Writing to Engage in Multivariate Calculus: Students' Perceptions of Math, Writing, and the Curriculum[1]

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Abstract: Writing-related activities have long been identified as supporting students' mathematics mastery and overall math success (Bahls, 2012). To further understand student experiences using writing in college math coursework, the present mixed-methods study explored the perceptions of a group of students (*N* = 55) in Multivariate Calculus who encountered writing-to-engage (WTE) assignments (Palmquist, 2020) at a four-year university in the midwestern USA. Pre- and post-course survey results suggest student preferences for technical and transactional writing over other forms, statistically significant positive movement away from skeptical thinking about math and math instruction, and enhanced perceptions of students' writerly selves and student perceptions that the course was relevant for future careers.

Important variables involved in mathematics mastery include cognitive understanding and self-efficacy beliefs (Bahls, 2009). Meanwhile, writing-related activities have long been identified as supporting students' mathematics success (Bahls, 2012). Scholars have identified writing as a potentially powerful experience to help individual students process math concepts in isolated courses, and experts on the issue of writing and math have noted the personal, national, and even global benefits of quantitative literacy (Feigenbaum, 2015), which, according to Miller (2010), integrates skills that students encounter in English composition, mathematics, and other disciplines and represents an increasingly essential habit of mind and set of skills for meaningful participation in a skilled workforce. The present mixed-methods study enters the conversation by measuring and exploring the perceptions of a group of students (*N* = 55) in multivariate calculus at a four-year university in the midwestern United States who encountered writing-to-engage assignments (Palmquist, 2020). The goal of this project was exploratory, to better understand the nature of students' engagement with a set of assignments used to support positive perceptions of the class, the curriculum, and the use of writing in math.

Writing across the curriculum (WAC) pedagogy has traditionally been described along a continuum, with writing-to-learn (WTL) activities and experiences toward one end of the continuum and writing-in-the-disciplines (WID) activities and experiences toward the other (McLeod, 1992,2000; Emig, 1977). Recently, Palmquist (2020) further detailed this continuum to include a middle ground, writing to engage (WTE). Drawing on a version of Bloom's taxonomy (Bloom, 1956) modified by Anderson and Krathwohl (2001), Palmquist (2020) added reflecting as a cognitive activity (see Figure 1).

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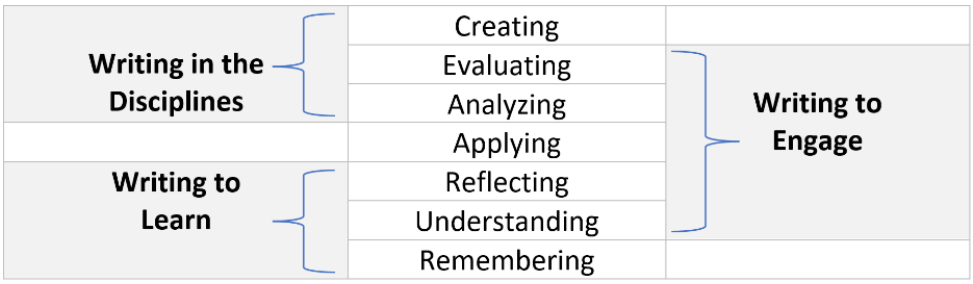

Figure 1: Cognitive Skills and a WAC-Approach Continuum

For Palmquist, WTE does more than traditional WTL activities but stops short of the composing of genres, like peer-reviewed journal articles or research posters, meant for public dissemination and circulation among discipline-relevant insiders. For Palmquist, WTE accomplishes more than assisting in understanding or remembering: WTE also supports reflection, application of theory to data, and analysis of data sets or other complex information. It is writing that draws on key rhetorical and cognitive moves found within publishable genres but positions those moves more or less as classroom-contained practice.

Further assisting in categorizing the types of writing students may encounter in college, Britton et al. (1975) categorized writing assignments as transactional, expressive, or poetic in their germinal and still-helpful work: transactional writing asks students to report, summarize, analyze, and theorize; expressive writing challenges writers to more intimately and personally use writing to understand ideas through feeling and reasoning; and poetic writing includes the composing of traditional literary genres, such as poetry, fiction, creative nonfiction, and drama. In his influential monograph that explored thousands of writing assignments from 400 courses across 100 US colleges, Melzer (2014) concluded that most assignments used in college were, perhaps at the expense of flexible rhetorical knowledge development, transactional rather than expressive or poetic. When writing is used, and when WAC pedagogy is involved, most of that writing is transactional.

