Writing with Research: Understanding How Students Perceive Sources in the Sciences

Kristin M. Klucevsek, Duquesne University

Abstract: Students in the sciences learn to engage with primary research articles as a fundamental part of their discipline, essential to both writing and research. These sources are difficult to navigate, leading students to use (and misuse) these sources in a variety of complex ways. As instructors and researchers, we are aware of these challenges, but less aware of why they happen. Here, I analyze surveys, student papers and reflections to understand how students perceive primary research articles across science majors at one institution, as well as their challenges in citing these sources. Together, these results suggest that students gradually develop an understanding of a primary source as a model of the scientific process. To teach source use in the sciences and develop thresholds concepts, there must be an iterative approach that combines instruction and research from writing, STEM education, and information literacy.

Introduction

Scientific writing is deeply rooted in the relationship between the scientific process and information literacy. As students read and analyze research, they practice writing with it, eventually finding connections across research and situating their work into that existing space. While the relationship between research and sources may be natural, it isn't easy. Learning how to use sources in the sciences is a critical part of any scientific curriculum, yet these sources are intended for more technical audiences.

The *Framework for Information Literacy for Higher Education* (2016) provided by The Association of College and Research Libraries (ACRL) names threshold concepts in information literacy. This *Framework* provides a lens through which we can understand source use in the sciences. For example, when students find and cite peer-reviewed sources, they practice threshold concepts like *research as inquiry* and *information has value*. The *Framework* also structures information literacy concepts essential to writing instruction (Purdy, 2018). Ideally, when writers use sources to create new meaning, they use processes of metaliteracy and reflection, too. As they design an experiment, they *consume* scientific sources and *produce* their own, using existing research to inform new questions and make connections across a scholarly conversation (Brungard & Klucevsek, 2019; Mackey & Jacobson, 2011).

This article examines how students perceive sources for writing and research across their science curriculum. Specifically, this article will focus on two common peer-reviewed sources in scientific writing: primary research articles[1] and reviews[2]. In an earlier study, my coauthor and I found that students commonly confuse primary research articles and review articles and incorrectly attribute these sources in their writing (Klucevsek & Brungard, 2016). For example, students may cite background from the introduction of a primary research article, when this information belongs to another source. Another

Across the Disciplines wac.colostate.edu/atd
A Journal of Language, Learning and Academic Writing ISSN 554-8244
https://doi.org/10.37514/ATD-J.2022.19.1-2.06

common mistake is to cite a review for specific data, rather than crediting the original primary research. This suggests that some students have difficulty identifying the authority of information in a source.

There are other challenges to using sources, too. Source use is a dynamic and evolving process as students combine writing, STEM, and information literacy concepts. Writers identify a need, find and distinguish the appropriate source, then read, analyze and decide how to cite it. Several disciplines have examined how students use sources, but the student challenges are best understood when these disciplines intersect. The following literature review will emphasize these connections to better understand how students grow as scientists and writers through their use of primary research.

Evolving Source Use

To understand source use in scientific writing, citations have been categorized by several functions. Some studies code citations by pattern and rhetorical choice, such as the use of a source for support or the use of a source to connect a scholarly conversation (Mansourizadeh & Ahmad, 2011; Wolfe et al., 2014). These citation patterns likely evolve as writers progress through their education and training (Karatsolis, 2016). Citation types can also be characterized by whether or not the writer mentions the author's name as part of the sentence (integral) or simply cites the source (non-integral). In the sciences, non-integral citations are used more often with increasing expertise (Mansourizadeh & Ahmad, 2011; Swales, 2014; Thompson & Tribble, 2001), supporting that a scientist's citation style evolves with practice.

In the sciences, citations often concisely synthesize data from multiple sources within a paragraph, allowing the citation to attribute credit rather than using an integral citation. However, if a student's previous writing experience is based in the humanities, they may start writing with integral citations or quotes in scientific writing. The Citation Project, which categorizes the ways in which students write with their sources, has found that quoting is common in student writing across courses (Howard et al., 2010; Jamieson, 2013). While quotations are discouraged in scientific writing, paraphrasing technical language is notoriously difficult. This makes it important for instructors to help students reflect on discipline as they build on past experiences (Wolfe et al., 2014), especially until they become more comfortable summarizing scientific data in a new context.

Attributing Research

Cross-disciplinary research on source use aligns with research in STEM, helping us understand common challenges. For example, it is common for students to cite material from the first few pages of a source (Jamieson & Howard, 2013), writing from individual sentences (sentence-mining) rather than summarizing a source (Howard et al., 2010). Sentence-mining could mean that they find this information important, but it could also mean that they aren't understanding the larger purpose of a source (Howard et al., 2010). Similarly, students sometimes sentence-mine data and incorrectly attribute a background sentence from a primary research article, even though this sentence is linked to another source (Klucevsek & Brungard, 2016). In another study of scientific writing, half of first-year biology lab reports contained patchwriting errors or attributed information to the wrong source, too (Bertram Gallant et al., 2019). This incorrectly attributed information is commonly background information from the abstract of introduction, the first few pages of the source.

Students might sentence-mine and incorrectly attribute information because they prefer background. Scientific writing is anchored in both primary research articles and reviews, but relies on evidence from primary research for analysis. Primary research articles are more difficult to understand, even though they promote more critical thinking (Baram-Tsabari & Yarden, 2005). An issue only exists if a writer prefers reviews over primary evidence. For example, one study identified papers that only cited secondary sources in paragraphs to support claims (Breuch & Larson, 2017). When students read primary research articles, they favor highlighting background in the introduction, suggesting they prefer this background

information, which may be similar to the ways in which they read a textbook (Gallo & Rinaldo, 2012). A student's preference for background suggests that students need guidance with primary research articles and how sources work together in a disciplinary conversation.

Other students may make mistakes because they can't yet identify or use a primary research article. Students might cite from the first few pages of an article because they don't yet have the analysis skills for other sections (Jamieson, 2013). In fact, students state the introduction of a primary research article is the easiest to read, while the methods and the results are the most difficult (Hubbard & Dunbar, 2017). Students may also incorrectly attribute information because they aren't reading or summarizing the whole source. In one study, only 61% of undergraduates reported that they read a journal article before citing it, and 15% reported that they only read the introduction or discussion of a journal article before using it in a writing assignment (Verkade & Lim, 2016), but students should learn to analyze the results before paraphrasing and citing research, even if this is the most challenging part.

Citation errors can also happen as part of the writing process when one works with so many sources. Published papers also contain errors, including incorrect attribution, incorrect reference information, and inaccurate evaluation of the research. In a subset of orthopedic journals, for example, 38% of citations had some type of error, with 7.5% of references referencing the wrong source (Davids et al., 2010). These errors have been found at varying rates in published science articles (Bagga et al., 2020; Luki et al., 2004; Luo et al., 2013; Montenegro et al., 2020; Wager & Middleton, 2008).

With so many steps to using sources and so many ways to use them, mistakes will happen during learning, writing, and revision. Therefore, all mistakes cannot be automatically labeled as an immoral use of sources (Jamieson & Howard, 2019). Giving feedback on citation use helps, but it is intensive. Publishers, as well as instructors, are too taxed to check *all* sources. Yet, we can presumably address citation use pedagogically so that writers build on previous citation experiences and improve over time.

Aims of the Current Work

The results presented here are part of my large-scale, ongoing study of source use across science-related majors and years. While these results are specific to one institution, the methodology will evolve as we continue to examine source use. Serviss and Jamieson (2018) describe the need for transparency and discussion of methodology in citation studies to obtain a greater understanding of source use across contexts, strengthening the data. In the end, cross-contextual research will also help us develop more global threshold concepts for source writing. Therefore, this article describes preliminary results with method transparency to engage a wider conversation about writing with scientific sources, bridging STEM education, information literacy, and writing research.

