Writing Circles in STEM: Why Structured Peer Review Engages Students as Writers, Thinkers, and Collaborators in Their Discipline[1]

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Abstract: This study explores how students' perceptions of themselves as thinkers and communicators within a STEM discipline are impacted by structured peer review. Quantitative and qualitative coding led to thematic analysis of students' reflective writing papers produced during partial-credit companion courses called writing circles, which are weekly peer review groups facilitated by an instructor who is not the students' disciplinary instructor. Study participants, during their circles, reviewed peers' research proposals or lab reports for kinesiology courses, lower-division and upper-division. Analysis reveals that circles result in American STEM undergraduates increasing a) facility and appreciation for collaborative dialogue; b) ability to transfer communication and revision strategies; and c) confidence in their abilities as communicators, reviewers, and critical thinkers. These findings are relevant for educators searching for methods to support the learning of writing, critical thinking, and collaborating in STEM courses.

Students learning to communicate in the science, technology, engineering, and math (STEM) fields often experience co-occurring challenges: they struggle to understand the genre conventions and requirements of communication in their discourse community (Gillen, 2006) and lack enough confidence to progress in their discipline (Simon et al., 2015). Insufficient confidence may undermine their perception of themselves and their peers as writers and researchers, which in turn can delay their acquisition of STEM genre knowledge and their ability to collaborate effectively.

Measuring student writing and critical thinking can be a complex task: improvements in one area—specifically, better writing—may not translate to improvements in other areas—specifically, enhanced critical thinking (Condon & Kelly-Riley, 2004). In undergraduate STEM courses, writing-to-learn pedagogy (WTL) has been shown to enhance student learning through the process of extrapolating and applying course content. Reviewing the benefits of WTL in STEM, Rivard (1994) notes that students become more aware of language usage, have better understanding of course content, can recall it more readily, and show more complex thinking about content.

Still the question of what kinds of tasks generate these gains and how is less clear. Rivard (1994) calls for more research about how WTL generates conceptual change and critical thinking in students,

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while also noting disciplinary teachers' perceived lack of preparation for implementing WTL as a major obstacle.

Eighteen years after Rivard's call, a National Science Foundation-funded study brought together experts in biology, chemistry, physics, psychology, and writing education to review research and extend Rivard's (1994) review by identifying links between writing, conceptual change, and the critical thinking invoked in students within specific STEM disciplines (Reynolds et al., 2012). Noting that writing offers a good way to make thinking visible and that WTL allows students to learn content as well as how to think within a discipline, the authors proposed a conceptual framework for a research agenda to aid researchers in studying and teachers in implementing effective WTL practices.

Formative peer review groups have a long history as a type of collaborative learning (Bruffee, 1984; Gere, 1987). Students improve the quality of writing within a specific document and become better writers in general (Cho & MacArthur, 2011). Indeed, giving feedback on others' work may be just as, or more, important than receiving feedback on one's own, because providing quality feedback is cognitively demanding and strengthens skills for identifying problems with texts and suggesting solutions (Cho & MacArthur, 2011; Lundstrom & Baker, 2009). In addition to analyzing others' drafts, receiving comments and making revisions to one's own draft are key drivers for becoming a stronger writer (Wu & Schunn, 2020).

Peer review is increasingly being adopted for STEM writing assignments (Brownell et al., 2013; Finkenstaedt-Quinn et al., 2021; Geithner & Pollastro, 2016; Marks et al., 2022; Petterson et al., 2022). Other active-learning and small-group interactions have also been recognized as beneficial (Freeman et al., 2014; Wilson & Varma-Nelson, 2016). As more STEM students engage in peer review, it presents opportunities for further research to measure how and to what extent the findings on peer review generally manifest in the sciences specifically. This manifestation includes not only internal aspects of writers' experiences, self-perception, and understanding of peer review, but also external aspects of the writing they actually produce, and research tends to focus on either internal or external aspects. For example, our initial studies (Kramer et al., 2019 & 2022) address the external aspect by analyzing writing produced in kinesiology courses that use writing circles, which are weekly, structured peer review. Meanwhile, Keating (2019) examines internal aspects—how peer-review participants perceive their growth, learning, and confidence. Therefore, an integrated study encompassing both internal and external aspects would be an advantageous contribution. Our current study adds the internal aspect to our previous studies on the external aspects, thereby creating triangulation.

The purpose of our current study is to analyze STEM students' reflection papers, written during writing circles, to determine perceptions of their development in writing, critical thinking, and discussion skills while participating in the circles. This study's results offer context for why the same participants improved their writing and critical thinking in their companion kinesiology courses, as analyzed in Kramer et al. 2019 & 2022. Combined, our three studies offer evidence that through repeated employment of facilitated peer review, students learn how to more confidently enter disciplinary conversations and position themselves as STEM researchers, thinkers, and communicators. Our current study's quantitative data show how much and with what complexity the participants reflect on their development of these skills. Our qualitative data, based on thematic coding and analysis, offer details about how students perceive the circle experience as helping them increase facility and appreciation for collaborative dialogue; increase their ability to transfer communication and revision strategies; and improve confidence in their abilities as communicators, reviewers, and critical thinkers.

Literature Review

Peer Review and Collaboration

Writing circles, like those studied here, are a course-based intervention that promotes active learning and peer-based collaboration through multiple feedback and revision cycles, or what we call iterated peer review. To understand how circles contribute to these ends, in this section we consider the cognitive process model of writing and revising; review research on formative feedback and peer review; and consider a social cognitive model of writing self-regulation.

Experts and novices differ in their approach to disciplinary writing. This was a key contribution of Flower et al. (1986) and Hayes et al. (1987) and their development of a cognitive process model of writing and revising. Experts tend to establish plans for revising the text as a whole, while novices tend to focus their attention at the sentence-level. In addition, experts can draw on more revision strategies. Therefore, one way for novices to improve their writing is to emulate the practices of experts by receiving formative feedback on content and structure issues. In addition to enhancing student writing, this practice also aids students in learning course content (Olson & Raffeld, 1987; Riddell, 2015; Vardi, 2012).

Since the 1970s, there has been considerable research into peer assessment of writing as means for receiving formative feedback, including biology, psychology, geography, math, and film making (Topping, 1998). It is generally accepted that formative peer feedback of writing, when planned well, improves student writing and can be at least as good as assessment by teachers, and sometimes better (Huisman et al., 2019; Topping, 1998 & 2009). Peer feedback can focus on areas in the text that need attention, summarize issues, and offer solutions (Nelson & Schunn, 2009). Peer review can correct student understandings of course content, though it also can introduce incorrect information or terminology (Halim et al., 2018).

There is some evidence that writing tasks in science courses offer little benefit for learning without repeated practice and opportunities for metacognitive reflection that allow novice writers to successfully integrate subject knowledge into their writing (Armstrong & Paulson, 2008). In addition to frequency, timing also matters. Some studies show that scheduling peer review sessions in advance—at least four weeks before a due date—encourages students to begin writing earlier and gives students enough time to make substantial revisions based on peer feedback (Baker, 2016; Chaktsiris & Southworth, 2019). Other factors that contribute to successful peer review are the amount of feedback (Wu & Schunn, 2020), its quality and focus, the training students receive in giving feedback (Min, 2006; Cho & MacArthur, 2011), and the emphasis on collaborative reciprocity between writer and reviewer (Roscoe & Chi, 2008). These conditions—timing, frequency, training, and collaboration among peers—are important considerations that separate effective peer review from that which is ineffective.

While a number of studies have investigated the use of peer review as a one-off event, fewer studies have explored the impacts of repeated peer review over time, particularly as part of a WTL curriculum in science. Results from repeated use of peer feedback are unclear or undescribed in many studies (Bangert-Drowns et al., 2004).

Related to more opportunities to practice writing is the theory of self-regulation, which plays an important part in the development of confidence. Writing self-regulation is the self-initiated thoughts, feelings, and actions that writers use to meet goals. Zimmerman & Risemberg (1997) propose a social cognitive model with 10 strategies used by prominent writers, including the use of books, peers, tutors, reading aloud, and other social sources of knowledge and skills that can be relied

upon or imitated. This model suggests feedback loops as writers monitor and control their physical and social environment, writing behaviors or activities, and cognitive beliefs and affective states.

Peer review groups, when structured well, can support students in becoming self-regulated writers, while building confidence in the collaborative process and providing practical guidance for improving writing. With a structured feedback form and training on ways to focus on issues of meaning and argument, students are able to identify problems in a peer's text from the reader's perspective and suggest solutions (Baker, 2016; Hansen & Liu, 2005). When done well, facilitated and iterated peer review in STEM disciplines can lead to a multitude of benefits, including both greater confidence and greater skills in writing and reviewing.

