ARTICLE
PopScience: Teaching students to Communicate Scientific Findings to the General Public

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Scientific communication has become more important than ever before, yet most scientists are not trained in how to communicate their research findings to the general public. The PopScience assignment is a semester-long writing and oral communication project that focuses on how to communicate primary scientific literature to the general public. The overall goals of the PopScience project are to teach students how to: 1) critically evaluate neuroscience primary literature, and 2) translate and convey primary literature findings to a lay audience. Students completed a pre- and post- assignment perceptive assessment to evaluate the skills they obtained (e.g., reading comprehension and critical thinking), and the effectiveness of the assignment in improving these skills. Students reported that overall, the assignment improved their ability to read primary literature articles and explain them to a lay audience. Self-evaluation and professor assessments suggest the PopScience assignment also improved student's ability to integrate and summarize results from multiple sources, as well as identify and explain neuroscience terminology that often leads to confusion for lay audiences. In conclusion, this assignment teaches students how to communicate basic neuroscience to the general public, a skill that continues to be critical in successful scientific careers.

Key words: neuroscience, undergraduate education; primary neuroscience literature; scientific communication

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One essential component of the scientific process is the ability to communicate findings widely and effectively to both those within the field and the public. In science, dissemination of findings to a lay audience can be more difficult compared to non-scientific disciplines. This is unfortunate, as scientific communication is important for both the general public and policy makers to counter misconceptions that impact future science education and funding (Irwin, 2008; Illingworth and Prokop, 2017).

Scientists are often blamed for both the lack of research dissemination to the general public and the failure to clearly communicate with a non-scientific lay audience. Rationale for these shortfalls range from lack of training (Brownell et al., 2013), to a lack of understanding the field of scientific communication (Illingworth, 2017; Illingworth and Prokop, 2017), or only viewing scientific communication through a deficit model (Bubela et al., 2009; Illingworth, 2017). For example, the field of scientific communication demonstrates that two-way rather than one-way communication is preferred when disseminating to a lay audience. The focus of the presentation is also important, as critics claim that communication fails with the deficit model because the presenter focuses solely on individuals' deficits in scientific knowledge rather than external factors such as ideology. Independent of underlying factors, scientists are blamed for the disconnect between scientific findings and the general public.

Research suggests, however, that it isn't the scientists themselves, but the inherently complex scientific vocabulary that makes scientific communication to the general public difficult (Radford, 2011; Brownell et al., 2013; Salita, 2015; Beardsworth, 2020). Because scientific jargon is not part of lay individuals vocabulary, it deters the general public from learning about scientific studies, and in a world where information can be obtained through a quick internet search, this encourages misunderstandings and doubt in science (Beardsworth, 2020). For example, both *Scientific American,* which was originally created as a science newspaper, and the major journals across scientific disciplines, have increased in reading difficulty since 1880 (Hayes, 1992; Plaven-Sigray et al., 2017). Similarly, the use of acronyms in scientific abstracts has increased 10 fold from 1956 to 2019, which further decreases readability for both scientists and non-scientists alike (Barnett and Doubleday, 2020). The increase in reading difficulty due to scientific jargon and acronyms, is inversely correlated with readership from the general public (Hayes, 1992; Chawla, 2020). This has resulted in a less informed public. Ultimately, when scientific jargon leads to misunderstanding, or makes individuals feel alienated, they turn to other online sources, to back up arguments. Depending upon the source and critical thinking skills, this can often lead to a rise of misinformation and "alternative facts" (Beardsworth, 2020). Thus, over the last century, as the vocabulary within the science field has become more complex, distrust of science and misinformation has risen.

In order to counter misinformation, it is vital that scientists are trained to effectively communicate science to lay individuals. Undergraduate education is a well-positioned entry point into such training. Written and oral communication are pillars of undergraduate education (Association for American Colleges and Universities, 2007), and both are included as core competencies for neuroscience, biology and psychology (Woodin et al., 2010; American