Previous research with citation use has helped us understand how students use sources, but also presents a challenge. There are many ways to study citations, yet little understanding of *why* mistakes happen or *how* learning connects. What we do know is that all of these issues come back to the source itself. Primary research articles are the keystone of source use in scientific writing and research, but a difficult source for students to identify and use. We must first understand what students learn about primary research and how they apply this learning. This article lays this groundwork, assessing student understanding across science majors and years in two parts:

1. Using a survey, students tell when they learn about source use and how they perceive primary research articles.
2. Through reflections and paper analysis, students reveal their use of primary sources in writing, as well as their challenges.

Together, these results indicate that students grow as scientists and writers while working with primary research articles over time. While they can correctly articulate the ways to use primary research articles by their second or third year, many will still struggle with source use in practice, indicating the need for continual cross-curricular emphasis.

Methods

Institutional Context

Duquesne University of the Holy Spirit is a private, Catholic institution in Pittsburgh, PA. It is classified at the R2 Carnegie level. This study collected data from the spring of 2016 to the fall of 2020. As a representation of demographics, the fall 2018 statistics were as follows: The undergraduate enrollment was approximately 6,000 students, with 70% of the students in-state residents and most students full-time. The undergraduate population was approximately 80% Caucasian, 5.2% African American, 3.6% Hispanic, 3.4% Asian, and 7.8% Other or Not Reported.

Survey Data and Analysis

All data described here were collected as part of a study approved by the Duquesne University IRB Board. Most of the students in this study were natural and environmental science majors (biology, chemistry, biochemistry, physics, environmental science, and forensic science), health science majors or pre-pharmacy majors (Table 1). The following courses or programs distributed the survey (Appendix) electronically or in-person: First-year Biology Lab I and II (serving all science, pharmacy, and health majors), Scientific Writing, Healthcare and Literature, Biology third-year lab, Forensics Professional Development, Natural and Environmental Science first-years, and the Occupational Therapy program. Responses were always higher when the survey was delivered in person. Few students identified as fifth-years. These students were included in the fourth-year data set unless they specifically indicated graduate status. Table 1 describes the majors and years of students responding to this survey. It was possible for a student to take the survey more than once at two separate time points. For data analysis, blank responses were removed. Data was assessed with Excel or Voyant (https://voyant-tools.org/).

Table 1: Major and year of survey respondents

	Biology	Chemistry /Biochem	Physics	Environmental Science	Forensics	Health Sciences	Pharmacy	Other	Total
First-year	16	2	2	2	9	34	34	7	106
Second-year	52	3	1	7	36	15	2	1	117
Third-year	34	10	4	4	5	5	1	1	66
Fourth-year	17	8	2	1	18	5	0	2	53
Graduate	0	0	0	0	16	4	1	1	22
Total	119	23	9	14	84	63	38	10	364

Relevant Curriculum Background

At Duquesne University, all first-year students take a broad or discipline-specific information literacy course. Beyond the two-semester first-year sequence of English composition for students, students take at least three writing-intensive courses, with at least one course within their major. Many of the students in this survey took the scientific writing course as one of these writing-intensive courses, required for all the natural and environmental science majors. A biologist by training, I teach this course through our English department. This course combines scientific information literacy instruction with the writing process. While students read and cite sources in their lab courses, this is the first time that writing with sources is a course objective in the sciences. Students usually take this course in their second or third year. Some of the students in this study took the survey before taking the course, some while enrolled in the course, and some long after. Students in health and pharmacy would take different writing-intensive courses connected to their major. This article does not take course objectives into account because of this diversity, but it is possible that the timing of writing-intensive courses affects responses at the time of survey.

Paper and Reflection Analysis

Students who took this survey as part of a course also consented to the use of course writing for analysis. Eighty-eight first drafts of literature reviews from the scientific writing course were analyzed as part of this manuscript. In this literature review, students identify the type of sources they used in their draft, citing mostly primary research articles and reviews. As part of the drafting process, I check the students' identification of sources and give feedback on the use of at least one source for analysis, paraphrasing, attribution, and mechanics. Incorrect attribution is a common mistake and a focus for this article (Klucevsek & Brungard, 2016). For this manuscript, I only coded attribution errors because attribution is always incorrect or correct. I would be unable to code other uses, such as patchwriting and rhetorical choice, without a more complicated coding scheme and additional researchers to reconcile coding. These students also completed reflections before draft 1 to describe how they believe primary and secondary sources should be used in the sciences. This reflection was an assessment of what they had learned from class activities, *before* applying it. Thirty-six students also reflected on their source use *after* reading my feedback on source use on draft 1.

Results

Students Learn to Work with Sources over Time

To better understand science and health undergraduate students' growth throughout a curriculum, I first surveyed students across majors and years (Table 1). The survey (Appendix A) asked students to identify information literacy and writing skills they believed they had learned at that point.

While students learn a range of writing and information literacy skills each year, this survey gives an idea of their perceived learning through exposure to primary sources in information literacy, science, writing, and lab courses, as well as research experiences (Figure 1). Students stated their learning increased in most skills each year, such as using databases and identifying sources. Students at this institution take an information literacy course in their first year, which might be why 92.5% of first-years agreed they could find a peer-reviewed research article using a database (Figure 1a). However, only 69.8% of first-years felt they knew how to identify a peer-reviewed journal article, which indicates some may not understand what they find in databases. Students encounter primary research articles and reviews in their first-year lab courses, but this may not be enough familiarity to learn the difference between scientific articles. This response jumped during the second year, when 81.2% of students felt they had learned how to distinguish scientific sources. This is the most common year for students to take scientific writing, and source

identification is a major objective of the course, which may cause an increase in confidence. The largest skill area of growth from first-year to graduate year was writing a scientific article. Although these students write lab reports in first-year labs, many did not believe they learned to write until later in their curriculum (Figure 1b).

