strategies in students learning to read PSL is not easy. In fact, it may be easier to determine PSL implementations that don't work (e.g., students reading PSL alone) rather than what does work. In our study, results led the instructors to contemplate how specific details of their implementation protocols may have influenced expert-like behavior among their students and how their implementation protocols could be refined for the future.

While collecting data mostly from introductory students in this study is not a limitation, it is possible that more advanced students will respond differently to the assessment, and it would be interesting to validate the initial set of items with more advanced students. The PSL Reading Strategies assessment offers information relevant to a certain learning environment at a specific time point in a student's career studies, and further studies on student experience versus their score on these metrics would be valuable. In this way, the assessment could be used as a longitudinal measure of tracking students' progress over time (and with different implementations of PSL).

SUPPLEMENTAL MATERIAL

Supplemental material is available online only.

SUPPLEMENTAL FILE 1, PDF file, 0.2 MB.

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