Psychological Association, 2013; Wiertelak et al., 2018). While written and oral communication are listed as core competencies in the sciences, the focus of these skills is communication to peers. Per the core competencies, written communication utilized in the classroom should mirror research dissemination in the scientific field via journal articles (APA, 2013). Similarly, competencies suggest oral communication in the classroom should focus on professional oral presentations and presenting research findings to peers (APA, 2013; Wiertelak et al., 2018). Thus, communication to a lay audience is seldom incorporated into the undergraduate science curriculum (Brownell et al., 2013). It is important to emphasize oral communication to a lay audience, as it is a much different skillset than when presenting to peers. For example, two-way communication allows for audience engagement, and results in a positive reverence for science as individuals gain scientific knowledge. As such, it is important for undergraduate STEM programs to teach students scientific communication, and in particular, scientific communication for a lay audience at the undergraduate level. The PopScience assignment was created to teach undergraduates at a liberal arts college how to read, critically evaluate, and communicate scientific findings to a lay audience. The goals of the PopScience assignment were to 1) develop skills to critically evaluate primary literature and 2) convey primary literature findings to a lay audience, with a focus on avoiding scientific jargon.

MATERIALS AND METHODS

Participants

This study was conducted at a Midwest liberal arts college, and included students (n=30) enrolled in a three-credit hour behavioral neuroscience course. The behavioral neuroscience course was the second of a three-course sequence for neuroscience majors and minors. Students were surveyed at the beginning and end of the course, prior to and after conducting the PopScience assignment. The study was declared exempt from oversight by North Central College's Institutional Review Board.

Study Context

In developing a mid-level behavioral neuroscience course that was part of a three-course sequence, there were two learning outcomes (LOs) for students 1) develop skills to critically evaluate primary literature and 2) learn to convey primary literature findings to a lay audience. The PopScience assignment was developed to reach these goals. This is a two-part assignment in which students first read and critically evaluate a popular press article based on the primary literature, and in the second part, gather additional literature on the topic to present to a lay audience.

Previous Course Preparation

All students enrolled in the behavioral neuroscience course had previously taken an introductory neuroscience course at the institution. In the introductory neuroscience course, students had initial exposure to primary literature through 4 review articles from scholarly journals such as Nature Reviews and Science. Through these articles and writing their own lab reports, students learned to read literature overviews, write methods and results sections (without analyses beyond means), and how to make/interpret graphs and tables. Thus, there was no expectation of student exposure to original primary research articles.

Preparation for Part I

Prior to completing part I of the assignment, students received several days of instruction on reading and evaluating scientific articles, as well as using library resources to locate articles for the project. First, students were instructed on different ways to read a journal article (e.g., introduction followed by figures and tables, and then methods), as well as where to find the aim, hypothesis, etc. Students then read an original research article the instructor assigned pertaining to lecture material. After reading, students answered online questions on what order they read the article, where to locate pertinent information in the article such as the aims and hypotheses, found a complementary primary literature article that built on the knowledge presented in the assigned article, and critically evaluated the study. These items were all discussed in class after students completed the reading and online questions. Throughout the term, students read a total of 14 primary literature articles and for each, answered questions such as the aim/hypothesis of the article, what researchers did (methods), and what researchers found (results), prior to in-class discussions of the articles.

Second, students attended a course tailored library session about using search engines such as Academic Search Complete or ProQuest to find a popular press article on a topic of their choosing that met the assignments criteria. On the assignment example magazine, newspaper, and websites that are presumed to be quality news sources were listed (e.g., Associated Press, NPR, Science Daily); alternatively, students could have other sources not listed in the syllabus approved instructor. Students were required to find a popular press article that reported on a particular research study, and it could not be an opinion piece, editorial, or press release from a college or university. Students also received instruction on finding the journal article cited in the popular press article using search engines such as PsycInfo and PubMed, as well as tips on finding a supplementary article, that complemented the first article, such as going to the senior author's lab website or locating a cited source within the original article. Students were not allowed to use reviews, meta-analyses, dissertation abstracts, commentaries, or opinion pieces for their primary literature article. As with the popular press article, major peer reviewed neuroscience journals were listed on the assignment; students could also receive approval to use articles from other journals. Finally, at the end of this library session, students had time to work on finding articles on their topic, and the instructor spoke with each student about search terms to make sure their topic was not too broad (hundreds of articles), or too narrow (under 10 articles). During this session, students were given tips on what similarities they should look for in a supplementary article (e.g., staying within the same animal model/human, or similar brain areas), to assist in incorporating findings together in part II of the assignment.