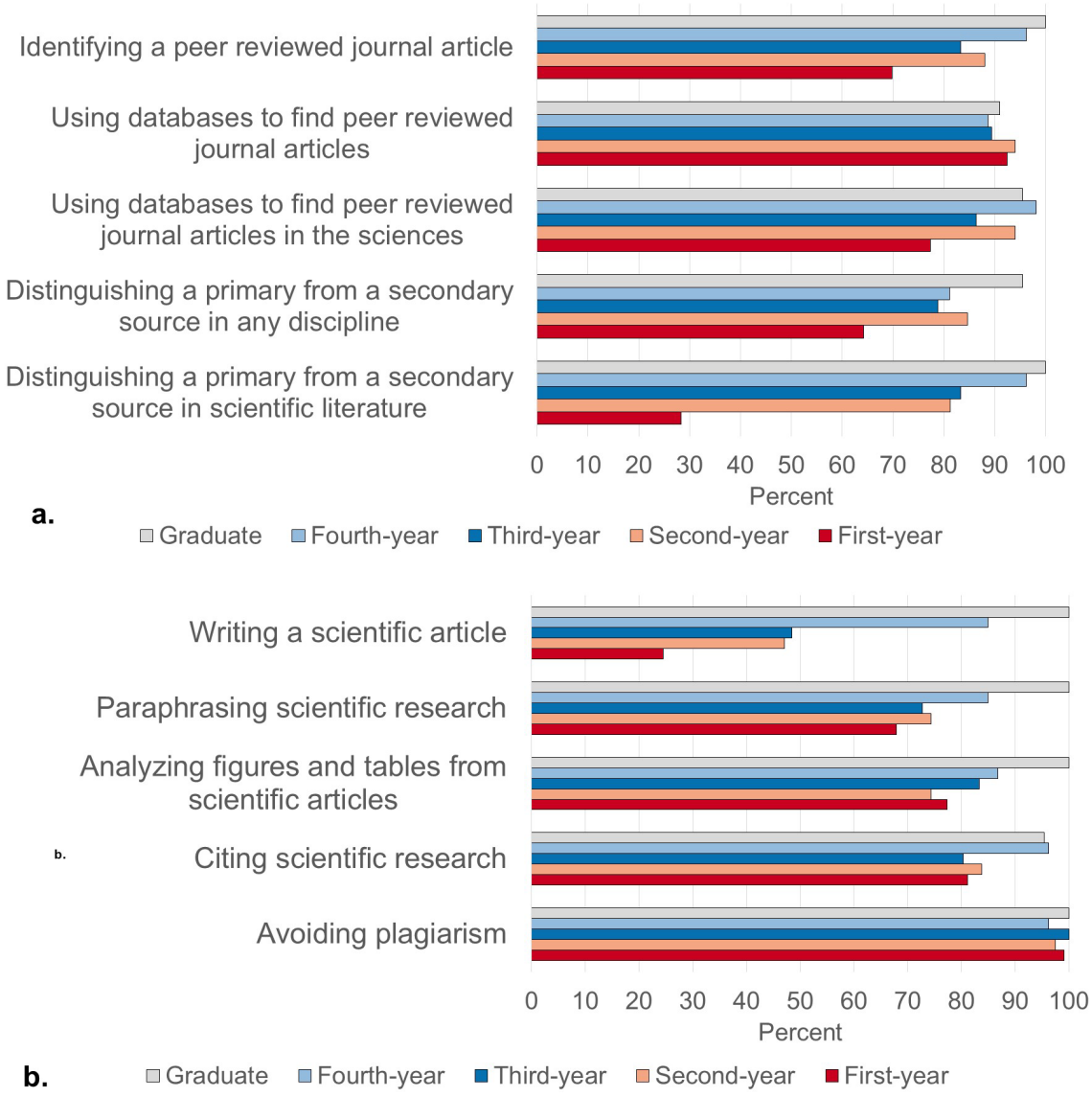

Figure 1: Students (N = 364, Table 1) reporting a learned skill by year, responding to a survey asking them to identify skills they had learned at that point in their major. These skills represented information literacy skills needed to find and identify scientific literature (a) and skills write with primary research sources (b).

By their first year, students were already confident they had learned about plagiarism. Interestingly, this confidence did not match their responses to paraphrasing, analyzing, or citing scientific research (Figure 1b). This suggests that many students do not see an inability to cite sources correctly as a potential issue for plagiarism, and may believe that citing is simply mechanical, rather than a complex rhetorical choice one makes as they engage with sources.

Figure 1a shows that only 28.3% of first-years felt they could distinguish a primary research article from a secondary source in the sciences, while 64.2% felt they could do this in any discipline. This discrepancy implies that some students learn the difference between primary and secondary sources, but don't understand how this skill can be discipline-specific. To further examine this discrepancy, I separated the data from three schools that were almost equally represented among first-years (Table 1). All first-year students in health or science-related majors take introductory labs and first-year writing courses, but Health Sciences and Pharmacy majors take a health-focused information literacy course. Previously, a pilot study of this health information literacy course found that students could identify scholarly research to answer a health-related question, though students may not identify scholarship with 100% success because this skill takes time (Rapchak et al., 2018). However, other majors on our campus take a broad, non-specific information literacy course. This curriculum difference could explain why first-years in the Natural and Environmental Sciences reported that they could distinguish primary sources in any discipline more often than the sciences specifically (Figure 2).

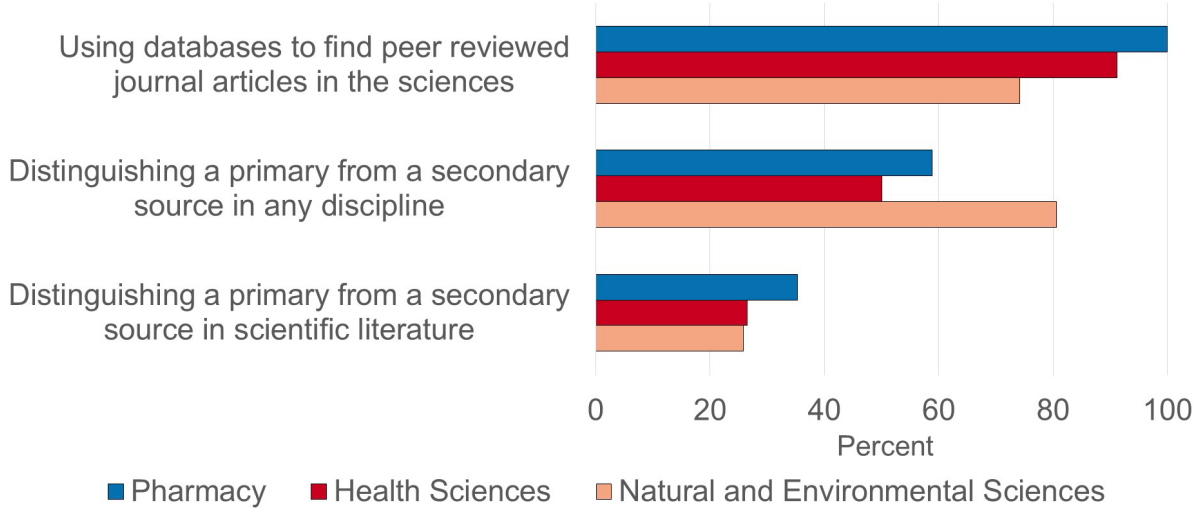

Figure 2: First-years (N = 99) reporting a learned skill by school, responding to a survey asking them to identify skills they had learned at that point in their major. Majors were grouped by school: Pharmacy (N=34), Health Sciences (N=34), and Natural and Environmental Sciences (31). These skills represent information literacy skills needed to find and identify scientific literature.

Students' Understanding of Primary Research Articles Evolves

While Figure 1 provides insight into what students learned, it does not reveal if they understand primary research. To examine this, the survey also asked students to describe primary research in their own words. Of the 106 first-years in this survey, almost half could not define a primary research article. There were no school-specific differences in these results (12 Natural and Health Sciences, 16 Pharmacy, and 16 Health Science students), suggesting that taking a science-specific information literacy course may have improved confidence in finding primary research (Figure 2), but not ability to define it. To analyze students' definitions of primary research articles, I originally coded for terms I expected to see, such as a peer-reviewed source and a hypothesis-driven experiment. However, most students simply defined a primary research article in the sciences with *author as researcher*. This definition was nonspecific. *Author as researcher* is a definition that can be applied to a primary source in any discipline. In some contexts, the term *research* means searching for information, but this is not the recognized use of primary *research* in the

sciences. If I ask a student if they perform research in the sciences, it is implied that I am asking if they perform experiments with a mentor and research group, creating new knowledge through empirical data or theoretical work that reflects a hypothesis or objective. Therefore, to help me see science-specific trends, I used the text-analysis tool Voyant.

Corpus analysis confirmed that the most common definition for a primary research article was to use the words *research* and *author/s* together. These terms had the strongest and only correlation with a significance below the 0.01 level. These terms were consistently used across all years, in contrast to the term *unsure*, which decreased over years (Figure 3a). Students were given an option to use the term *unsure* if they did not know the answer, rather than leaving the open-ended response blank because a blank response does not distinguish between a student who doesn't know and a student who didn't answer. The only corpus term frequently repeated and increasing over time was the term *original,* used 64 times across all responses (Figure 3b). This suggested that students understood that primary research articles could only be primary if they published new, original data for the first time. While I expected to see more science-specific terms in fourth-year and graduate responses, such as experiment and data, these types of terms varied in the definitions (Figure 3b).