Writing has long been used in math and continues to represent a viable complementary element for math instruction across primary and secondary education. Schmidt (1985,2012) concluded decades ago that, while writing may not ensure learning or liking of math, it allows for more communication between teacher and student. Estes (1989) likewise argued that math could indeed be taught with writing, and the three main types of writing were "ordinary narrative, technical writing, and the writing of proofs" (p. 10). While Estes's conclusion may be said to support mainly transactional writing, Russek (1998) argued for additional space for expressive writing: while writing has long been essential in math, Russek argued that journaling and asking students to write reflectively about math and problem solving represented newer trends and applications of writing. Indeed, scholars have drawn parallels between aspects of math and aspects of writing, with Jamison (2000) arguing that "making the syntactical and rhetorical structure of mathematical language clear and explicit to students can increase their understanding of fundamental mathematical concepts" (p. 45). Speaking from the viewpoint of a math professor using English as an additional language, Flesher (2003) likened learning to write about math to learning to communicate in another language. Additionally, Flesher reflected on the assessment affordances of using writing in math instruction: "I had never had such complete information about each individual student's knowledge of the topic before a test until I began using writing to learn" (p. 44). Arguments, then, have abounded for years that WAC approaches, in particular WTL and WTE, have a place in math instruction, with types of writing generally being transactional and perhaps at times approximating a kind of expressive writing.

In addition to practice-informed argumentation by instructors, empirical studies have underscored relationships between writing and math success. In one study asking what rhetorical devices were used by math undergrads as they began to write research articles in their discipline, Bahls et al. (2011) identified rhetorical devices in the mathematical writing of students (N = 16) in a summer research experience program at a U.S. university. Shared rhetorical conventions were identified between English composition and math in students' writing, including transition use, style and tone, visual rhetoric, and source use.

Writing does more than facilitate mathematical communication; it also mediates intellectual grappling with math concepts. In a study addressing this issue, Craig (2016) asked how the writing of explanatory strategies in the context of mathematical problem solving impacted, if at all, students' problem-solving behavior. In the study, which took place in the author's first-year math course involving mostly calculus, students experienced a 12-week intervention in the second of two semesters. Students (N = 39) wrote explanations of how they solved problems and gave them to tutors, resulting in 155 writing samples. Considering the data through Piaget's theory of cognitive development, Craig concluded that students perceived writing as forcing them to confront incomplete understanding of problems. Writing about how to solve a problem, then, may lead to deeper understanding of concepts and problem-solving behavior. In another, similar study, Elder and Champine (2016) explored what impact WTL assignments had, if any, on students' perceptions and success in a Survey of Math class for non-STEM majors and a Calculus I class for STEM majors at one university. The students (N = 36) completed pre-surveys for demographic information and math perceptions and experience before completing WTL activities. Post-surveys about how the activity related to learning were followed by end-of-semester focus groups. Student class performance was also explored via assignments, tests, and grades. Students were equally divided into two groups, a writing and non-writing group. In the findings, 33-56% of students agreed WTL helped their learning; 22-47% were not sure; and 18-26% disagreed. Memo-writing assignments were most preferred, as it reportedly forced students to explain their procedures, but no statistically significant impact was measured when WTL score was measured for association with grades. Qualitative analysis suggested that high-impact math writing activities are ones that ask students to write about procedural knowledge or analyze problem-solving processes. Thus transactional writing (Britton et al., 1975) may be seen by students and practicing math professors as most relevant.

While the above studies mainly covered transactional and expressive writing in math, Bahls (2009) asked how poetry, as an alternative poetic discourse, enabled students to explore mathematical ideas. To answer the question, Bahls asked Calculus 1 students to write poems about their math experiences. Bahls gave feedback on first drafts before asking for final drafts, and students identified the theme of their poems. A survey measured student experiences with the assignment. Analyzed through the framework in which cognitive understanding and confidence represented important variables impacting math mastery, the findings included poetry seemingly offering a new conceptual lens based on linguistic metaphorical thinking that helped students consider and reconsider mathematical concepts. In Bahls' (2009) words, "writing poetry emboldens students and gives them confidence by allowing them a more familiar idiom in which they can express themselves mathematically" (p. 79).