PopScience Paper Rubric	**Pts**
Overview of Article #1 • What did they investigate? • How did they investigate the problem? • What did they find? • What brain areas or pathways were involved? • What are the implications of this research?	4 pts
Overview/Incorporation of Article #2 • What did article #2 find • Incorporate into discussion of findings and implications from article #1	4 pts
Critique of Popular Press Article • Accuracy of popular press article • Was language simplified for a lay audience?	4 pts
APA formatted Reference section and citations	4 pts
Grammar and Quality	4 pts
PopScience Presentation Rubric	**Pts**
Grab audience's attention	2 pts
Use all 5 articles and incorporate them to discuss the topic (supplied in annotated bibliography). All references must be in APA format.	10 pts
APA format of references	5 pts
Simplify message to convey to general population (no scientific jargon!)	5 pts
Presentation Format	5 pts
Overall Presentation Quality	5 pts
Presentation Write-ups	8 pts

Table 1. Grading rubrics utilized for part I, the PopScience Paper and part II, the PopScience Presentation.

In the next class period, the professor presented examples of common misinterpretations students should look for in their popular press article. For instance, did simplifying scientific language alter the overall conclusion of the study? Were important details left out that would help the reader understand the findings; or the opposite, would taking out details help simplify the findings? Were the findings reported incorrectly, such as reporting a correlational relationship as causal (Mueller, n.d.)? How did the authors simplify scientific language/eliminate jargon, or if not, how could they simplify the language?

Part I

In the first part of the assignment, following the model used in the preparation period, students were tasked with finding a popular press article that reported on a single, original scientific finding. Students then found the original primary literature article that the popular press article was based on, in addition to a second primary literature article that supported the findings, to critically evaluate how the author of a popular press article interpreted original scientific findings. In this first part, students wrote a paper of the evaluation, identifying ways the author simplified findings for a lay audience, and evaluating instances where generalization potentially altered the conclusions drawn from the original findings. The goal of this first part was for students to identify what aspects of scientific communication were or were not successful when communicating to a lay audience (outlined in the part I preparation section). This set the foundation for developing skills to critically evaluate primary literature (LO-1). The professor utilized a rubric to evaluate student's assignments, and whether LO-1 was met (Table 1: Paper Rubric). When grading the paper, the professor also provided advice/considerations for students when creating their talk. For instance, if a student's article covered molecular changes that they had not yet learned about, the professor steered them towards not as technically challenging material within their topic. Or if the study used an intricate behavioral test such as set-shifting, how could the student use a figure to explain this in a simplified way. Additionally, the professor provided extensive feedback on integrating the primary literature studies together, or when methods needed to be paired down, to integrate the studies together more easily and form a story.

Group Discussion Questions for PopScience Talk
1) How will you capture your audience's attention? • How will you keep the audience engaged during your talk? Will you involve the audience?
2) What is the message you want to impart on your audience (the main point)? • How will you make your main point "stick"? • When in your talk will you state your main point?
3) Map out the "story" of your talk • Introduce topic/message • Are there any neuroscience concepts or parts of the brain you will mention and need to explain? • Why should the audience support your message? • What does the research show? How will you integrate this information together? • How will you conclude your talk? • Did you loop back to your introduction?

Table 2. In preparation for part II of the assignment, students discussed their topic and mapped out their talk with peers utilizing the following questions.

Preparation for Part II

In preparation for part II of the assignment, the professor took one of the primary literature papers that students read for class (e.g., a paper on the gut microbiome and synaptic changes when discussing ingestion), and after the paper discussion, gave an example of how the findings could be simplified for a lay audience, and incorporated with other primary literature in a concise and effective manner. The professor demonstrated and then questioned the students on key factors to consider when developing their talk. For instance, the talk should have a main point that is repeated several times rather than just a general overview giving the example of scientific TED talks as a resource; the professor demonstrated how to integrate findings together without

discussing the methods in detail, how to simplify scientific jargon from the paper, or explaining what it meant if terminology such as gut microbiome needed to be used. Following this example, students were placed in groups and worked through guided questions with peers to assist them with identifying the key factors for their topic (Table 2). The professor specifically conducted this activity with peers so that individuals who had not read the primary literature on their topic could help identify jargon and help students that needed to clarify the point of their talk.