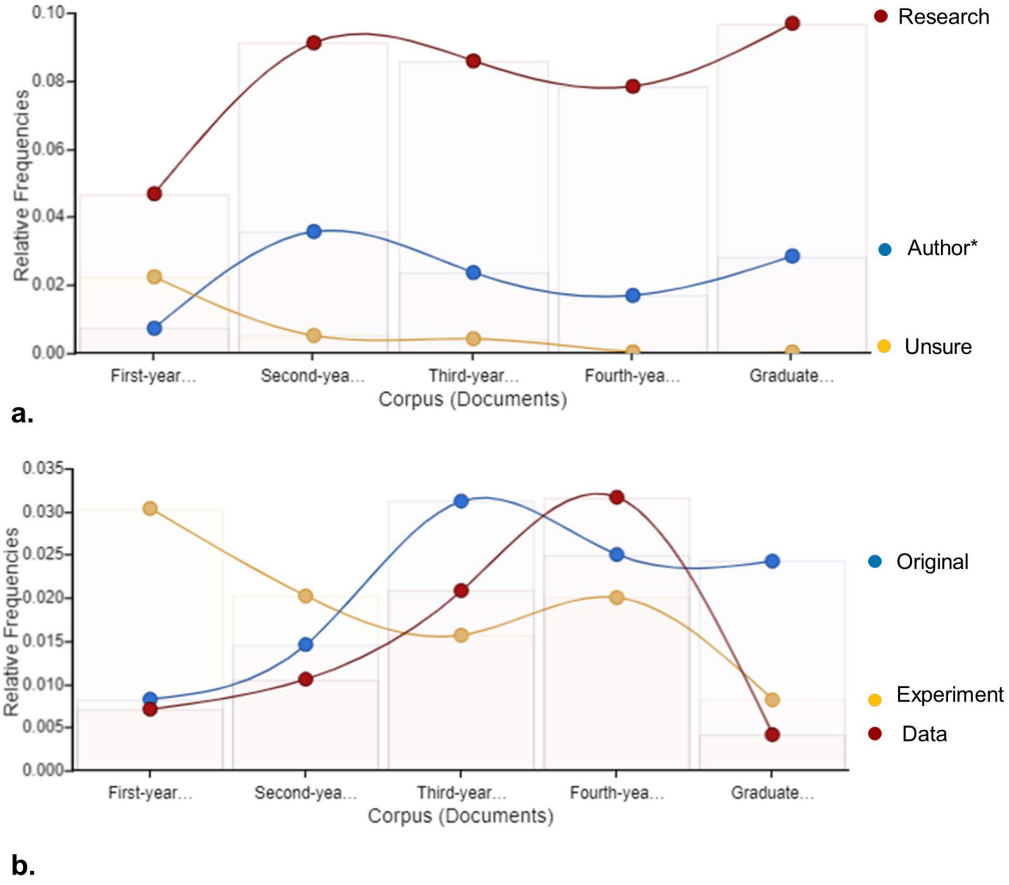

Figure 3: Text analysis of student definitions of primary research articles by class. Students (N=364, Table 1) defined a primary research article in the sciences. The most common definitions included "research" and "author" (author or authors) (a), with some terminology that was more specific to the sciences (b). Figures and data made with Voyant. Relative frequencies indicate frequency of a term per million of words.*

In contrast, students' responses to a prompt about distinguishing articles provided better insight into students' perception of these sources. I chose to combine the third-year, fourth-year, and graduate responses for this analysis. At this point, most students perform research and/or take higher level research courses, making the distinction between these years less clear. Figure 4 displays the relative frequency of six corpus terms. Similar to Figure 3, students' response of unsure decreased among second-years and the term original was more common in upper-class/graduate students.

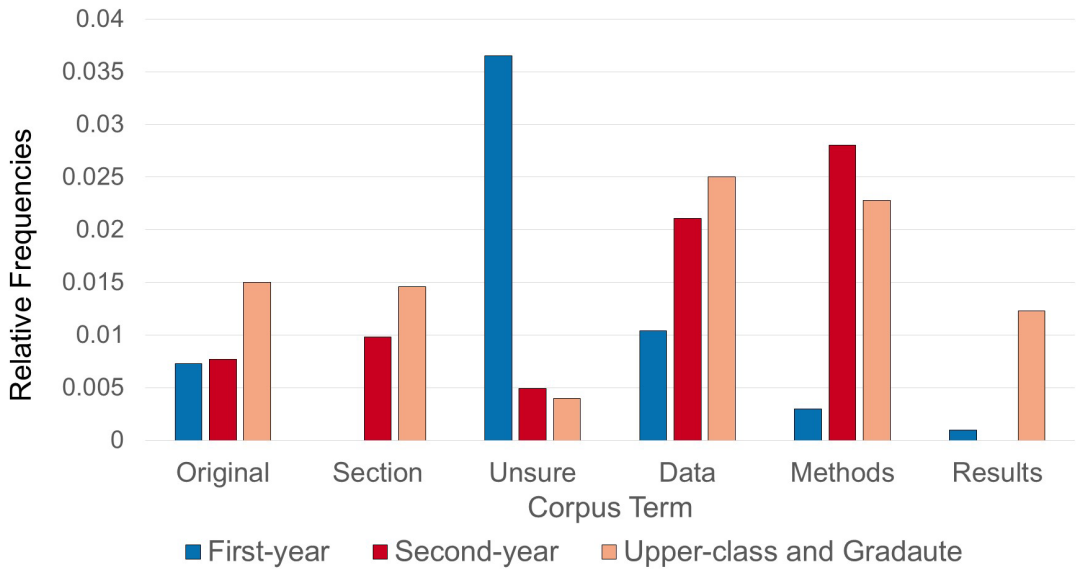

Figure 4: Text analysis of student responses to the prompt "How would you distinguish a primary research article from another source in the sciences?" The terms presented here were common across first-year (N=106), second-year (N=117), or upper-class (third and fourth years) and graduate students combined (N=141). Data calculated using Voyant. Relative frequencies indicate frequency of a term per million of words.

More students used words specific to empirical data when describing how they would distinguish a primary source in the sciences. Terms such as *data*, *methods*, and *results*, were more common in later years. Some of these terms represent *sections* of a primary research paper, also a more frequent term. Figure 5 presents a word cloud of the text analysis from Figure 4. Here, the terms were more diverse with the second-year and upper-class/graduate responses. There was more language alluding to the common introduction-method-results-discussion (IMRD) structure of a primary research article, such as material, figures, tables, and abstract. There was also language to describe the scientific process, including experiment. In later years, students used language to describe citations and sources, suggesting they were beginning to see how scholarship intersects. This may indicate that students in the upper-class years have a stronger ability to locate and analyze the scientific method in primary research articles, similar to the ways in which faculty read and use primary research articles (Gallo & Rinaldo, 2012).

Figure 5: Word cloud of student responses to the prompt "How would you distinguish a primary research article from another source in the sciences?" Corpus includes answers from first-years (N=106), second-years (N=117), or the upper-class (third and fourth year) and graduate students combined (N=141). Word clouds generated with Voyant.

Figure 6: Changes over time: Student responses to the prompt "How would you distinguish a primary research article from another source in the sciences?" The open-ended responses from students who answered this prompt at two separate times (N=23) were compared. Each survey response was independently collected at varying time points across the student's learning (three months to two years). Word clouds generated with Voyant.

Over the years of this survey, some students responded more than once. Initially, I hoped to compare the growth of these individual students, but the difference in time between surveys ranged from months or years. Therefore, to examine how students' relationship with primary research evolved, I compared prompt responses from the same group of 23 students over time (Figure 6). Students used many of the same terms

in their first and second survey, but their second survey was more complex and diverse, suggesting collective expansion in their perception of primary research.

Students Reflect on Using Sources

The survey responses offered an overview of when students learned the skills necessary to interact with primary research articles, as well as how they perceived these sources. In tandem, I explored how students work with primary sources through writing samples and reflections.