Communication Process

While iterated peer review offers multiple opportunities to practice giving and receiving feedback, how exactly might increased practice benefit students in terms of their ability to communicate feedback and improve their writing? In this section we review previous studies that consider whether peer review impacts STEM students' communication skills.

Artemeva and Logie (2003) describe their attempts to teach peer review in an undergraduate engineering communication course, including a discussion of the role of reviewers. Over time and with practice, students commented with more frequency on organization and flow and offered more evaluative comments. The authors attribute this change to increased recognition of the need to guide readers through technical documents, increased comfort and confidence working collaboratively with peers, and a sense of responsibility for helping peers improve their writing.

Cho and MacArthur (2011), examining lab reports in an introductory undergraduate physics course, found that students who reviewed their peers' work and received feedback from peers significantly outperformed students who wrote their reports alone. This study adds evidence to the hypothesis that students improve their own writing by reviewing and commenting on the work of others. More recently, Peterson et al. (2020) reviewed best practices for WTL assignments: among their recommendations are extensive scaffolding, rubrics, peer review, and revision.

In a qualitative case study of an undergraduate ecology program, Reddy et al. (2020) describe how training students in reciprocal peer review, with multiple iterations over five courses in three years, positively contributes to students' knowledge of their subject and their skills and confidence in reviewing the work of others: students describe developing a greater appreciation for peer review as part of a culture of research; greater confidence in making qualitative judgements about the work of others; and an appreciation for the dialogue necessary to communicate, understand, and apply feedback related to their projects. Students demonstrate the personal responsibility and independence needed to create a collaborative research culture among their peers, by, for example, doing research about peers' topics in order to provide knowledgeable feedback. An earlier study by mostly the same team of researchers (Harland et al., 2016), illustrates that students see opportunities to transfer experience of peer review to other contexts by helping friends and flatmates with academic writing projects.

Writing Circles build on earlier efforts to incorporate peer review in writing in the discipline (WID) courses. In our previous studies analyzing kinesiology final papers (Kramer et al., 2019 & 2022), we illustrate significant improvements in writing and critical thinking when students give and receive formative peer feedback through writing circles every week. Iterated, facilitated peer review can benefit students when it is planned well and integrated into the curriculum. Such integration requires institutional structure and support, without which peer review can be perceived as an informal or secondary commitment compared to seemingly more pressing concerns (Kramer, 2016).

Confidence and Transfer of Knowledge

Whether and how students gain confidence as writers and reviewers is another important question with implications for structuring peer review. Confidence, generally understood as assuredness in being able to accomplish a goal or task, is related to several constructs in psychological, educational, and writing and composition research touching on social theories of cognition and learning. Theories of self-efficacy and community of practice contribute to understanding human behavior, particularly as it relates to agency, choosing or following a course of action, identifying goals, and succeeding. In this section we briefly review these theories and consider how they apply to iterated peer review and the development of students' writing ability within STEM and how they can explain students' change in confidence and their ability to transfer knowledge.

Self-efficacy, proposed by Albert Bandura in 1977, is one component of a social cognitive theory for an individual's sense of being able to produce desired effects based on actions. Self-efficacy determines the activities that people choose to engage in, the effort they expend, and their persistence through difficulties. He identifies four sources of self-efficacy. First, performance accomplishments or mastery experiences, with past experience successfully performing a task or meeting a goal influencing one's self-efficacy or performing a similar task. Second, vicarious learning, or observing models performing a task, contributes to one's self-efficacy for performing the same task. Third, encouragement, persuasive communication, and evaluative feedback can enhance self-efficacy, particularly when the source is someone perceived as knowledgeable and credible; however, without accompanying mastery experiences, verbal persuasion cannot enhance self-efficacy for long. And fourth, emotional or physiological states, including heart rate, sweat, and mood, affect self-efficacy and cognitive processing (Bong & Skaalvik, 2003). As a construct, self-efficacy sits within a larger framework of triadic reciprocity, proposed by Bandura to describe how personal thoughts and actions have a reciprocal relationship with the environment. All of these sources of self-efficacy are present in writing circles.

Research in self-efficacy and writing has expanded within the last two decades, as researchers examine variables such as performance, anxiety, and goals. In this effort, Schmidt and Alexander's (2012) development of a 20-item post-secondary writerly self-efficacy scale (PSWSES) allows researchers to quantitatively measure changes: the scale aligns with the process model approach to writing, considering students' self-efficacy for incorporating research in their writing, their ability to read and respond like a writer by focusing on local and global issues; their rhetorical awareness and ability to write to communicate, their awareness of personal writing strengths and challenges, their management of writing processes, and their ability to be affected by modeling (2012). Using PSWSES, Adeyemi and Muhammad (2016) found that final-year mass communication undergraduates at tertiary institutions in Nigeria had above-average writing self-efficacy; they suggest that self-evaluation may allow students to become more aware of writing self-confidence, a desirable attribute in workplaces (2016).

Miller et al. (2015) researched the writing competence and self-efficacy of students pursuing bachelor's in nursing who participate in a 16-week writing-intensive supplement (a scaffolded capstone project): the students' work demonstrated statistically significant improvements in organization/structure, word choice/diction, sentence fluency, conventions, and presentation, and these improvements paralleled increases in the students' self-efficacy. Similarly, Dowd et al. (2019) found that STEM courses structured to scaffold the writing process for a senior thesis capstone were associated with student gains in self-efficacy about writing and ability to do scientific research.

van Blankenstein et al. (2019) suggest that the roles of writer, editor, and reviewer increase self-efficacy and confidence: based on surveys and interviews throughout a yearlong undergraduate education and child studies course, students receiving frequent feedback and a variety of peer

opinions report improvements in writing self-efficacy. In a review examining self-efficacy in undergraduate writers, Mitchell et al. (2023) look at variables tested in research on writing self-efficacy, writing environments, teaching interventions, and implications for writing instruction. Among their findings are that writing performance is the most assessed variable associated with self-efficacy, with performance being operationalized differently across studies. They note studies showing that self-efficacy often improves over time when measured at the beginning and end of a term and that it can fluctuate or drop off as students take different courses or transition to new writing contexts. This has important implications for the transfer of knowledge, suggesting that writing self-efficacy in one context may not always transfer to other contexts. Taken together, these studies highlight the role of performance accomplishments as a source of self-efficacy, while suggesting a fluctuating pattern in developing writers' self-efficacy over time and in different contexts.

Less explored in the literature on self-efficacy in writing are emotional and physiological states as contributors. The affective or emotional environment is an important element of writing circles. A positive environment that allows students to be receptive to giving and receiving feedback is important for developing confidence through peer review. Research by Bharuthram and van Heerden (2023) suggests that peer feedback is a mostly positive emotional experience. They report that the majority of students in a community and health sciences program described giving and receiving feedback positively: students enjoyed giving feedback—an activity achievement-based emotion—and felt pride in positively contributing to a peer's writing improvement. This research adds support for scaffolded peer-review as a positive emotional practice for students.

Other research confirms the role of work with peers as improving self-efficacy in STEM, mostly from outside a writing context. Peer led team learning (PLTL), a guided, active-learning model adopted in the 1990s in chemistry and taken up more widely since, has been shown to increase students' sense of belonging and self-efficacy, especially for female-identifying students (Wilton et al., 2019). Aikens & Kulacki (2023) describe five group work experiences that increase self-efficacy for quantitative skills, including accomplishing assigned problems, getting help from peers, confirming answers, and teaching others. In the context of supplemental instruction, small-group peer-learning programs have been developed to support self-efficacy for course tasks and self-regulated learning, as well as the development of learning strategies (Micari & Pazos, 2021).

While confidence may be well-explained by Bandura's theory of self-efficacy and research, transfer is not. Indeed, the review by Mitchell et al. (2023) suggests a fluctuating pattern in writing self-efficacy over time and across contexts. If writing circles do promote transfer, what theory beyond self-efficacy—with its focus on mastery experiences or performance accomplishments—might explain how? One possible answer may come from anthropologist Jean Lave and Etienne Wenger-Trayner's theory of community of practice (Lave & Wenger, 1991; Wenger, 1998). In this theory, more central to knowledge is an understanding of identity and practice across time periods. A community of practice involves mutual engagement, a joint enterprise, and a shared repertoire. In writing circles, students are mutually engaged in reciprocal peer review with a common goal or purpose of helping their peers improve their drafts. Collaboration and discussion in writing circles, however, may not be about just reviewing other students' writing and improving their own drafts but also developing a shared repertoire of writing and reviewing strategies. This repertoire, unlike confidence or self-efficacy in writing, may be what proves more durable in different writing contexts and over time, facilitating transfer.

The results of our study of students' written reflections during circles, combined with the results of our studies (Kramer et al., 2019 & 2022) of the same study participants' report writing in their kinesiology courses, offer insight into why interactive processes enhance learning, disciplinary authority, and confidence in STEM.