In summary, then, WAC approaches—with writing that is transactional, expressive, or poetic—may have potential to help students engage at deeper levels with math concepts. Writing may also be expected to help learners identify what they know or need to learn, both conceptually and procedurally.

The Present Study

The study being reported here used a mixed-methods approach. Participants (N = 55) in Multivariable Calculus completed pre-intervention survey scales and, during the course, completed three writing assignments: a review of a previous student assignment, a formal report incorporating multilinear regression and multivariable optimization, and an open-ended assignment where participants created their own assignment for future courses.

The first writing assignment had students review a formal report from a previous term. Students were given the assignment prompt, student work, and a rubric. After summarizing the report and checking the mathematics used for correctness, students reported on what aspects of the writing they liked, what they believed could be improved, and used the rubric to assign a grade to the writing. This first assignment allows for students to be exposed to an IMRaD style report that can be written in a math class and take away uncertainty about writing what the professor wants.

Next, a formal report assignment prompted students to compose a letter from a fictionalized company asking them to answer a question as if they were a consulting firm. (An assignment used in this study is included in Appendix C.) In this assignment, students were asked by a coffee company to find the optimal distribution of coffee types to be included in a package subject to shipping constraints. This problem required the use of techniques from multivariable calculus and multilinear regression to answer properly. A notable inclusion in this assignment was the data provided by the company to the students. This required students to use regression to first fit a function to the data and then use multivariable calculus techniques with the function. The goal was to help students see the connections between the world of data analytics/statistics and the calculus techniques in the course. Moreover, the instructor hoped that the inclusion of the data/regression step helped students view the problem as less contrived and as a more real-world problem they might see in the future.

The final assignment asked students to create their own writing assignment prompt for a future course. At this point in the semester, students had seen a couple prompts in their assignments and were shown a few others to prepare. Students did not have to solve the problem they designed in their writing prompt, but the prompt had to require techniques from the course. The assignment asked students to make connections between the material they were learning and a recent experience or a personal interest. The assignment allowed for creativity, and the goal was to reinforce connections between the material covered in class and its applicability outside of class.

Table 1: Scales Used Pre- and Post-Intervention

Pre-Intervention	Post-Intervention
1. Perception of Math	1. Perception of Math
2. Perception of Curriculum – Adapted from Davidson et al. (2009)	2. Perception of Curriculum
3. Writerly Self-Efficacy – Adapted from Schmidt and Alexander (2012)	3. Writerly Self-Efficacy
4. --	4. Engagement – Adapted from Busselle and Bilandzic (2009)
5. --	5. Perception of Course

Research Questions

The following research questions guided inquiry:

1. Is there a difference between perceptions of math pre- and post-intervention?
2. Is there a difference between perceptions of the curriculum pre- and post-intervention?
3. Is there a difference between writerly self-efficacy pre- and post-intervention?
4. What are students' engagement levels with writing assignments?
5. What are students' perceptions of the course?
6. What kind of writing do students in Multivariate Calculus express preferring and why?
7. What kind of writing do students in Multivariate Calculus perceive as most relevant and why?

Methods

This study was issued exempt status by the Institutional Review Board of the University of Wisconsin-Stout. All interactions with participants and participant data were guided by the basic ethical principles outlined in The Belmont Report (1979)—respect for persons, beneficence, and justice.

Participants

Student participants were enrolled at a comprehensive, public, career-focused four-year polytechnic university of approximately 7,700 (about 6,600 undergraduates). The university is a predominantly White university, with 85% of students institutionally categorized as "White/Caucasian" and with 54% of its students designated as "male."

Of 55 responding participants, 17 (31%) reported being math majors, with 38 (69%) being non-math majors. Forty-eight (87%) identified as male, 6 (11%) as female, and 1 (2%) preferred not to answer. Six (11%) were first-year students, 18 (33%) were sophomores, 20 (36%) were juniors, and 11 (20%) were seniors. Regarding ethnicity, 50 (91%) identified as White, 4 (7%) Asian, 1 (2%) Hispanic/Latin@, and 1 (2%) Two or More Races.