The present study included students who were enrolled in my scientific writing course. I've tried several pedagogical interventions to improve source use over the years, including examining source use in sample writing, peer review to check sources, quizzes, and reflections. Students learn to identify source types and practice how to use articles. They also learn methods to avoid patchwriting by focusing on the analysis of figures and tables, and writing from what they see rather than what they read. Yet, I have learned that no combination of these pedagogical methods improves the rate of source use on a first draft. Every semester, 30-50% of students will make the identification and attribution mistakes, leading me to believe that mistakes are part of the natural learning process for many students. Therefore, I choose to give detailed feedback on source use. While labor-intensive, a successful way to improve how students use sources is through this scaffolded writing process (Klucevsek & Brungard, 2016).

To explore students' ideas of source use, I used a series of student reflections and matched this with attribution errors on their first draft of a literature review. Of 88 students, 45 incorrectly attributed at least one source. Consistent with previous findings, the most common error was to cite a primary research article for background information from the introduction, even if this information cites another source (Klucevsek & Brungard, 2016).

Interestingly, Table 2 shows that 40 of these 45 students who incorrectly attributed a source, correctly described how to attribute information in a reflection. Students answered these reflection prompts prior to writing and making their mistake. These reflections imply that students understood the technical use of sources, but there was a disconnect between knowledge and application. There were no obvious differences in the responses between the students with or without an attribution error (Table 2).

Table 2: Student reflections on the use of primary research articles (N = 88)

	Total students (#)	**Students correctly describing the use of sources in reflection (#)**	**Example reflections before drafting: How do you use primary research?**
Correct attribution of primary research in draft	43	41	"We can only cite the hypothesis, methods, and results from these primary sources because that information has to be from the authors who conducted the research. The background information may have come from other sources (that the authors may or may not have cited), so we should only use the information that we know came directly from the authors." "I feel paraphrasing is a more powerful tool over quoting…paraphrasing allows us to truly explain something that makes sense to our audience level." "It is essential that primary research articles are used just for the new information...A primary source contains data that may have taken years to

			gather, and citing this source means crediting the team of researchers who worked hard to publish their findings."
Incorrect attribution of primary research in draft	45	40	"Reviews are used differently than primary research articles because they are not research studies but information collected form someone else and analyzed." "If we [wanted] the background information [from a primary research article], we would have to trace it back to the original source and cite that source instead of the primary research article we were looking at. This is most ethical because we want to ensure that we are giving credit to the original authors who deserve the credit." "Paraphrasing is used instead of quoting because the purpose of writing the review is to synthesize a large amount of research into a single article, and paraphrasing allows the author to combine multiple sources in the same sentence."

After receiving my feedback on source use on draft 1, I asked students to reflect on their challenges. Table 3 categorizes reflections from 36 students. Here, students name the challenges they have when they write with sources. Some students attributed sources incorrectly because they could not identify the source as primary or secondary. Students also reported the challenging nature of the source itself. Students described fear over paraphrasing and maintaining the original meaning of a source, which could lead to patchwriting. Students were also challenged by rhetorical choice, deciding which information fits their need. Importantly, students confessed confusion and stress, issues that we must acknowledge when students write with sources.

There were also some students who reported no challenges at all. These students reflected on the methods they use to read and analyze articles. It may be that these students had more experience with reading and using sources, increasing their confidence (Kozeracki et al., 2006; Sato et al., 2014).

Table 3: Themes in students' reflections after drafting and source feedback: What were your challenges when using sources? (N = 36)

Types of Challenges	**Example Reflections**
Identifying article types	"It was challenging to identify [articles] correctly because of the way they are written and organized." "…the article contained a large amount of useful and specific information so it was difficult to determine that it was not a primary research article."
Finding and using secondary information is easier	"I think I made mistakes with my references in the beginning because I initially had so much trouble finding good primary sources to gather information from…This led me to misuse secondary sources to find background information." "…reading a good abstract or introduction gives you the insight of what the [primary] article is all about, but it is easier to read secondary reviews..."

Reading or analyzing the research	"Primary sources in themselves are difficult, as the majority of them are jam-packed with scientific jargon that can make the content nearly incomprehensible." "It is hard to use primary sources for their methods and results because, most of the time, those are the most complex sections of the article to understand and reiterate."
Paraphrasing concerns	"Sometimes authors write things that are so accurate that they can stand alone by themselves without needing rewording, serving as a viable quote for a paper, but with primary research articles, even if there is a sentence that is concise and specific enough in the article, it cannot be quoted." "It is difficult to paraphrase sections of an article that have lots of terms. Using alternate phrasing changes the meaning of the sentence, so we should keep the terms used by the author, but it still feels like I'm using too much wording from the article."
Deciding which information can be used	"I find it challenging to use primary sources for methods and results. This is entirely because I don't know what information I can include without taking away the integrity of the paper. " "…I made an error while adding citations to my paper, confusing a secondary fact that was used in a primary research article... I believe it is challenging to figure out which facts go with which article and how these sources can be placed within your own paper." "I made [a] mistake because I forgot that we cannot use information from a primary reference as background information, and that particular reference provided such good information for the background."
Deciding which information fits the need	"It is difficult to interpret another person's work and then make it flow in your own paper." "I am having trouble deciding which material could be excluded from the paper and which is important."
Underlying motivation or stress	"I made [a] mistake because I was extremely stressed about my upcoming exams and completely forgot." "I didn't use one of my primary sources correctly. I think I made this mistake because I was working on it at night and wasn't properly making sure that I was taking information from the proper locations." "For me personally, it's about laziness. I can tell you that it is much easier just to just cite a secondary source for the data points they used rather than look into it and cite the source they used for their data points. It is not right, and it may be a simple mistake to make as well. It's also much easier to almost cite someone's phrase nearly word for word rather than form your own sentences."
No Challenges	"The primary [articles] have so much more to offer in my opinion... Primary articles' literal point is the results. As long as you know how to interpret them, you can use them pretty easily." "I did not find it challenging to use only the methods and results sections [of primary research articles] … As I read the introduction/conclusion of an article, I open the sources they cite that I think I may be able to use as they mention them. This is mildly time consuming and forces me to have to sort through many sources for relevancy after skimming only one source, but this has helped me to find many of the sources that I cite..." "…looking at tables or figures by themselves has helped me to see the trends… without being confused by big words and other data. This approach also forces me to understand the data which is very helpful when trying to write about it."

Discussion

Developing Scientific Information Literacy Skills

To write in the sciences, students must engage with the existing primary research, employing scientific information literacy skills while situating their work in the scholarly conversation. Writing with sources is a difficult task with several layers. Students must find and identify a source to fit the need, analyze the article, choose and paraphrase the relevant information, then cite it. At more sophisticated levels of source use, students consider the rhetorical context and connection between sources. While previous research has examined how students use sources in these ways, it is less clear why these sources challenge students and how we can help them. Serviss and Jamieson (2018) write that we have to understand what writers know and do across contexts before developing strategies to address source use. Using a survey, this study examined how students perceive primary research articles and some of the skills required to use them, giving insight into their learning process throughout the curriculum. Importantly, through paper analysis and reflections, this study also finds that knowing these skills is different than applying them.

The cross-disciplinary survey of science students found an increasing awareness of scientific information literacy skills over time. Students learned science-specific skills between their first and second years (Figure 1). First-year students in this study would have encountered primary research and review articles in their science labs, reading and citing these sources in their reports. However, using these sources alone does not necessarily translate into the ability to identify or use them. Open-ended responses suggested that most students were not able to define or distinguish primary research articles using science-specific terms until their upper-class years (Figure 3 and Figure 4). This is supported by previous research, which has found that more confidence with primary research articles may come with increasing exposure and practice within a course (Kozeracki et al., 2006) or previous research experience, though this alone does not necessarily translate to greater comprehension of these sources (Sato et al., 2014).