Research Context: Kinesiology

The kinesiology major at Saint Mary's College of California includes areas of emphasis in exercise science, health promotion, and sport & recreation management. Students take kinesiology courses in addition to courses outside the department in the natural sciences, social sciences, and/or business, depending on their area of emphasis. Thus defined, kinesiology is an interdisciplinary and multidisciplinary field through which students develop communication styles, abilities, processes, and backgrounds that are reflected in majors across campus.

Kinesiology students in all three areas of emphasis enroll in the lower-division research methods and writing in kinesiology course, typically as second-year students. Students in this course consider fundamental research questions in kinesiology, read and interpret research articles, and explore evaluation and measurement techniques. This is the department's WID course and is a prerequisite for a majority of the upper-division kinesiology classes. Students in the exercise science emphasis all enroll in the upper-division exercise physiology course and its companion lab, typically as fourth-year students, all having successfully completed the lower-division Research Methods & Writing in kinesiology.

Both courses include learning outcomes specific to communication, and the faculty of both have decided to collaborate with the Center for Writing Across the Curriculum (CWAC) by requiring students to concurrently enroll in writing circles. In the lower-division course, students' final project is a research proposal that includes a comprehensive literature review and a detailed proposal for an experiment. In the upper-division course, students write four lab reports, each requiring them to incorporate theories learned in lecture to the hands-on experiments conducted in labs. During circles that accompany both courses, students primarily work on these WTL assignments. Given that students in the upper-division course have already successfully completed the lower-division course, they are taking their second circle.

Research Context: Writing Circles

Writing circles are one credit courses created by CWAC to meet the demands of students in writing-intensive courses, such as the two kinesiology courses included in this study. Each circle includes three to five students, all of the same disciplinary course. The students are guided each week by an instructor whom CWAC hires and trains in writing-process pedagogy; therefore, all the circles follow the same pedagogical method. Syllabi are coordinated so that students bring drafts to the circle for assignments due in the near future in their disciplinary course. Writing circles are labor-based; students either pass or fail.

The majority of writing circle time is spent post-outlining, which is a process of reading, annotating, analyzing, and discussing texts. The writer reads aloud a section of their draft, and they and all their peers in the circle annotate the section by underlining key ideas and highlighting topics. They also put notes in the margin to describe the purpose of each paragraph or section, for example, evidence, counterargument, or results. The annotations are jumping-off points which ground the discussion in description and readerly feedback, offering peers something substantial to comment upon, which prevents the common peer-review problem of students thinking they have nothing to offer. Another important component is the author's intentions: the student author shares their goals, and the peers consider whether the draft achieves those goals. The instructor teaches, guides, and models as needed, particularly early in the term. Critiquing via post-outlining merges the communication skills of written annotation, oral discussion, and note-taking during discussion.

Students in writing circles reflect on their experience and progress at both the beginning and end of the semester. Both of the open-ended writing prompts ask students to reflect on themselves as

writers, including their transfer of skills from the past and into the future. Only the final prompt suggests collaboration as a specific option on which to reflect. The initial reflection is based on the following prompt:

> Compare your previous writing experiences to what you expect this semester. Think about writing in your particular program: Integral, kinesiology, communication, etc. What kinds of writing have you done? What tools have you used? What strategies have you used? Describe your process, from developing ideas, through drafting, through turning it in. What about "free-writing"? Does free-writing work well for you? Why or why not? If it does, how could you weave it into more of your writing process? What are your goals for the semester: Generally, as a writer? Specifically, for certain classes? How are you going to be proactive? What work habits have been successful in the past? What ideas can you adopt from others? What are your goals for this writing class? What do you hope to have learned by the end of the semester?

The final reflection is based on the following prompt, which sets the minimum number of words at 300:

> Talk about your journey as a writer: describe how you have evolved this semester -- incorporating new strategies, developing your skills, and/or confirming your strengths. Think about the four questions you answered at the start of the semester and how you might discuss them differently now: A) What are your strengths as a writer? How have they improved or changed since the beginning of the semester? B) What areas of writing do you still hope to improve upon? C) How has your writing process changed since the beginning of the semester? D) What were your goals for this writing class? What did you hope to have learned by the end of the semester, and how did the class meet those expectations? Write about one of the following: A) Talk about collaboration, for example, what you learned about peer discussion or how it affected your writing. B) Talk about transfer of the tools or strategies you have learned through this class and how you will use them in other contexts to ensure your future success. Note: throughout, use specific references to class discussions and strategies.

For the current study, in order to determine STEM students' perceptions of their own growth in critical thinking and communication skills, reflection papers were analyzed in light of the following research questions:

1. How and to what extent did participants' expressed understanding of communication and collaboration change from the start to the end of circles?
2. How and to what extent did participants' expressed understanding of communication and collaboration change in lower-division circles compared to upper-division circles?
3. How and to what extent did participants' expressions of confidence change in lower-division circles compared to upper-division circles?

Method

Participants, Artifacts, and Collection

Students in the lower-division WID course in Spring 2015 (*N* = 39) and students in the upper-division lab course in Fall 2016 (*N* = 13) were simultaneously enrolled in writing circles. The reports these students wrote in their parallel kinesiology courses were studied separately (Kramer et al, 2019 & 2022).

After receiving approval through the university's Institutional Review Board and the consent of participants, we gathered the participants' reflections. A research assistant de-identified each artifact and assigned a number and a pseudonym. Through the consent process, participants knew their work would be de-identified; the IRB process approved the use of pseudonyms for the presentation of quotes.

Quantitative Coding

Using a rubric derived from the university's learning outcomes for written communication and developed to assess the experience of students in circles attached to WID courses, norming sessions were held to ensure consistency across coders. Each reflection was coded by two coders independently using the rubric (see Table 1), which categorically organizes the depth of understanding and perceived value of four key areas of the peer-review process (collaboration, brainstorming, revising & editing, and post-outlining), with a range of 0 (no mention) to 4 (highly developed understanding and perceived value that enables transfer of knowledge and skill). Coders were instructed to give any value between each evaluation point, for example, 3.2 or 2.9. These rubric scores were used to measure not only the depth of understanding and perceived value in each category, but also the frequency with which each appears in reflections. Any score of zero was taken to indicate the category was not addressed, while any non-zero score was taken as indicative of engagement with that category.

Table 1. Rubric for Writing Process Outcomes WID and Writing Circle Assessment Projects

	4 - Highly Developed (Transfer)	**3 - Developed (How)**	**2 - Emerging (What)**	**1 - Initial**
Collaboration *Written & Oral Communication*	In addition to the Developed stage, reflects on a change in perspective or growth as collaborator in other situations. Discusses the value of collaboration.	Describes how peers interacted in specific detail, such as explaining what was said or which topics were covered, and how peer dialogue affected a particular piece.	Refers to peer interactions, or giving or receiving feedback, in detail. General mention of impact on own writing.	Mentions peer interactions, or giving or receiving feedback, but with little or no detail.
Revising & Editing	In addition to the Developed stage, reflects on the	Describes revising or editing in detail, explaining how a	Refers to revising or editing in detail, describing specific	Mentions revising, editing, or proofreading

Written & Oral Communication	impact on writing or design process overall or transfer to specific assignments, courses, contexts, genres, or future uses.	discovery and the resulting changes impacted the design or content. Changes are more substantive.	changes to a particular draft. Changes tend toward proofreading rather than substantive revision.	with little or no description of any changes to the draft.
Post-Outlining and Reading Aloud *Written & Oral Communication*	In addition to the Developed stage, reflects on the impact on writing or design process overall or transfer to specific assignments, courses, contexts, genres, or future uses.	Describes how using post-outlining led to making specific changes to a particular piece.	Describes the process of post-outlining accurately or mentions how it affected writing or design.	Mentions post-outlining with little or no description.
Brainstorming *Written & Oral Communication*	In addition to the Developed stage, reflects on impact on writing or design process overall or transfer to specific assignments, courses, contexts, genres, or future uses.	Describes storyboarding, freewriting, outlining, listing, looping, questioning, or other brainstorming in detail, including explorations of discourse community, rhetorical situation, or genre.	Refers to storyboarding, freewriting, outlining, listing, looping, questioning, or other brainstorming in detail. General mention of impact on own writing.	Mentions storyboarding, freewriting, outlining, listing, looping, questioning, or other brainstorming with little or no detail or examples.