Part II

Following written feedback on their paper from the first part of the assignment, students proceed with the second part of the assignment with the LO-2 of conveying primary literature findings to a lay audience. For the second part, students kept the same topic, and gathered a minimum of three additional primary literature articles (for a total of 5 primary literature articles). Students were tasked with synthesizing and incorporating findings from all 5 studies together so that they could convey an overview of the current literature on their topic. Students then took this information, and developed a 10-minute presentation on the topic for a lay audience, focusing on applying what they learned about scientific communication in the first part of the assignment. Prior to their talk, students were required to turn in an annotated bibliography, citing their sources, explaining exactly what information they utilized and how that information would be utilized in their talk. At the end of the semester, students delivered their talk in-person to the class, as well as family and friends that would like to join, with the intent of producing a lay audience. Students were encouraged to involve the audience throughout their talk, and audience members were encouraged to ask questions during the talk, to promote two-way communication. The professor utilized a rubric to evaluate student's talk, and whether LO 2 was met (Table 1: Presentation Rubric).

Survey

Prior to, and following the assignment, students filled out a questionnaire rating their abilities and skills with regards to primary literature reading and interpretation.

Student Confidence Question

Students were first asked to rate on a 1-10 scale their current ability to read primary neuroscience literature and explain it to a lay audience with no science background. For this first question, 1 represented "No idea how to explain scientific literature to someone without a science background," 5 represented "I can read scientific literature,

Primary Literature Reading Skills
Understanding the introduction
Ability to summarize previous work in the field
Identifying the question the authors are asking
Identifying hypotheses
Understanding the methods
Ability to read graphs and tables
Understanding the meaning of statistics/significant vs non-significant
Differentiating between correlation and causation
Ability to summarize results from the results section
Identify whether the results answer the research question
Ability to generalize study results
Ability to determine holes in the research, or issues with the authors interpretation of results
Ability to explain neuroscience terminology that may stump a lay audience
Ability to integrate several findings together and produce a take-home message

Table 3. Pre- and post- assignment assessment where students rated the skills utilized/learned from the assignment related to reading primary literature. Students rated each statement on a 10-point scale, with 1 representing "Never used the skill", and 10 representing "Mastering the skill."

but am not at the level to explain it to someone else," and 10 represented, "Confident in ability to read scientific literature and explain difficult neuroscience concepts to someone without a science background."

Primary literature skills
Students were presented with a list of skills related to reading primary literature, that they rated on a 1-10 Likert scale with 1 representing "Never used that skill" to 10 "Mastering that skill." All skills are reported in Table 3.

Post-assignment question
On the post-assignment questionnaire students were also asked to rate on a 5-point scale (1 = strongly disagree to 5 = strongly agree), whether they felt the assignment improved their ability to read and interpret primary neuroscience literature and if it improved their ability to present scientific findings to a lay audience.

Statistical Analyses
T-tests were conducted on grouped pre- and post-assignment questionnaire ratings. Significance was set at $p<0.05$.

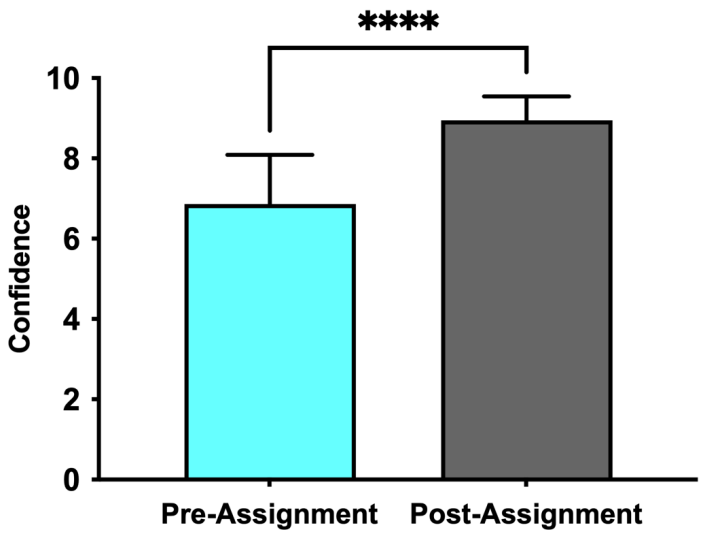

Figure 1. Student confidence question: students were asked to rate their confidence in ability to read primary neuroscience literature and explain it to a general audience with no scientific background. A 1 represented "No idea" and a 10 represented "Confident." This result demonstrates a significant improvement in presenting primary literature to a lay audience, **** $p<0.0001$.