Data-Analysis Procedure

The appropriate statistical tests were run based on assumptions and research question. Statistical significance was measured with an $\alpha = 0.05$ threshold, and effect sizes are reported as small, medium, or large using conventional thresholds of $r = 0.2, 0.5, 0.8$ (Cohen, 1992). For open-ended replies, a constant-comparative method was used (Glaser & Strauss, 1967,2012), whereby the data was perused in a stage of pre-coding, then analyzed with the assistance of NVivo. Codes were collaboratively created between this study's two co-authors (Smagorinsky, 2008) and applied to the data with a correlation coefficient of .852, indicating reliable agreement.

Results

In this section, data is organized by research question. In the discussion section of the report, these findings are considered in the context of existing and potential future scholarship.

Perceptions of Math Pre- and Post-Intervention

Research Question 1 asked whether there was a difference between perceptions of math pre- and post-intervention. Survey question results are shown in Table 2 and Figure 2 below. Results show some improvement in the perception of how mathematics problems are approached with a small-to-moderate effect size. There is not much statistical evidence for a change in perception of how writing can impact the learning of mathematics.

Table 2: Survey Question Statistics About Students' Perceptions of Math

Survey Question	Pre-course mean	Pre-course median	Post-course mean	Post-course median	p-value	Effect size
1) Math problems can be done correctly in only one way.	2.11	2.0	1.6	2.0	0.018	0.32
2) Good mathematics teachers show you the exact way to answer the math questions you'll be tested on.	2.94	3.0	2.31	2.0	0.012	0.31
10) In general, writing about a subject is an effective way to learn the subject.	3.6	4.0	3.66	4.0	0.83	0.03
11) Writing is helpful for really learning how to apply math in the real world.	3.51	4.0	3.77	4.0	0.079	0.21

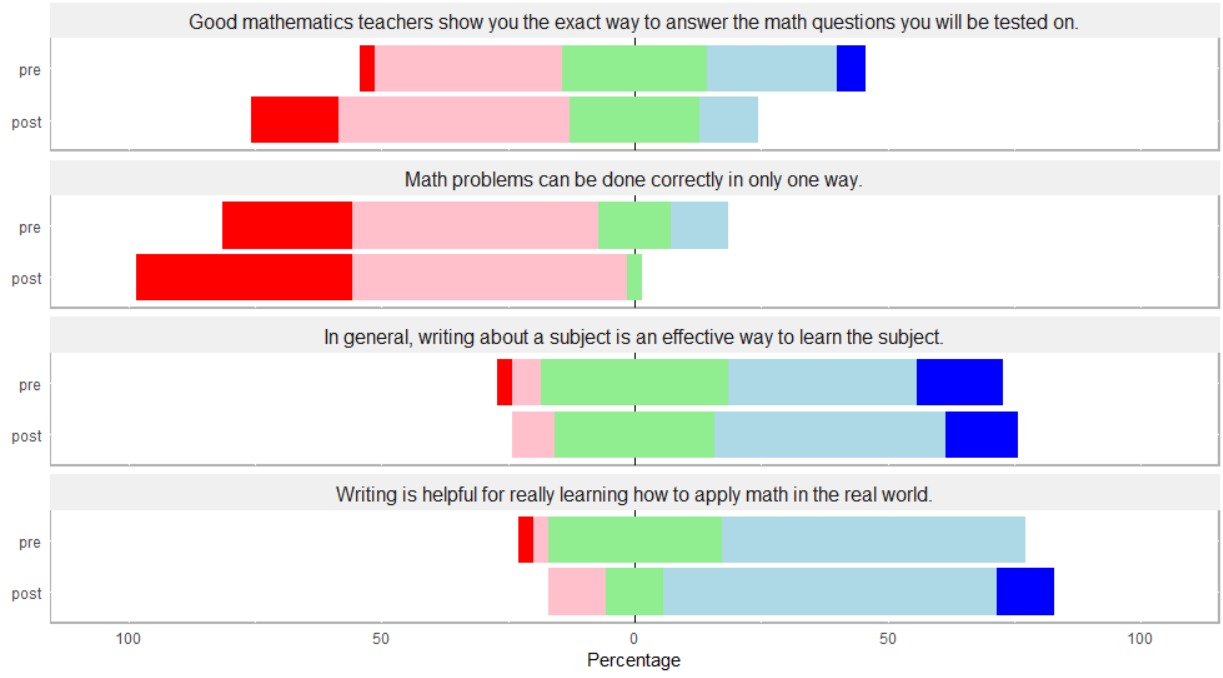

Figure 2: Pre- and Post-Course Results of Students' Perceptions of Math

Perceptions of the Curriculum Pre- and Post-Intervention

Research Question 2 asked whether there was a difference between perceptions of the curriculum pre- and post-intervention. Survey item results related to this research question are shown in Table 3 and Figure 3. Descriptive statistics and results from Wilcoxon signed rank tests show that students understand the importance of this course in their curriculum at the beginning of the course and this perception did not change by the end of the course.