Here are examples of phrases in the artifacts that triggered coding on the quantitative rubric:

> Collaboration: “collaboration helps to review writing assignments and allows you to read your writing from a different point of view” - scored as 3.0 on the rubric
>
> Revising & Editing: “move paragraphs around and combine some until I get mentally back to where I was before I stopped writing in the first place” - scored as 2.1 on the rubric
>
> Post-Outlining & Reading Aloud: “write concise outlines” - scored as 2.0 on the rubric
>
> Brainstorming: “lengthy process that includes a brainstorm, an outline and then building from an outline”- scored as 1.5 on the rubric

Analysis of variance (ANOVA) was conducted on each of the four categories of the peer-review process in order to determine how students’ reflections on each category differ across four data points: the beginning and the end of the first, lower-division circle, and the beginning and the end of the second, upper-division circle. In order to determine how time and course intersect with each other to influence student understanding and appreciation of each category, a series of 2x2 factorial ANOVA was conducted.

The four peer-review process categories were treated as interval measures because the coders were allowed to choose any value between each category. The inter-coder reliability was calculated across all the artifacts (r = .85) and within each course (r = .82 WID; .89 Lab) using Pearson's correlation coefficient (see Table 2). Values of 0.7 are typically the minimum standard for reliability in writing studies (Ross & LeGrand, 2017). Given that the reliability for each category ensured sufficient consistency between coders, the average score for each student per category was computed for subsequent analysis.

Table 2. Inter-Coder Reliability

Course	**Peer-Review Process Categories**	**Reliability (r)**
Lower-Division WID Course N = 76	Collaboration	.92
	Revising & Editing	.85
	Post-Outlining	.76
	Brainstorming	.77
	WID Average	**.82**
Upper-Division Lab Course N = 25	Collaboration	.95
	Revising & Editing	.81
	Post-Outlining	.94
	Brainstorming	.87
	Lab Average	**.89**
	Overall Average	**.85**

Qualitative Coding

To determine themes, each reflection paper was coded independently by two coders, using inductive and deductive inference. Descriptive, inductive inference allowed for coders to distinguish patterns: coders began with immersion—reading through all the artifacts—and then identified recurring concepts; then, coders grouped the concepts into patterns (Fereday & Muir-Cochrane, 2006). Subsequently, coders deduced which patterns aligned with the study research questions; and finally, the patterns were synthesized to determine themes for analysis until the data were saturated (Glesne, 2011). The following themes were derived: collaboration, communication process, confidence and transfer of knowledge, and—least frequently—kinesiology as a genre. We decided not to analyze kinesiology as a genre as its own separate theme but instead to subsume it into the communication process theme.

Here are examples of phrases in the artifacts that triggered coding for each qualitative theme:

> Collaboration: "talk about it out loud with my peers" and "have four other people help organize it"
>
> Communication process: "learn how to go into more detail" and "when drafting a paper"
>
> Confidence and transfer of knowledge: "confidence in my abilities to write" and "tools for the future"

The reflections were then coded a final time. In order to perform detailed analysis, the researchers devoted the final stage of coding to the reflections of participants whose written reports in their parallel kinesiology courses had scored the highest in the researchers' connected studies (Kramer et al, 2019 & 2022): 7 upper-division lab course students and 7 lower-division WID course students. This data and methodological triangulation (Denzin, 2008) enables more meaningful analysis: correlating the students' improvements in writing and critical thinking in kinesiology with the same students' reflective comments about how they perceived themselves as communicators and collaborators during their writing circles. The 14 artifacts were coded for quotes that address each theme: collaboration, communication process, and confidence and transfer of knowledge. The content of each theme was analyzed using constant comparison, resulting in interpretation of the data.

Results

Quantitative Results[2]

The mean rubric scores and standard deviations for each category are reported in Table 3; The same mean rubric scores are represented in Figure 1. The frequency with which each rubric category appears in the reflections is reported in Table 4, and the same data are represented in Figure 2.

Collaboration

Students' understanding and appreciation of collaboration significantly increases within each circle, from .47 on a 4-point scale to 2.18 in the first, lower-division circle, and from .52 to 2.33 in the second, upper-division circle (Table 3, Figure 1). In their final reflections, students reflect on collaboration in more depth than in any other category.

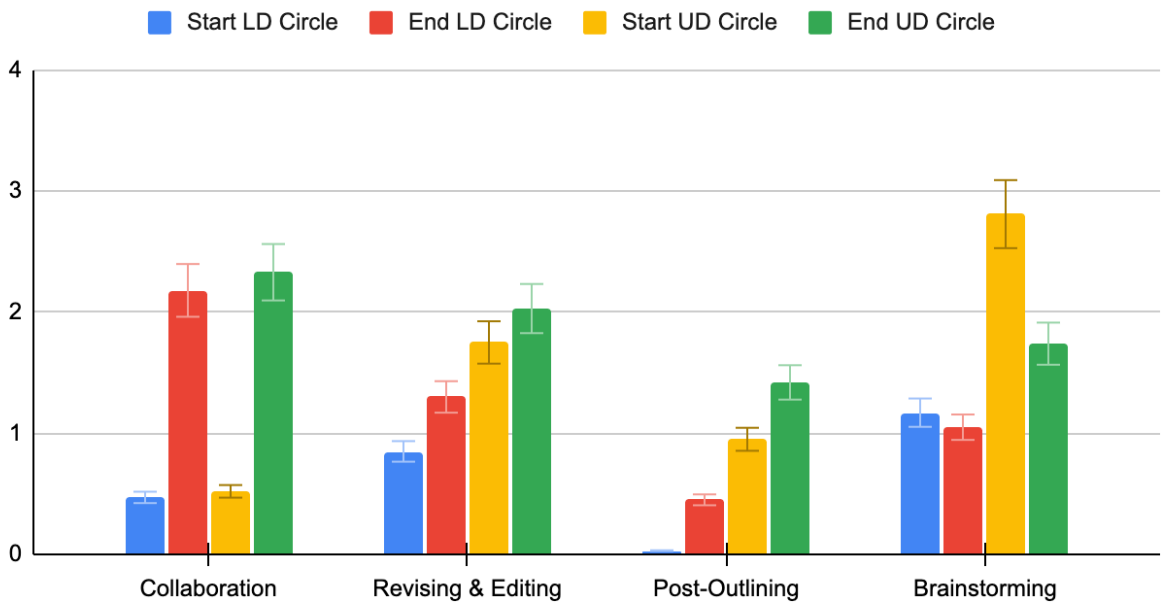

Figure 1: Descriptive Statistics: Depth of Reflection (Mean Rubric Scores)

Brainstorming: Communication Process

Students start their second, upper-division writing circle with a significantly deeper understanding and appreciation of brainstorming (2.81) compared to when they start the first, lower-division circle (1.17). Their understanding and appreciation of brainstorming also increases from the end of the first circle (1.05) to the beginning of the second circle (2.81). However, there is no significant change in the understanding and appreciation of brainstorming within the first circle, and it significantly decreases during the second circle, from 2.81 to 1.74 (Table 3, Figure 1). Students conclude their second circle with an increased understanding and appreciation of brainstorming (1.74) compared to the end of their first circle (1.05).

There is a significant interaction effect between course and time on brainstorming, $F(1, 97) = 8.10$, $p < .01$ (Table 4**)**. There are also significant main effects of course, $F(1, 97) = 48.02$, $p < .001$, and time, $F(1, 97) = 12.57$, $p < .001$, on brainstorming. The significant interaction effect means that time impacts students' understanding and appreciation of brainstorming differently for the first and second circles. Specifically, the decline in the understanding and appreciation of brainstorming is significant for the second circle but not for the first.

Revising & Editing: Communication Process

Students start their second, upper-division circle with a significantly deeper understanding and appreciation of the revision process (1.75) compared to when they start the first, lower-division circle (.85). Understanding and appreciation of the revision process grows within each course, though it does not increase between the end of the first circle and the start of the second. Still, students complete their second circle with greater understanding and appreciation of the revision process than they have at any other time (Table 3, Figure 1).

There are significant main effects of course, $F(1, 97) = 22.74$, $p < .001$, and time, $F(1, 97) = 4.35$, $p < .05$ (Table 4**)**, on revising & editing, meaning that students in their second circle have significantly deeper understanding and appreciation of revising & editing than students in their first circle, and

that students demonstrate significantly deeper understanding and appreciation of revising & editing at the end of each circle compared to the beginning.

Post-Outlining: Communication Process

Students start their second, upper-division circle with a significantly deeper understanding and appreciation of the post-outlining process (.95) compared to when they start their first, lower-division circle (.03). There is no decrease of this understanding between the end of the first circle and the beginning of the second (Table 3, Figure 1). There are significant main effects of course, $F(1, 97) = 27.45$, $p < .001$, and time, $F(1, 97) = 6.01$, $p < .05$ (Table 4**)**, on post-outlining, meaning that students in the second circle have significantly deeper understanding and appreciation of post-outlining than students in the first circle and that students demonstrate significantly deeper understanding and appreciation of post-outlining at the end of each circle.