RESULTS

Student Confidence Question
Students were asked to rate their confidence on a 1 to 10 Likert scale of their ability to read primary neuroscience literature and explain it to a lay audience with no science background (Figure 1). Students rated their abilities significantly lower on the pre-assignment questionnaire (M=6.86, SD=1.23) compared to the post-assignment questionnaire (M=8.95, SD=0.59), $t(20)=7.292$, $p<0.0001$. This shows that overall, students felt more comfortable reading primary literature and translating that information to others following the assignment. This was also supported by data from the post-assignment questionnaire as students believed the assignment improved their ability to read and interpret neuroscience literature (M=4.47, SD=0.68), and present scientific findings to a lay audience (M=4.40, SD=0.72), with 1 on the Likert scale representing strongly disagree, and 5 representing strongly agree.

Comparative Assessment of Student Learning
When breaking down students' abilities in different parts of the assignment, students rated on a 1 to 10 scale, from "never using" to "mastered," the skill with regards to reading primary literature (Table 3). At the beginning of the course, it was assumed that all students had a baseline competency of reading primary literature reviews, as this was covered in the pre-requisite course (see Previous Course Preparation section). Prior to taking the pre-assignment assessment, all students in the class were taught how to read primary literature articles, including but not limited to the parts of the paper, reading graphs and tables, and determining study hypotheses (see Part I Preparation section). As this assignment built on previous skills in reading primary literature, the questionnaire confirmed that students perceived they had mastered those skills. Students did not believe their reading skills changed pre- and post-assignment for basic skills such as identifying hypotheses, understanding methods, or reading tables and graphs. Students did, however, perceive an improvement in their ability to analyze and evaluate the primary literature from pre- to post-assignment. Figure 2 reports on the skills where the student questionnaire showed a difference pre-and post-assignment.

Students believed the assignment improved their ability to interpret and translate primary literature as intended (Figure 2). In part I of the assignment, students were tasked with critically evaluating a popular press article based on primary literature paper findings. Students reported that they did learn to identify holes in the reporting, and issues in the lay interpretation of scientific results, $t(59)=5.27$, $p<0.00001$, corresponding with the goal of part I. Through part II of the PopScience assignment, students reported their ability to summarize results from several articles, $t(59)=4.61$, $p<0.001$, integrate these results to produce a take-home message, $t(59)=5.66$, $p<0.00001$, and generalize the results, $t(59)=3.67$, $p<0.001$; all improved. Students also felt that their ability to summarize previous work in the field was enhanced, $t(59)=3.66$, $p<0.001$. These findings all evaluate student perceptions of meeting the first learning outcome, to critically evaluate the primary literature during this assignment. Students also believed they met the second learning outcome of conveying primary literature findings to a lay audience, as they reported they were able to identify and explain neuroscience terminology or "science jargon" that often times confuses lay audiences, $t(59)=4.60$, $p<0.0001$. (Figure 2)

DISCUSSION

The PopScience assignment was developed to teach

students how to effectively communicate scientific findings to the general public. The two overarching LOs of this assignment were to 1) develop skills to critically evaluate primary literature and 2) convey primary literature findings to a lay audience; both of which were quantified in pre- and post-assignment assessments of student's confidence conducting these tasks. We acknowledge that a pre- post-survey is indicative of student perceptions and not knowledge based learning (Price and Randall, 2008), but since it is one of the few ways to conduct a pre-post- design on an assignment, we believe that students' perceptions provide valuable insights into the components of each learning outcome and when evaluating the specific skills students need further instruction on to improve future assignments.

In the PopScience assignment, students believed that overall, they gained the skills to critically evaluate scientific literature, and to translate this information for a lay audience. While students ranked this item high from the start of the course (M=6.86), when breaking down into individual components of reading and presenting, we see that this high rating is likely because students felt comfortable reading and understanding parts of the primary literature such as the introduction (pre M=8.32, post M=9.00) and methods (pre M=8.00, post M=8.13). They were not, however, as confident in their abilities to critically evaluate or interpret the