Interestingly, though most students reported that they learned the skills necessary for writing with sources by their third or fourth year, many did not feel they had learned to write until their fourth or graduate year (Figure 1). In describing primary sources, students in later years also mentioned citations and sources within a primary research article (Figure 5 and Figure 6), suggesting that they recognized the scholarly conversation within these sources. We know that the reading and citing habits of scientists evolve with training (Gallo & Rinaldo, 2012; Hubbard & Dunbar, 2017; Karatsolis, 2016; Mansourizadeh & Ahmad, 2011; Swales, 2014; Thompson & Tribble, 2001). Therefore, it may not be surprising if students themselves consider writing a higher-order activity and more than a set of skills that they learned as first-years.

Learning through Challenges and Mistakes

While source writing challenges occur across disciplines, some of the reasons why students make mistakes are clearer in the context of a discipline. For example, errors in scientific writing include the inability to identify primary research articles and correctly attribute the primary research (Table 2) (Bertram Gallant et al., 2019; Klucevsek & Brungard, 2016). This research study begins to identify some of the reasons for these mistakes, connecting what students do with what they know about primary sources.

For example, some students use sources at the sentence level, often for information from the first few pages (Jamieson & Howard, 2013). In a primary research article, much of that content on the first page cites other sources. In this study, we see several reasons that explain why a student might use and attribute a primary source incorrectly. Before students can use a primary research article, they must be able to identify one. However, students commonly defined a primary research article simply as author as researcher (Figure 3), which does not support a distinction between primary research articles in the sciences, and instead may mean that students are relying on previous knowledge about primary sources in any discipline. In later

years, the use of terms like original and experiment pointed to the recognition of empirical or theoretical research in a primary research article (Figure 3). A student must know how to read and analyze the results section of a primary research article before they can cite it, but students find these sections challenging to read (Hubbard & Dunbar, 2017) and some may not read them at all before citing the article (Verkade & Lim, 2016). In this study, first- and second-year students were less likely to distinguish primary research articles based on these fundamental methods and results sections (Figure 4 and Figure 5), and students commented on the challenges of identifying, reading, and understanding primary research articles in Table 3. Together, these results further support that the inability to navigate primary research may contribute to difficulties citing sources.

Writers likely make mistakes with sources as a natural part of learning. In fact, failure, reflection, and revision may be an important threshold concept for writing in general (Adler-Kassner & Wardle, 2015), but students may also be unaware of their mistakes and opportunities for growth without pedagogical interventions. As first-years, almost all students reported that they had learned about plagiarism as a concept (Figure 1), but many had not learned about paraphrasing or citing in the sciences. Students learned what not to do, but not what they needed to do. Students can feel a fear of plagiarism while also feeling undereducated about how to use sources (Benedicks, 2017), which could lead students to cite incorrectly if they focus on the presence of a citation to avoid plagiarism, rather than engaging with their sources. Pedagogy should instead emphasize practice with sources, recognizing that mistakes happen as part of this learning process (Jamieson & Howard, 2019).

Identifying Thresholds for Source Writing in the Sciences

By identifying threshold concepts in source writing and the sciences, we can intentionally connect research that crosses STEM, WAC/WID, and information literacy instruction. This is essential, as these groups do not always have the opportunity to communicate student challenges that are fundamentally linked. In addition to helping educators design curriculum intentionally, threshold concepts in STEM writing can also make students aware of common misconceptions (Thornton, 2020).

While there are many challenges to writing with primary sources in the sciences, Table 3 gives us some candidate concepts to explore. Figure 7 begins to put this together, while considering the existing goals and thresholds for reading, writing, information literacy, and metaliteracy (Adler-Kassner & Wardle, 2015; Association of College and Research Libraries, 2016; Davies, 2018; Mackey & Jacobson, 2011). After all, many science students begin their journey with sources through information literacy or writing instruction outside of STEM. As they write in the sciences, and become producers of their own research, students will learn how sources work together and reflect on how their own writing makes new meaning (Brungard & Klucevsek, 2019; Klucevsek, 2017). In *Naming What We Know*, Adler-Kassner and Wardle (2015) categorize many threshold concepts in writing, several of which intersect with source writing. Johnson and McCracken (2016) connect these writing threshold concepts to the ACRL Framework, situating the Frame "Scholarship as a Conversation" as fundamental to all other concepts. The ultimate goal of writing with sources in the sciences fits this, too. Using a source should prompt several reflections for students, such as: How does this experiment advance the field? What is a research need for the future?

Thresholds for scientific writing and source use should consider the choices students make when using primary and secondary sources, and the opportunities for both mistakes and growth at each of these points. These opportunities occur at different phases: identifying a need and source, analyzing the research, and deciding how, what, and when to cite. These phases are iterative, overlapping and not always linear (Figure 7). To cross thresholds of source writing, some students will need to make mistakes, reflect, revise, and try again in a new context. In addition, an author may only recognize they have passed a threshold retrospectively. Given the variety of challenges named in Table 3 and previous research on the ways in which students use sources, we should expect that writers can encounter different challenges depending on

the source, assignment, or even their personal non-academic situations. Future research should explore this individual reflection and growth.

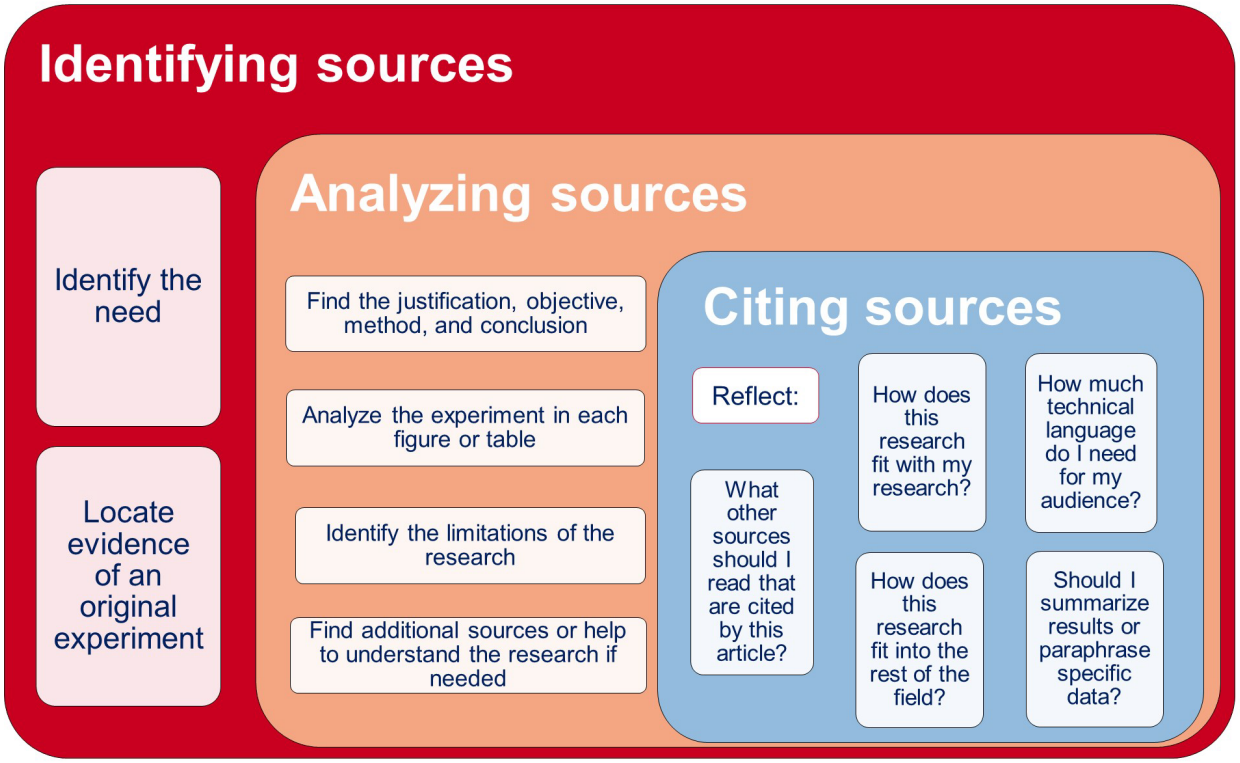

Figure 7: Writing in the sciences requires identifying, analyzing, and citing sources. Source use should be an iterative and reflective process, similar to writing. In the sciences, the primary research article is fundamental to the discipline. As students engage and write with these sources, they learn how to analyze published research while producing their own.