Table 3: Survey Questions Statistics About Students' Perception of the Curriculum

Survey Question	Pre-course mean	Pre-course median	Post-course mean	Post-course median	p-value	Effect size
3) I understand why this course is part of my academic program.	4.23	4.0	4.31	4.0	0.70	0.05
7) I see a strong connection between what I am learning in this class and my future career possibilities.	3.69	4.0	4.03	4.0	0.11	0.19
8) This class is important to help me be successful in my major.	4.09	4.0	4.09	4.0	0.91	0.01
9) This class is important to help me be successful in my possible future career paths.	3.80	4.0	3.97	4.0	0.45	0.09

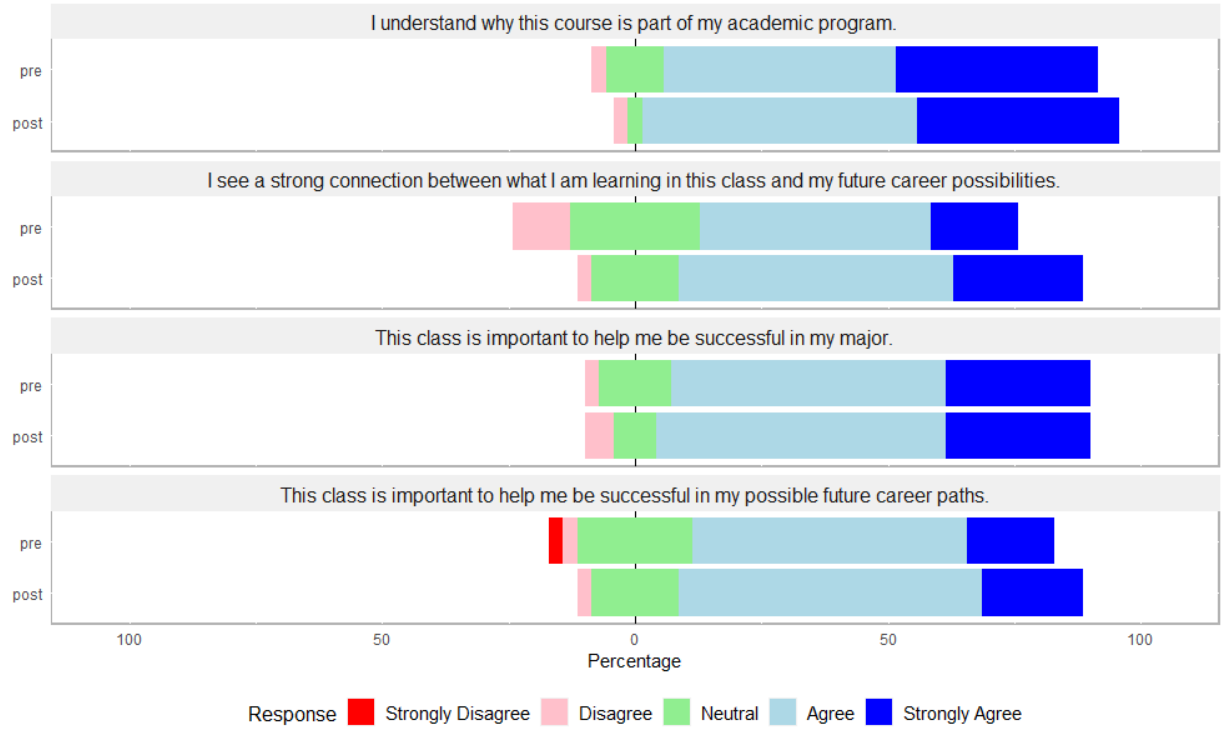

Figure 3: Pre- and Post-Course Results of Students' Perceptions of the Curriculum

Perceptions of Writerly Self-Efficacy Pre- and Post-Intervention

Research Question 3 asked whether there was a difference between writerly self-efficacy pre- and post-intervention. Survey item results related to this research question are shown in Table 4 and Figure 4. Results of Wilcoxon signed rank tests do not show much statistical evidence for changes in students' perceptions of themselves as writers pre-course to post-course.