Qualitative Results[3]

Collaboration

The theme most often discussed throughout the study participants' final written reflections is collaboration (Figure 2):

> Writing down our thoughts is one thing but once you talk it over it's a completely different ball game. … Being able to say your thoughts and have four other people help organize it is amazing. What I think is perfect others think of as sloppy. But once I talk about it out loud with my peers, their suggestions helped my paper flow a little better. (Nora, upper-division student)

> [Peer] feedback helped me to include or exclude information I found that I liked sharing with others, I liked knowing their opinions, and I liked hearing their work as well. Ultimately, it made me more conscious of my writing. … Writing Circles has definitely helped me with getting stuff done in a more timely manner. Part of this is because you obviously cannot hide or expect to "slide through" unnoticed when you do not bring in work for review. (Kip, lower-division student)

Communication Process

Students' final reflections at both levels often discuss collaboration and the writing process together; writing process is the second-most-common theme reflected upon (Figure 2):[4]

> Having a Writing Circle, where my peers were able to give me feedback before turning my reports in, helped me grow as a writer. I was able to see others' writing techniques and apply them to my own writing. … Starting out, my methods section was all over the place, however, towards the last two lab reports, I was able to condense and clarify what exactly we did, and if someone were to recreate our lab [they] could do it based on my methods. (Milo, upper-division student)

> Another strategy that I was able to walk away with from Writing Circles was the ability to further break down the writing prompts of assignments to gain a better understanding of what material would best improve my overall paper as well as give me a general idea of how to approach the overall paper. (Lonnie, lower-division student)

Confidence and Transfer of Knowledge

Students of both levels reflected on affective dimensions of collaboration, particularly how peer review increased their confidence as writers and critiquers, often intertwined with comments about what they might transfer into future situations:[5]

> I will continue to utilize outlining, drafting, and detailed revision skills we used in our Writing Circle, for papers in the future as well. Whether they be lab reports or Seminar essays, these techniques have proven to be helpful for me. (Omar, upper-division student)

> I never used to read my papers aloud, but I definitely see the benefit of doing so and I may continue this practice in the future. (Kip, lower-division student)

Discussion

These quantitative and qualitative findings offer insights into how students experience facilitated, iterated peer review and what impacts the students perceive writing circles to have on learning, specifically related to the study's research questions: How and to what extent did participants' expressed understanding of communication and collaboration change from the start to the end of circles? How and to what extent did participants' expressed understanding of communication and collaboration differ in lower-division circles compared to upper-division circles? How and to what extent did expressions of confidence differ in lower-division circles compared to upper-division circles?

The findings provide context for the evidence in connected studies of the same students' work within parallel kinesiology courses. In Kramer et al. (2019 & 2022), data analyses reveal improvements in these students' writing and critical thinking skills during writing circles, including how the iterated peer review impacted the students' work differently at the beginning and the end of their undergraduate disciplinary development. The current study's assessment of the students' circle-written reflection papers, therefore, provides insight into how and why the students' writing and critical thinking improved in the kinesiology courses they took in tandem with the circles lab.

Collaboration

In their writing circle reflection papers, the study participants reflect substantially on growing as collaborators, in both their own skills and their appreciation for each other as experts. The theme most often discussed in participants' final reflections is collaboration and the ways in which it contributes to learning (Figure 2). Of the final reflections, 93% address collaboration in some way, with 27% of those reflections scoring a developed or highly developed on the rubric.

Self-Efficacy

Study participants discuss appreciating their peers' contributions by realizing that peer review improves their own writing and their ability to critically analyze texts. These findings help explain and extend some research in education and STEM which demonstrates that collaborative work can increase students' self-efficacy through multiple, interacting sources such as mastery experience and social persuasion (Aikens & Kulacki, 2023; Fencl & Scheel, 2005; Usher & Pajares, 2008). As did the physics students in Fencl & Scheel's (2005) study, our participants reflect that cooperative learning increases their self-efficacy, while also improving their academic self-concept, or how they perceive themselves (Shavelson et al., 1976). In our study participants' reflective writing, there are many

phrases that indicated a growth in self-efficacy, such as upper-division student Joan's remark, at the end of a reflection about reading her drafts aloud to peers, that circles have "helped me become a stronger writer."

Peer feedback enhances academic self-concept in writing for students in STEM (Simonsmeier et al., 2020). The role of evaluative judgment features prominently here, with feedback impacting one's self-concept. Bong and Skaalvik (2003) suggest that feedback can act as a precursor to stronger, more stable self-concepts. Positive self-concepts allow students to feel less anxious in achievement settings and experience more enjoyment in academic work, while persisting longer at tasks and feeling better about themselves (Bong & Skaalvik, 2003).

Appreciating Readerly Response

Our study participants reflect that the collaborative experience of live readerly response helps them realize that their intended meaning is not always received by their audience. "Writing down our thoughts is one thing but once you talk it over it's a completely different ball game. … Being able to say your thoughts and have four other people help organize it is amazing," reflects upper-division student Nora, adding, "What I think is perfect, others think of as sloppy. But once I talk about it out loud with my peers, their suggestions help my paper flow a little better." Such comments also add context to Roscoe and Chi's (2008) conclusions that getting ideas out is an important aspect of learning. And as did the biology students of Aikens & Kulacki's (2023) study, our participants reflect that group discussion increases their willingness to seek help from peers.

Learning Critiquing Skills

Throughout our data, there is evidence that as students share and co-construct ideas, they simultaneously become more open to self-evaluation and reflection. This adds context to meta-analyses, such as Huisman et al.'s (2019) argument that students improve their writing more when they give and receive formative feedback from peers than when there is no peer feedback. Students view the skills and the collaborative process as supporting each other. The participants of our study reflect amply about learning critiquing skills during the structured and learned discussion of writing circles: "I have realized there is a correct way to edit and suggest ideas that will allow people to feel comfortable and come back for more help if they need," lower-division student Jon writes. "I found when I remained in a neutral tone as well as added something positive after a critic that they responded well."

Engaging More Deeply with Disciplinary Concepts

When some students reflect on learning how to analyze others' drafts, they include the dimension of realizing what they themselves are learning through doing. Lower-division student Bud writes: "I learned that when I help others and talk about their papers, it helps me understand the topic better. I also learned to analyze things more in depth." This indicates learning in terms of subject-matter knowledge and critical thinking. And his peer Max reflects, "Before this Writing Circle, I would cut my ideas off too soon, but through talking about it, I was able to learn how to go into more detail." These reflective comments about analyzing in more depth and going into more detail align with Halim et al.'s (2018) findings that WTL assignments coupled with peer review are useful for "engaging in a social knowledge-building process" (p. 2) that prompts students to address their own or their peers' misconceptions or elucidate new conceptions, as they write in more detail and engage more deeply with disciplinary concepts. In our study, student comments such as Bud's and Max's show that they understand and value iterated peer review as a useful tool for encouraging students to engage in

more in-depth analysis, helping them understand concepts better and offer more detailed and accurate explanations.

Managing Time and Goals

The weekly schedule and expectations of writing circles have practical benefits for time management, students say. As lower-division student Kip reflects, "Writing Circles has definitely helped me with getting stuff done in a more timely manner. Part of this is because you obviously cannot hide or expect to 'slide through' unnoticed when you do not bring in work for review." Upper-division student Mari reflects, "I think I made good use of this Writing Circle by keeping myself on track with my assignments and bringing in my work to look at frequently." And her peer June reflects on how improved planning impacts her work: "I have been more organized and on task this semester. With having such important lab reports, I am completing what I need to do sooner and have time to send it to other people for review, which therefore helps me improve my report." These comments align with findings from Chaktsiris & Southworth (2019) that suggest peer-review offers benefits for personal time management.

Our study participants' comments also support theories of self-regulation. Zimmerman and Risemberg's (1997) social cognitive model of writing self-regulation, which proposes ten strategies of self-regulation for writing, aligns with at least seven strategies that are routinely practiced in writing circles. These include strategies for time management and goal setting as well strategies for self-evaluation of one's work. As students become more self-regulated, their writing self-efficacy also increases. The self-efficacy or confidence gained contributes to their further growth as students set more difficult goals and expend more effort to meet the demands of more challenging writing tasks.

Research has further demonstrated that self-regulation rarely happens in solitude but often in collaborative learning or learning from peers (Greene et al., 2023). Research also suggests that the process model that writing circles employ, involving learning and practicing specific writing and revising methods and tools, is more effective for developing self-regulated writers. For example, Schunk & Swartz (1993) demonstrate that a process-oriented writing goal where fifth-grade students learn strategies for writing, coupled with progress feedback, is more effective at building students' writing self-efficacy than product-oriented or general goals. As Greene et al. (2023) describe, students may gain strategies for self-regulating their processes through new writing, editing, and revising strategies, such as understanding and incorporating feedback from peers, planning their texts through outlining, and managing their time. The semester-long iterated peer review of circles provides a way for students to learn about, incorporate, and practice strategies that enhance their capacity for self-regulation.