Moving Forward with Research and Pedagogy

To create successful pedagogy around source use and help students recognize disciplinarity, we need a coordinated, immersive effort of working with sources across the curriculum, and a merger of STEM, WAC/WID, and information literacy concepts. After all, a variety of experiences will shape students' growth with sources. Students learn to write with sources from writing and STEM instructors, librarians, lab TAs, the Writing Center, and peers. As scientists in training, many students will also perform research, giving them situated experience and mentoring in scientific writing in collaboration with professors and labmates. All of these experiences also complicate how researchers study source use, introducing a range of variables to consider in future studies. Comparing data across contexts and institutions will help, but these variables are important as we think about interventions and research (Serviss & Jamieson, 2018). Pedagogically, it will help to work with departments and research labs within our institutions to emphasize source use from early lab classes to writing and research experiences.

Importantly, faculty of all disciplines need to consider source writing that moves beyond the plagiarism concepts that many students are already aware of as first-years (Figure 1). Some courses won't situate source use as a writing concept beyond a clause about plagiarism in the syllabus. This means students may cite sources in their first-year labs without an understanding of the types of sources they are using (Figure 4 and Figure 5) and how to work with them. First-year writing will undoubtedly teach source use as well, but we

can't expect students to transfer this source use to a scientific context without intentional pedagogy. Pedagogical solutions could cross disciplines, such as linking information literacy courses or objectives to first-year labs. Solutions can also acknowledge that working with sources is a gradual learning process, and mistakes are a natural and expected part of crossing thresholds. To that end, faculty can also benefit from their own set of threshold concepts for writing instruction, which would encourage STEM faculty to reflect on and participate in writing across the curriculum (Basgier & Simpson, 2020). STEM faculty need to consider what they want students to be able to do with sources at each stage. Still, I do not recommend that we teach source writing as a set of vertical skills, but rather introduce a variety of source writing techniques recursively in context, throughout a curriculum.

Another pedagogical solution includes building a series of curriculum reflections on source writing, integrated across disciplines. Encouraging reflection across courses could help us collect information on how students perceive sources, while simultaneously serving as a pedagogical intervention (Serviss & Jamieson, 2018). There are several ways to do this. For example, LILAC uses a video-catch method to watch how students identify and choose sources in real-time (Blackwell-Starnes & Walker, 2017). A video-reflection might ask students to capture their search process for an assignment, asking them to talk through their identification, analysis, and citing process. Students could also reflect on their sources by coding their own source use (Serviss, 2017). This may make them more self-aware of their source use and track their own growth, from the mechanics of citations to more complex and expert rhetorical uses.

This study presents a singular reflection on source use (Table 3) that provides rich examples of student challenges, but only in the context of one assignment, in one course, at one institution. As we design reflections across institutions and contexts, we can ask questions that combine our disciplinary knowledge, such as:

- How do non-science writing and information literacy courses influence source use in the sciences?
- Which practices promote transfer of source writing across the curriculum and within the sciences?
- How do students identify and use primary research?
- How do students reflect on their challenges and when do they recognize growth?
- Are students more likely to use sources in a specific combination of ways?
- Which variables influence source use, such as prior research experience?

To answer any of these questions, it's important to recognize information literacy in scientific writing as a pedagogical issue that can only be addressed by connecting disciplines. Previous writing research has helped us understand how students use sources. Combined with WID and STEM research, we can situate our questions, helping students grow as scientists and writers and transfer experiences from first-year courses to discipline-specific writing.

Conclusion

The ability to navigate primary research articles is essential to scientific writing and research. Students in this study learned about source use throughout their curriculum, but reached a more discipline-specific understanding about primary research sources in their upper-class years. Though most students stated they understood how to use primary sources, incorrect attribution still occurred. Students stated specific challenges with using these sources, including difficulties in identifying, reading, and paraphrasing the source. Based on these results, the path towards learning source use is likely recursive and complex, best supported by a spectrum of writing, STEM, and librarian faculty. Future pedagogy and research should explore cross-curriculum pedagogical solutions. While not all source writing thresholds will be discipline-specific, thinking about them through a discipline-specific lens may ultimately help our students reflect on research and writing within their disciplines.

Appendix: Survey

1. What is your major?
2. What is your year?
3. What past sciences courses have you taken?
4. What past writing courses have you taken?
5. Which of the following skills have you been taught? Check all that apply and indicate which courses have taught you that skill (if any).
    a. Identifying a peer-reviewed journal article.
    b. Distinguishing a primary from a secondary source in any discipline.
    c. Distinguishing a primary from a secondary source in scientific literature.
    d. Using databases to find peer-reviewed journal articles.
    e. Using databases to find peer-reviewed journal articles in the sciences.
    f. Compiling a reference list in any discipline.
    g. Compiling a reference list in the sciences.
    h. Paraphrasing scientific research.
    i. Analyzing figures and tables from scientific articles.
    j. Avoiding plagiarism.
    k. Citing scientific research.
    l. Writing a scientific article.
6. Define a primary research article in scientific literature:
7. Define a secondary article (review) in scientific literature:
8. How would you tell if a journal article contains primary research? What would indicate this to you?
9. How would you tell if a journal article is a review? What would indicate this to you?

References

Adler-Kassner, Linda, & Wardle, Elizabeth. (2015). *Naming what we know: Threshold concepts of writing studies*. University Press of Colorado.

Association of College and Research Libraries. (2016). Framework for Information Literacy for Higher Education | Association of College & Research Libraries (ACRL). http://www.ala.org/acrl/standards/ilframework

Bagga, Rahul, Cay, Peter, Ricketts, David, Roper, Tom, & Phadnis, Joideep. (2020). Quotation errors related to the Proximal Fracture of the Humerus Evaluation by Randomization (ProFHER) study. *Shoulder & Elbow*, https://journals.sagepub.com/doi/10.1177/1758573220950235.

Baram-Tsabari, Ayelet, & Yarden, Anat. (2005). Text genre as a factor in the formation of scientific literacy. *Journal of Research in Science Teaching*, 42(4), 403-428. https://doi.org/10.1002/tea.20063

Basgier, Christopher, & Simpson, Amber. (2020). Reflecting on the Past, Reconstructing the Future: Faculty Members' Threshold Concepts for Teaching Writing in the Disciplines. *Across the Disciplines*, 17(1/2), 6-25. https://doi.org/10.37514/ATD-J.2020.17.1-2.02

Benedicks, Crystal. (2017). Storied Research: Using Focus Groups as a Responsive Method. In Tricia Serviss & Sandra Jamieson (Eds.), *Points of departure: Rethinking student source use and writing studies research methods* (pp. 123-140). University Press of Colorado. http://www.jstor.org/stable/j.ctt1xzh15w.15

Bertram Gallant, Tricia, Picciotto, Madeleine, Bozinovic, Goran, & Tour, Ella. (2019). Plagiarism or not? Investigation of Turnitin®-detected similarity hits in biology laboratory reports. *Biochemistry and Molecular Biology Education*.

Blackwell-Starnes, Katt, & Walker, Janice R. (2017). Reports from the LILAC Project: Designing a translocal study. In Tricia Serviss & Sandra Jamieson (Eds.), Points of departure: Rethinking student source use and writing studies research methods (pp. 62-82). University Press of Colorado. http://www.jstor.org/stable/j.ctt1xzh15w.11

Breuch, Lee-Ann K, & Larson, Brian N. (2017). *Research and rhetorical purpose: Using genre analysis to understand source use in technical and professional writing*.