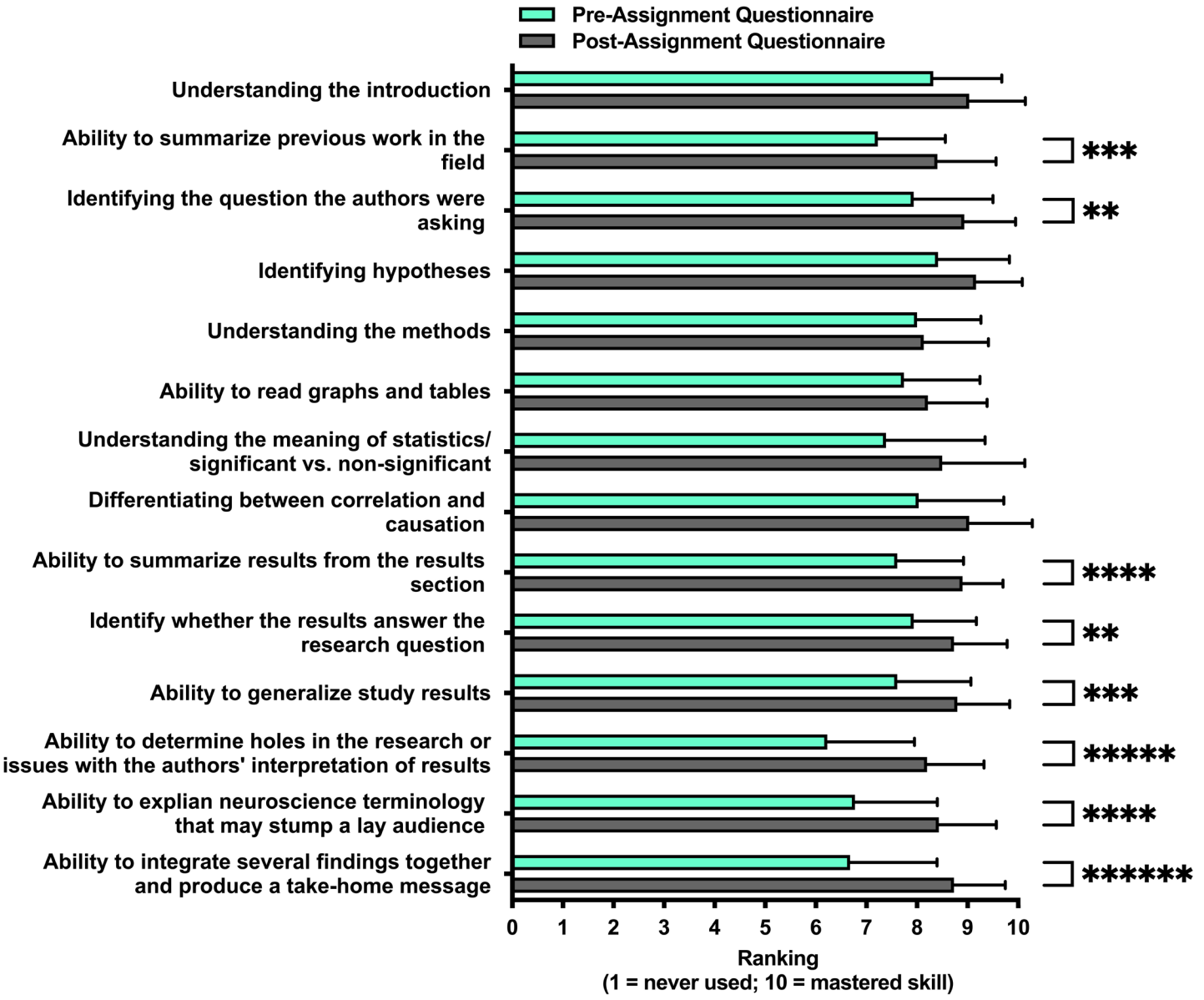

Figure 2. Comparative assessment of student learning: questionnaire items that demonstrate significant improvement from pre- to post-assignment. Students were asked to rate each skill on a 10-point scale, with one representing never used, and 10 meaning they have mastered that skill. Significant t-test comparisons **p<0.01, ***p<0.001, ****p<0.0001, *****p<0.00001, ******p<0.000001.

literature, as represented by lower pre-assignment rankings, and significant improvement pre-/post- on items such as summarizing previous work in the field (M=7.23), and summarizing results (M=7.61). This perception is in line with the professor's evaluations and is displayed in writing pitfalls such as difficulty synthesizing studies together, or presenting too much detail from individual studies. Evidence of these specific examples are provided below.