Role of Instructor Versus Peer

While our study participants of both levels reflect at length about collaborating with peers, only lower-division students reflect on the roles of instructor and peer. It is possible that younger students define more sharply the division between themselves and their instructors and therefore are more likely to view a peer environment as more relaxed.

The lower-division students reflect on a certain comfort that builds during writing circles, thanks to a perceived absence of judgment. "In class, I would feel intimidated when my professor would ask about my research papers. However, in Writing Circles, I felt more comfortable sharing my work because we were in a smaller group. … I learned that it is helpful to receive feedback from peers along with a professor," writes Fry. And peer Jon writes similarly of the circle environment: "I found my Writing Circle to be a very calm, open, relaxed place where everyone was there to help each other, not judge each other."

Communication Process

The data reveal steadily increasing awareness and appreciation for post-outlining and other revision tools throughout writing circles, as per both the frequency (Table 4, Figure 2) and depth (Table 3, Figure 1) of references to post-outlining in the students' initial vs. final course reflections. The mentions of brainstorming, however, are fewer in the final than initial reflections (Table 4, Figure 2). Discussions of collaboration and revising and editing often overlap in the final reflections: revising and editing is the second most common category reflected upon, with 89% of reflections addressing it, following collaboration, with 93% (Table 4, Figure 2). Students in both lower-division and upper-division circles reflect that by learning how to collaboratively review peers' work—putting post-outlining-based discussion into practice week after week—they improve their own communication skills. Their reflections help explain the demonstrated improvements in the reports these same students wrote for their kinesiology courses (Kramer et al., 2019 & 2022).

Students commingle reflecting about several aspects of creating and revising communication, including learning revision strategies, adding steps in the drafting process, and expanding considerations of brainstorming.

Brainstorming

The brainstorming scores decline in both depth and frequency from start to finish in both lower- and upper-division writing circles. In the upper-division circles, the drop is precipitous, with depth scores falling by more than 33%, after spiking 168% between the end of the lower-division circles and the start of upper-division circles (Table 3, Figure 1). We consider expectations as an explanatory factor. For example, the relatively low scores and little change from start to finish of the lower-division circles suggest that students went in with fairly modest expectations of the role that brainstorming would play, and then found those expectations were born out by the end; that is, they did not think in depth about brainstorming to start, and they still did not at the end. This makes sense because in many courses—outside of writing circles—brainstorming is one of only very few drafting tools suggested and is offered primarily for prewriting and individual work.

Our data show that during circles, students develop other tools—expanding their repertoire—and therefore brainstorming becomes less prominent. Furthermore, the students' reflections at the end of each circle show that they learn to use brainstorming not to begin solitary writing but in a collaborative context—specifically, working together to improve the ideas in a draft.

Post-Outlining

Post-outlining, because it is a method created by Kramer, founding CWAC director, and further developed throughout its use in CWAC, was unfamiliar to most students before they enrolled in writing circles. Accordingly, only 0.02% of the reflections from the start of the lower-division circles mention post-outlining (Table 4, Figure 2). By the end of those circles, however, more than half (51%) of the reflections address it. This threshold is sustained through the initial and final reflections of the upper-division circles, at 53% and 54% respectively (Table 4, Figure 2). This further shows the students are not forgetting the method between the end of the lower-division circles lab and the beginning of the upper-division lab, even though a year might have transpired.

In addition to the consistent, significantly elevated frequency of reflection on post-outlining, students describe their understanding and appreciation for the method with ever-increasing depth and detail, indicating a growing facility and confidence in its application. Specifically, post-outlining rubric scores steadily grow in quality throughout the circle sequence, from .03 at the start of lower-division

circles to 1.42 by the end of upper-division circles (Table 3, Figure 1), which shows the students are learning, understanding, and consistently applying the method.

Some students discuss how they now incorporate post-outlining into all of their writing. Upper-division student Mari describes key steps of the method:

> My writing process has changed in that I organize the essay much better and more distinctly. … I now incorporate new strategies like highlighting my main ideas and making sure that everything connects back to my thesis or prompt. I make sure to go back to the requirements to ensure I have everything needed.

Her peer Joan writes, similarly, that

> one of the most important tools that I learned to use when drafting a paper was the ability to look at each paragraph that I am writing and asking myself, what is the main point of this paragraph? When attending my circle we went over ways in which to keep my writing organized such as going in and labeling with different colors a significant idea or argument from each paragraph.

Expanding One's Own Writing Process

There are many ways in which students credit the collaborative peer review with not only improving the drafts at hand but also expanding their individual processes of writing. The writing circle experience "helped me grow as a writer. I was able to see others' writing techniques and apply them to my own writing," reflects upper-division student Milo. We view this and similar reflections by other students as signs of growth as autonomous learners. Such reflections speak to the writing self-efficacy gained from vicarious experiences through observation of the work of peers, including using another's draft as a model for one's own writing improvement, a finding also explored by van Blankenstein et al. (2019).

Interpreting Prompts

Lower-division student Ave talks about co-occurring realizations—building in drafting steps and deconstructing assignment prompts—"As a writer, I usually just waited until the last moment to do my writing, and with this semester and the help of the Writing Circle, I have changed the way I attack my paper, … and getting an extra hour per week to look at the prompt really helps to start the writing process." Other students reflect on learning the benefits of post-outlining guidelines for assignments:

> Another strategy that I was able to walk away with from Writing Circles was the ability to further break down the writing prompts of assignments to gain a better understanding of what material would best improve my overall paper, as well as give me a general idea of how to approach the overall paper. (Lonnie)

Growing as Disciplinary Insiders

The unique purposes and audiences of kinesiology communication become more clear to students through weekly peer reviews. Lower-division students frequently reflect on how peers help them learn how to improve kinesiology communication skills, but mostly generally so, such as in the treatment of definitions. As lower-division student Manny says, "Just simple guidance or tips on how to expand a certain section really had a positive impact on my writing." By contrast, upper-division students reflect more specifically, indicating they view their peers as authorities in the discipline and welcome the sharing of genre and subject matter knowledge. Upper-division student Milo writes that

"details within the lab reports became stronger." Because they trust each other's authority, the upper-division students listen to each other's discipline-specific contributions.

Such writing circle reflections of upper-division students help explain students' growth in critical thinking in parallel kinesiology courses, as revealed through Kramer et al. (2019 & 2022). The current study's qualitative data adds explanatory context also to the comparisons in Kramer et al. (2022), which reveal growth in critical thinking but no change in writing skills between the lower-division and upper-division kinesiology courses. As others have suggested (Condon & Kelly-Riley, 2004), if critical thinking increases, writing clarity can decrease. Therefore, our triangulated study data, illustrating increases in critical thinking but no accompanying change in writing, are encouraging on the writing side, as well: upper-division students who collaborate with circle peers deepen their critical thinking without a decline in writing performance.

Confidence and Transfer of Knowledge

Our results show that students perceive confidence and their skills to be increasing together. These results triangulate with the results of Kramer et al. (2019 & 2022) to correlate the students' reflections on perceived improvements with their actual, assessed improvements in kinesiology writing.

Increasing Confidence as Communicators

The students' reflections on learning to critique include direct or indirect references to affective dimensions of peer review; in fact, affect is a thread woven throughout the reflections. Lower-division student Bud extends his reflection on learning to analyze work by also mentioning increased confidence in his contributions to others' learning, such as through post-outlining: "I learned that I could also help my peers structure their papers. It is now one of my strengths to outline papers and help people organize them." By experiencing their feedback being well-received by peers, students gain confidence and are more likely to step fully into collaboration.

Many of this study's participants not just implicitly but also overtly reflect on ways in which implementing new skills improves their confidence, indicating awareness of this connection. "I think I became a better writer. I still need to work on my grammar and syntax, but I do feel more confident in how I write, which is amazing," upper-division student Finn says. Similar comments are evident in the artifacts from both groups of participants. Lower-division student Lonnie writes, "I now have a higher confidence in my abilities to write a concise and informative paper." And her peer Jon reflects that he learned to be less timid about requesting feedback, adding that "after this Writing Circle, I feel much more confident with my writing ability and what my peers think of my writing skills."

Some students reflect on how the peer review helped them gain confidence through repeated practice and realizations about strengths they had already developed. As upper-division student Mari reflects, "This Writing Circle helped confirm my strengths in writing such as having many ideas and writing in a way that keeps my audience's attention." She is referring to the circle emphasis on considering purpose and audience.

Increasing Trust and Comfort with Feedback

The affective environment of writing circles is also mentioned directly by students. Feelings of timidity and resistance to criticism change for some students as they experience positive feelings through writing circles, which inspire more confidence in writing ability. As lower-division student Jon reflects,

> one weakness that improved for me was my ability to let people give me criticism on my work. … I was timid to show my work but after this Writing Circle I feel much more confident with my writing ability and what my peers think of my writing skills. … What I learned about peer dialogue throughout this semester is that people need to give it a chance. … I found my Writing Circle to be a very calm, open, relaxed place where everyone was there to help each other, not judge each other.