Brungard, Allison B, & Klucevsek, Kristin. (2019). Constructing scientific literacy through metaliteracy. In Thomas P. Mackey & Trudi E. Jacobson (Eds.), *Metaliterate Learning for the Post-Truth World* (pp. 81). American Library Association.

Davids, Jon R, Weigl, Daniel M, Edmonds, Joye P, & Blackhurst, Dawn W. (2010). Reference accuracy in peer-reviewed pediatric orthopaedic literature. *JBJS*, 92(5), 1155-1161.

Davies, Laura J. (2018). Getting to the Root of the Problem: Teaching Reading as a Process in the Sciences. In Alice S. Horning, Deborah-Lee Gollnitz, & Cynthia R. Haller (Eds.), *What is college reading?* (pp. 183-201). University Press of Colorado

Gallo, Mark, & Rinaldo, Vince. (2012, 12/03). Towards a mastery understanding of critical reading in biology: The use of highlighting by students to assess their value judgment of the importance of primary literature. *Journal of Microbiology & Biology Education: JMBE*, 13(2), 142-149. https://doi.org/10.1128/jmbe.v13i2.493

Howard, Rebecca Moore, Serviss, Tricia, & Rodrigue, Tanya K. (2010). Writing from sources, writing from sentences. *Writing and Pedagogy*, 2(2), 177-192.

Hubbard, Katharine E, & Dunbar, Sonja D. (2017). Perceptions of scientific research literature and strategies for reading papers depend on academic career stage. *PLoS One*, 12(12).

Jamieson, Sandra. (2013, December 11). What students' use of sources reveals about advanced writing skills. *Across the Disciplines*, 10(4). http://wac.colostate.edu/atd/reading/jamieson.cfm

Jamieson, Sandra, & Howard, Rebecca. (2019). Rethinking the relationship between plagiarism and academic integrity. *Revue internationale des technologies en pédagogie universitaire/International Journal of Technologies in Higher Education*, 16(2), 69-85.

Jamieson, Sandra, & Howard, Rebecca Moore. (2013). Sentence-mining: Uncovering the amount of reading and reading comprehension in college writers' researched writing. *The new digital scholar: Exploring and enriching the research and writing practices of nextgen students*, 111-133.

Johnson, Brittney, & McCracken, I Moriah. (2016). Reading for integration, identifying complementary threshold concepts: The ACRL Framework in conversation with *Naming what we know: Threshold concepts of writing studies*. *Communications in Information Literacy*, 10(2), 2.

Karatsolis, Andreas. (2016). Rhetorical patterns in citations across disciplines and levels of participation. *Journal of Writing Research*, 7(3).

Klucevsek, K. (2017). The intersection of information and science literacy. *Communications in Information Literacy*, 11(2), 354-365.

Klucevsek, Kristin M, & Brungard, Allison B. (2016). Information literacy in science writing: How students find, identify, and use scientific literature. *International Journal of Science Education*, 38(17), 2573-2595.

Kozeracki, Carol A, Carey, Michael F, Colicelli, John, & Levis-Fitzgerald, Marc. (2006). An intensive primary-literature–based teaching program directly benefits undergraduate science majors and facilitates their transition to doctoral programs. *CBE—Life Sciences Education*, 5(4), 340-347.

Luki, Ivan KreImir, Luki, Anita, Glun, Vicko, Katavi, Vedran, Vu Enik, Vladimira, & Maru, Ana. (2004, 2004-01-01). Citation and quotation accuracy in three anatomy journals. I, 17(7), 534-539. https://doi.org/10.1002/ca.10255

Luo, Ma, Li, Charles Chuan, Molina IV, Domingo, Andersen, Clark R, & Panchbhavi, Vinod K. (2013). Accuracy of citation and quotation in foot and ankle surgery journals. *Foot & Ankle international*, 34(7), 949-955.

Mackey, Thomas P, & Jacobson, Trudi E. (2011). Reframing information literacy as a metaliteracy. *College & Research Libraries*, 72(1), 62-78.

Mansourizadeh, Kobra, & Ahmad, Ummul K. (2011, 9//). Citation practices among non-native expert and novice scientific writers. *Journal of English for Academic Purposes*, 10(3), 152-161. https://doi.org/http://dx.doi.org/10.1016/j.jeap.2011.03.004

Montenegro, Thiago S, Hines, Kevin, Partyka, Paul P, & Harrop, James. (2020). Reference accuracy in spine surgery. *Journal of Neurosurgery: Spine*, 34(1), 22-26.

Purdy, James P. (2018). Common dispositions and habits of mind: The ACRL and WPA frameworks in conversation for tomorrow's researcher-writer. In Grace Veach (Ed.) *Teaching information literacy and writing studies: Volume 2, upper-level and graduate courses*, Purdue University Press.

Rapchak, Marcia E., Nolfi, David A., Turk, Melanie T., Marra, Lori, & O'Neil, Christine K. (2018, 2018-10-04). Implementing an interprofessional information literacy course: impact on student abilities and attitudes. *Journal of the Medical Library Association*, 106(4). https://doi.org/10.5195/jmla.2018.455

Sato, Brian K, Kadandale, Pavan, He, Wenliang, Murata, Paige MN, Latif, Yama, & Warschauer, Mark. (2014). Practice makes pretty good: assessment of primary literature reading abilities across multiple large-enrollment biology laboratory courses. *CBE—Life Sciences Education*, 13(4), 677-686.

Serviss, Tricia. (2017). The things they carry: Using design-based research in writing-teacher education. In Tricia Serviss & Sandra Jamieson (Eds.), Points of departure: Rethinking student source use and writing studies research methods (pp. 102-122). University Press of Colorado. http://www.jstor.org/stable/j.ctt1xzh15w.14

Serviss, Tricia, & Jamieson, Sandra. (2018). *Points of departure: Rethinking student source use and writing studies research methods*. University Press of Colorado.

Swales, John M. (2014). Variation in citational practice in a corpus of student biology papers. *Written Communication*, 31(1), 118-141. https://doi.org/10.1177/0741088313515166

Thompson, Paul, & Tribble, Chris. (2001). Looking at citations: Using corpora in English for academic purposes. *Language, Learning & Technology*, 5(3), 91-105.

Thornton, Steve. (2020). Threshold concepts in primary school maths and science: An investigation of some underlying ideas of STEM. In Amy MacDonald, Lena Danaia, & Steve Murphy (Eds.) *STEM Education Across the Learning Continuum* (pp. 233-247). Springer.

Verkade, Heather, & Lim, Saw Hoon. (2016). Undergraduate science students' attitudes toward and approaches to scientific reading and writing. *Journal of College Science Teaching*, 45(4), 83-89.

Wager, Elizabeth, & Middleton, Philippa. (2008). Technical editing of research reports in biomedical journals. The Cochrane Library.

Wolfe, Joanna, Olson, Barrie, & Wilder, Laura. (2014). Knowing what we know about writing in the disciplines: A new approach to teaching for transfer in FYC. *The WAC Journal*, 25(Fall), 42-77.

Notes

[1] For the purpose of this article, primary research articles are peer-reviewed publications authored by the scientists who did the research. For many sciences, primary research is empirical. However, primary research will be theoretical in some disciplines, such as physics.

[2] A secondary literature review synthesizes research in the field while a meta-analysis review can also contribute empirical, primary data. Therefore, the terms "secondary" or "review" in this article only refer to standard literature reviews.

Contact Information

Kristin M. Klucevsek
[position]
Duquesne University
Email: klucevsekk@duq.edu

Complete APA Citation

Klucevsek, Kristin M. (2022, November 4). Writing with Research: Understanding How Students Perceive Sources in the Sciences. [Special issue on *STEM and WAC/WID: Co-Navigating Our Shifting Currents*] *Across the Disciplines*, 19(1/2), 78-98. https://doi.org/10.37514/ATD-J.2022.19.1-2.06