While students perceived that the two main LOs for the course were met, we assessed the components needed to attain these two LOs, and these were quantified in the questionnaire (Table 3). For instance, in order for a student to critically evaluate the primary literature (LO #1), they need to be able to read and understand the primary literature. This was shown to be a skill that students felt confident in from the beginning of the assignment, as ratings did not change due to the assignment. As these are student assessments, however, we believe that these values are likely inflated due to overconfidence, as students ranked their skills greater than 50% on every pre-assignment skill, even those that they had not previously learned. This is not surprising as research shows that students tend to be overconfident in their abilities, and particularly when they are learning new skills (Kruger and Dunning, 1999; Svanum and Bigatti, 2006; Jensen and Moore, 2008).

The professor utilized rubrics for grading to ascertain what skills students had mastered. Based on these assessments, students were able to critically evaluate the primary literature, and convey these findings to a lay audience following the assignment We suspect, however, overconfidence in reading abilities in particular, as students were directly questioned on how they read the first primary literature article for the course, and about 50% of students read the article straight through, which most sources do not recommend for students unfamiliar with methods and statistical results (Fosmire and Edmondson, 2023). Despite evidence of overconfidence, the professor observed improvement in students' ability to read scientific literature throughout the course, as demonstrated by verbose primary literature article discussions, in which students averaged 80% on intellectual contributions made during these discussions throughout the term. Additionally, students earned an average of 90% on primary literature article questions that ranged from basic hypotheses questions, to interpreting what a finding meant. Thus, between student perceptions, graded work on part I of the assignment, and supplementary work in the course, we believe that students did meet LO-1, critically evaluating the primary literature.

Beyond understanding the primary literature, students needed to then synthesize and incorporate research findings together from multiple studies to convey an overview of their topic. When beginning to review the primary literature, students often find synthesis difficult as they all too often write a paragraph per individual study or categorize studies individually so findings aren't integrated together (Bosch, 2017). A second issue we observe when students fail to integrate information together, is that they present too much in-depth information, such as every detail of the study design (Beardsworth, 2020). Often times, this occurs when students don't understand what is important or the focus of the findings. Both of these examples are represented in the following paragraph based on a student's paper:

> "Work by Funkhouser and Schredl (2010) looked at the frequency of déjà vu with taking age, dream recall, and personality traits into consideration. The study surveyed 444 psychology students at three German universities. The study resulted in the incidence of déjà vu being ninety-five percent. The study also found that a majority of the participants (34.6%), experience déjà vu about two to four times a year. The researchers found it surprising that the percentage of participants that experienced déjà vu was so high at 95%. They believe that the high percentage can be explained by the fact that the participants consisted mainly of psychology students who might find this phenomenon interesting and related to their profession. The researchers also found out that dream recall frequency, imagination, attitudes towards dreams, and absorption were positively correlated with déjà vu frequency."

In this example, the student could pair this down to a single sentence such as:

> A large-scale research study found that 95% of college students experienced déjà vu, with 34.6% experiencing it 2-4 times a year (Funkhouser and Schredl, 2010).

Learning to integrate findings from separate studies together forces students to scale back on detail in order to form a coherent story and convey a strong message, rather than overloading the audience with information. By focusing on how to integrate research findings together in both the paper and presentation practice, students reported increased confidence and ability in summarizing results, as well as increased ability to integrate primary literature findings together to produce a take-home message (Figure 2). These are essential skills in presenting to the general public, as a lay audience will quickly lose attention if they are just presented facts or overloaded with information, and fail to be pulled into a story (Beardsworth, 2020). Once students are able to synthesize the results, then it is much easier for them to summarize the findings of several studies for a lay audience, which was reflected in their pre-post assignment confidence.

After students integrate and summarize results on a topic, then it becomes much easier to generalize the results, and transform them to a level appropriate for a lay audience, which was the LO of part II of the project. Students reported that both the ability to generalize results and convey primary literature to a lay audience improved through this assignment. By eliminating scientific jargon, and presenting a non-technical summary of scientific literature to a lay audience (Radford, 2011), students learn skills that they can utilize for the rest of their scientific careers, with the hopes

of decreasing scientific misunderstanding, and detachment from science (Beardsworth, 2020).

Overall, based on student perceptions and faculty evaluation, through the PopScience assignment students learned to critically evaluate the primary literature (LO-1), and convey these findings to a lay audience (LO-2). By teaching students these skills early in their scientific careers, they are able to tap into these skills when formally presenting scientific research, and when discussing scientific findings with non-scientists. This is also in line with recommendations of Brownell et al. (2013) to teach communication skills early on in basic science courses. These skills will continue to assist students and the neuroscience field for the rest of their scientific careers.

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