This validates and aligns with Chandler's (2007) focus on the emotional aspects of composition and the study of emotion as socially experienced and a type of discourse.

Our data also extends Bharuthram and van Heerden's (2023) findings that peer review produces mostly positive feelings in students and can generate trust. In circles, peers come to trust each other to maintain a positive environment, free of judgment. This allows them to experience criticism as constructive, and to build confidence in their own writing abilities.

Communities of Practice

We view such comments as aligning with research in collaborative pedagogy, particularly structured learning environments that are activity-based and learner-centered, which have been shown to improve academic achievement and academic self-concept in disciplines such as chemistry (Agwu & Nmadu, 2023) and physics (Fencl & Scheel, 2005). Community of practice theory (CPT) offers a way to understand how circles function to promote learning and transfer as they contribute to students' understanding of identity and practice across time periods. As Wenger-Trayner explains, CPT "is an attempt to place the negotiation of meaning at the core of human learning, as opposed to merely the acquisition of information and skills. And for human beings, a central drive for the negotiation of meaning is the process of becoming a certain person in a social context" (qtd. in Farnsworth et al., 2016, p. 145).

Through the sharing of techniques for organizing, editing, and writing, in a social setting where peers meet regularly, iterated peer review is an intervention that increases student beliefs about the value of practicing writing, writing strategies, and exchanging feedback. CPT thus helps explain students' perceptions of writing circles and the confidence boost which can accompany circle participation.

Increasing Confidence in the Writing Process

Our participants' references to increased confidence in both writing ability and engaging in peer feedback add evidence that peer review can impact writing ability and appreciation for peer feedback in STEM courses. Geithner and Pollastro (2016), surveying students in a scientific writing course, found that repeated practice with peer review increases student perceptions of their ability to provide peer feedback and incorporate feedback in rewriting and revising.

Our results show why a student's sense of increased confidence comes with increased understanding of techniques to analyze and work through drafts. Lower-division student Max reflects specifically about gaining enough confidence to modify his drafting process: "Before taking this circle, I used to write everything down by hand. While it was effective, it took a long time. Now, I am comfortable enough to just hand write the outline and then work my way through the paper on the computer. It is just as effective and much faster."

Transferring Writing and Critiquing Skills

During thematic analysis, a finding we had not anticipated arose: the students reflected often on transferring aspects of the writing and critiquing processes they learned during writing circles into

their later kinesiology courses as well as their repertoire as communicators generally. In a similar way, Harland et al. (2016) found that, among other findings, students see opportunities to transfer their experience of peer review to other contexts by seeking help and helping friends with their academic writing projects. In our study, there are many general references to transferring skills beyond the current situation. Lower-division student Max reflects, for instance: "Before Writing Circles, I used to be very singular in my approach because it was what I felt most comfortable with. But I have learned that there are different approaches that I can take that can make writing my papers a lot less stressful."

A few participants reflect overtly about applying their new skills in future situations, illustrating critical thinking. Lower-division student Lonnie writes that her writing circle experience "taught me a lot of new useful skills that I plan on implementing in my future writing … to expand the range of approaches that I can take when it comes to writing a paper." Likewise, her peer Kip reflects on reading aloud for the first time, during his circle, and considers whether to use that practice in other situations: "I definitely see the benefit of doing so and I may continue this practice in the future." Other students in both courses also reflect on continuing their new skill of reading aloud intentionally. "Whenever I write a paper, I will always want to read my paper aloud to someone else, especially when finishing a draft," reflects upper-division student Joan, concluding that "Writing Circles helped me to pick up valuable tools for the future." All of these students' comments illustrate that they have thought about applying their new skills in future contexts. We view these as direct references to transfer of knowledge.

While students at both levels reflect on transferring skills, upper-division students reflect in more specific terms. Omar's reflection, for example, illustrates thinking about both particular skills and particular situations: "I will continue to utilize outlining, drafting, and detailed revision, skills we used in our Writing Circle, for papers in the future as well, whether they be lab reports or Seminar essays, (because) these techniques have proven to be helpful for me."

The reflections illustrate Wenger's (1998) application of the theory of community of practice – with a shared repertoire of routines, tools, actions, and ways of doing things that are produced or adopted by a community over time. As students participate in writing circles week after week, they negotiate meaning with one another, pursue common goals, and share a repertoire of tools and techniques based on their learning and practice of post-outlining and discussion skills. The objects around which meaning is negotiated and organized, as per Wenger's theoretical model, are drafts that circle students produce in response to their kinesiology course assignments, the assignments themselves, and the post-outlining notes that they and their circle peers construct on drafts, increasing all of the circle members' (the community of practice's) understanding of disciplinary content, rhetoric, and collaboration skills.

Conclusions

This multi-year study shows that writing circles (or a similar weekly, facilitated peer-review model) are useful because they teach strategies for collaborative discussion and effective critique, while offering practice through which students experience growth over time as colleagues in their discipline. Other studies, such as Reddy et al. (2020), suggest the need for training and guiding peer review, and the need for its repetition over time. Through circles, peer review is regular enough and involves enough training and facilitation to impact student writing and critical thinking significantly (Kramer et al. 2019 & 2022). Accordingly, we recommend that iterated, structured, and facilitated peer review be a component in STEM courses, particularly WTL courses with the learning outcome of growth in ability to research and communicate in the discipline.

Iterated peer review, practiced in intervals throughout a semester and repeated in lower- and upper-division courses, addresses the need to negotiate meaning within a social context, by supporting students' identity development as writers, reviewers and practitioners within their discipline.

The benefits of peer review manifest differently earlier in the major compared to later, as evidenced in the kinesiology reports assessed in Kramer et al. (2019 & 2022) and now correlated by the same students' writing circle reflective papers analyzed through the current study. Early in their academic careers, as the study participants' reflections show, students view each other as consultants on general writing and research guidelines; they seek peer feedback on clarity and basic organization, for instance. But by the end of their studies, students realize that they and their peers are nascent experts in the discipline; they therefore seek each other's feedback on terminology, genre conventions, and other insider knowledge. Based on these results, we recommend that STEM courses lean into such realities at the two stages: focusing on general scientific communication skill development (i.e., organization and syntax) for lower-division students, and focusing on discipline-specific thinking and communication considerations (i.e., scientific methodology and description) for upper-division students.

Through our study participants' reflections, we see that iterated, reciprocal peer review groups have the effect of enhancing self-efficacy and self-concept—increasing confidence in writing, collaboration, and disciplinary knowledge, as described by van Blankenstein et al. (2019). This makes it possible for students to gain comfort and more readily accept constructive criticism of their writing without harming their disciplinary self-concept, described by Shavelson et al. (1976).

Additionally, we find notable that while the writing circle reflections of upper-division students include comments that point to students' perceived improvements in critical thinking, there was no accompanying decrease in writing clarity in these same students' kinesiology reports (Kramer et al., 2019 & 2022), as might be expected when complexity increases. Even as upper-division students grapple with deeper and more discipline-specific ideas, they simultaneously help each other, during writing circles, organize and clarify their report structures and wording. The weekly, multifaceted peer discussion helps students grow as thinkers, communicators, and contributors in their discipline.

Each institution could consider how to structure writing circles. At Saint Mary's, the circles are 1-credit lab courses, taught by adjuncts or graduate students. The circle students earn a Pass or Fail grade based on their labor—whether they attend regularly, bring drafts as determined by their disciplinary course syllabi, and write circle reflection papers. Some of our circles are required for the major; others are optional. At other institutions, circles could be structured to fit the context. Important foundations for effectiveness, we believe, are that the peer review is facilitated, is iterated (frequent and regular), and incorporates accountability (such as labor-based Pass/Fail).

Writing circles are intended to help students grow as critical thinkers and communicators in time-constrained and content-rich disciplinary courses. Evidence of circle participants' improvements in writing and critical thinking is already illustrated in assessments of reports produced within kinesiology courses (Kramer et al., 2019 & 2022). Now, by analyzing reflections written by the same students during their companion circles, the current study offers signposts for why such improvements occur. The students reflected on learning to rely on both themselves and their peers as expert insiders. This study illustrates students' perceptions of their growth as collaborators in their field, and how their perceived growth promotes transfer of communication strategies and increases their confidence.

Limitations

Because of timing in the semester, the initial writing circle prompt asks students to reflect on themselves as writers entering the circles, whereas the final prompt asks students to reflect on their circle experience. By revising the initial and final reflection prompts to include identical questions, more comparisons could be conducted. An additional limitation is the lack of a control group: it could be helpful to assess two sections of the same course—one with writing circles, and the other with peer review but not the structure, frequency, or methodology of circles.

Future Research

We suggest continuing to investigate pedagogies to help students both grow and position themselves as critical thinkers and communicators in STEM disciplines. Although this study analyzes students' reflections at the start and end of writing circles, the most revealing results pertain to what students say they learned by the end of each circle and why they chose to reflect more on some themes than on others.

We envision two potential pathways for future research: first, it would be helpful to determine how many peer-review sessions are needed to achieve similar results, given that it might not always be possible to hold weekly sessions or to create partial-credit companion labs, also known as writing circles. Would it be effective, for instance, to incorporate circles into already-scheduled science labs every other week? Other researchers have found that too few sessions have little impact (i.e., Armstrong & Paulson, 2008; Bangert-Drowns et al., 2004). We hypothesize that there is a minimum number of iterated sessions needed to produce improvements, and we wonder what that minimum is.

Second, along the lines of Bottia et al.'s (2021) review of research, we hypothesize that iterated peer review could help improve the retention of students from underrepresented demographic groups in STEM fields. Bottia et al. argue that positive interaction through peer review have an important and predictable influence on the persistence and graduation of racial and ethnic minority STEM students. Therefore, studying the disciplinary coursework and writing circle reflections produced by BIPOC STEM students could be illustrative.

Appendix A: Quantitative Data Tables

Table 3. Descriptive Statistics: Depth of Reflection (Rubric scores)

Course	Time	Collaboration	Revising & Editing	Post-Outlining	Brainstorming
Lower-Division WID Course	Beginning (N = 37)	M = .47 SD = .57	M = .85 SD = .54	M = .03 SD = .12	M = 1.17 SD = .53
	End (N = 39)	M = 2.18 SD = .77	M = 1.30 SD = .84	M = .45 SD = .76	M = 1.05 SD = .78
Upper-	Beginning	M = .52	M = 1.75	M = .95	M = 2.81

Division Lab Course	(N = 13)	SD = .69	SD = .53	SD = 1.01	SD = .62
	End (N = 12)	M = 2.33 SD = 1.19	M = 2.03 SD = 1.11	M = 1.42 SD = 1.51	M = 1.74 SD = 1.10

Table 4. Descriptive Statistics: Frequency with which reflections addressed each category

Course	Time	Collaboration	Revising & Editing	Post-Outlining	Brainstorming
Lower-Division WID Course	Beginning (N = 37)	43%	74%	0.02%	90%
	End (N = 39)	96%	82%	51%	70%
Upper-Division Lab Course	Beginning (N = 13)	34%	96%	53%	100%
	End (N = 12)	91%	96%	54%	91%

Appendix B: Qualitative Data

Example student comments coded as Collaboration.

Collaboration: Upper-Division Students
"Writing down our thoughts is one thing but once you talk it over it's a completely different ball game. … Being able to say your thoughts and have four other people help organize it is amazing. What I think is perfect others think of as sloppy. But once I talk about it out loud with my peers, their suggestions helped my paper flow a little better." Nora
"My Writing Circle helped me because I was able to bounce ideas off of my peers and see if what I have written made sense to someone reading it from the outside. They were able to help me decide if I needed to cut anything out or add anything to my lab reports to ensure they were as polished as they could be." Omar
"It is nice to have a second (or multiple) set of eyes on my writing to notice things that I cannot see for myself. For example I may think something and think I am explaining it well in writing but I need someone else to tell me that it doesn't make sense to them so I can rephrase it to read better. … I think I made good

use of this writing circle by keeping myself on track with my assignments and bringing in my work to look at frequently." Mari
"I have been more organized and on task this semester. With having such important lab reports, I am completing what I need to do sooner and have time to send it to other people for review, which therefore helps me improve my report." June
"I think one of the most valuable tools that Writing Circles has to offer is peer on peer evaluation on papers. It is one of the most sincerely helpful tools that has helped me as a writer." Joan
Collaboration: Lower-Division Students
"(Peer) feedback helped me to include or exclude information I found that I liked sharing with others, I liked knowing their opinions, and I liked hearing their work as well. Ultimately, it made me more conscious of my writing. … Writing Circles has definitely helped me with getting stuff done in a more timely manner. Part of this is because you obviously cannot hide or expect to 'slide through' unnoticed when you do not bring in work for review." Kip
"I have realized there is a correct way to edit and suggest ideas that will allow people to feel comfortable and come back for more help if they need. I found when I remained in a neutral tone as well as added something positive after a critic that they responded well." Jon
"Before this Writing Circle, I would cut my ideas off too soon, but through talking about it, I was able to learn how to go into more detail." Max
"I learned that when I help others and talk about their papers, it helps me understand the topic better. … I also learned to analyze things more in depth." Bud
"In class, I would feel intimidated when my professor would ask about my research papers. However, in Writing Circles, I felt more comfortable sharing my work because we were in a smaller group. … I learned that it is helpful to receive feedback from peers along with a professor. I felt that none of us judged each other, so it was never intimidating when we had to share our work." Fry

Example student comments coded as Communication Process.

Communication Process: Upper-Division Students
"Having a Writing Circle, where my peers were able to give me feedback before turning my reports in, helped me grow as a writer. I was able to see others' writing techniques and apply them to my own writing. … Starting out, my methods section was all over the place, however, towards the last two lab reports, I was able to condense and clarify what exactly we did, and if someone were to recreate our lab [they] could do it based on my methods." Milo

"[O]ne of the most important tools that I learned to use when drafting a paper was the ability to look at each paragraph that I am writing and asking myself what is the main point of this paragraph? When attending my Circle we went over ways in which to keep my writing organized such as going in and labeling with different colors a significant idea or argument from each paragraph." Joan
"My writing process has changed in that I organize the essay much better and more distinctly. … I now incorporate new strategies like highlighting my main ideas and making sure that everything connects back to my thesis or prompt. I make sure to go back to the requirements to ensure I have everything needed." Mari
Communication Process: Lower-Division Students
"Another strategy that I was able to walk away with from Writing Circles was the ability to further break down the writing prompts of assignments to gain a better understanding of what material would best improve my overall paper as well as give me a general idea of how to approach the overall paper." Lonnie
"Just simple guidance or tips on how to expand a certain section really had a positive impact on my writing." Manny
"As a writer, I usually just waited until the last moment to do my writing and with this semester and the help of the Writing Circle, I have changed the way I attack my paper. I have been able to plan ahead of time and getting an extra hour per week to look at the prompt really helps to start the writing process." Ave
"Before taking this circle, I used to write everything down by hand. While it was effective, it took a long time. Now, I am comfortable enough to just hand write the outline and then work my way through the paper on the computer. It is just as effective and much faster." Max

Example student comments coded as Confidence and Transfer of Knowledge.

Confidence and Transfer of Knowledge: Upper-Division Students
"I will continue to utilize outlining, drafting, and detailed revision skills we used in our Writing Circle, for papers in the future as well. Whether they be lab reports or Seminar essays, these techniques have proven to be helpful for me." Omar
"I think I became a better writer. I still need to work on my grammar and syntax, but I do feel more confident in how I write which is amazing." Finn
"This Writing Circle helped confirm my strengths in writing such as having many ideas and writing in a way that keeps my audience's attention." Mari

"Whenever I write a paper, I will always want to read my paper aloud to someone else … to hear feedback and if my ideas are coherent. It is also very helpful to me when I read aloud my papers because I hear my own sentences and I am able to read aloud any mistakes that I write. Overall, Writing Circles has helped me to pick up valuable tools for the future and has helped me become a stronger writer." Joan
Confidence and Transfer of Knowledge: Lower-Division Students
"I never used to read my papers aloud, but I definitely see the benefit of doing so and I may continue this practice in the future." Kip
"Before Writing Circles, I used to be very singular in my approach because it was what I felt most comfortable with. But I have learned that there are different approaches that I can take that can make writing my papers a lot less stressful. … (The Circle) taught me a lot of new useful skills that I plan on implementing in my future writing. … I now have a higher confidence in my abilities to write a concise and informative paper. … I have also acquired the skill to expand the range of approaches that I can take when it comes to writing a paper. … I definitely see the benefit of (reading aloud) and I may continue this practice in the future." Lonnie
"One weakness that improved for me was my ability to let people give me criticism on my work. … I was timid to show my work but after this Writing Circle I feel much more confident with my writing ability and what my peers think of my writing skills. … What I learned about peer dialogue throughout this semester is that people need to give it a chance. … "I found my Writing Circle to be a very calm, open, relaxed place where everyone was there to help each other, not judge each other." Jon

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[2] Please see Appendix A for descriptive quantitative data.

[3] Please see Appendix B for additional examples of qualitative data.

[4] Additional examples are found in Appendix B.

[5] Additional examples are found in Appendix B.

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