Table 4: Survey Question Statistics About Students' Perceptions of Their Writing Ability

Survey Question	Pre-course mean	Pre-course median	Post-course mean	Post-course median	p-value	Effect size
4) I can articulate my strengths and challenges as a writer.	3.44	4.0	3.6	4.0	0.35	0.11
5) I can be recognized by others as a strong writer.	2.86	3.0	2.94	3.0	0.66	0.05
6) I can write a paper without experiencing overwhelming feelings of fear or distress.	3.26	3.0	3.43	4.0	0.20	0.15

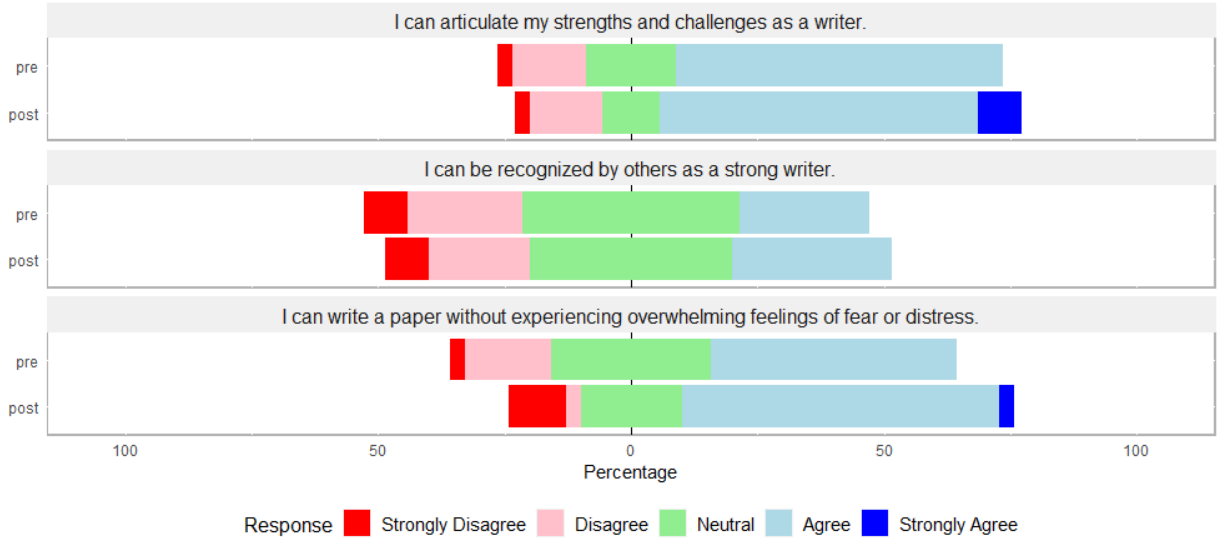

Figure 4: Pre- and Post-Course Results of Students' Perceptions of Their Writing Ability

Measurements of Engagement With Writing Assignments

Research Question 4 asked about students' engagement levels with writing assignments. Survey item statistics for this question are shown in Table 5 and Figure 5. Results show that students generally agree that the course required deeper thinking beyond memorization of a correct formula and plugging values into that formula. However, results also show that while students did perceive themselves as using deeper thinking than memorization, they did not go so deep as to lose themselves into the assignments. They were very much aware that they were writing an assignment for a math class.

Table 5: Survey Question Statistics About Student Engagement With Assignments

Survey Question	Mean	Median	SD
18) My math class really required me to think about what I was doing rather than just plugging numbers into formulas	4.31	4.0	0.80
20) This course required much more thinking than memorization.	4.23	4.0	0.73
23) At times when working on webwork assignments, my body was in the room where I was writing, but my mind was in the world created by the assignment.	2.89	3.0	0.92
19) During this course, I could do some of the problems, but I had no clue as to why I was doing them.	2.91	3.0	0.95
22) While writing, my body was in the room where I was writing, but my mind was in the world created by the assignment.	2.83	3.0	0.92
21) At times while writing this assignment, I completely forgot that I was writing for a math class.	2.11	2.0	0.83

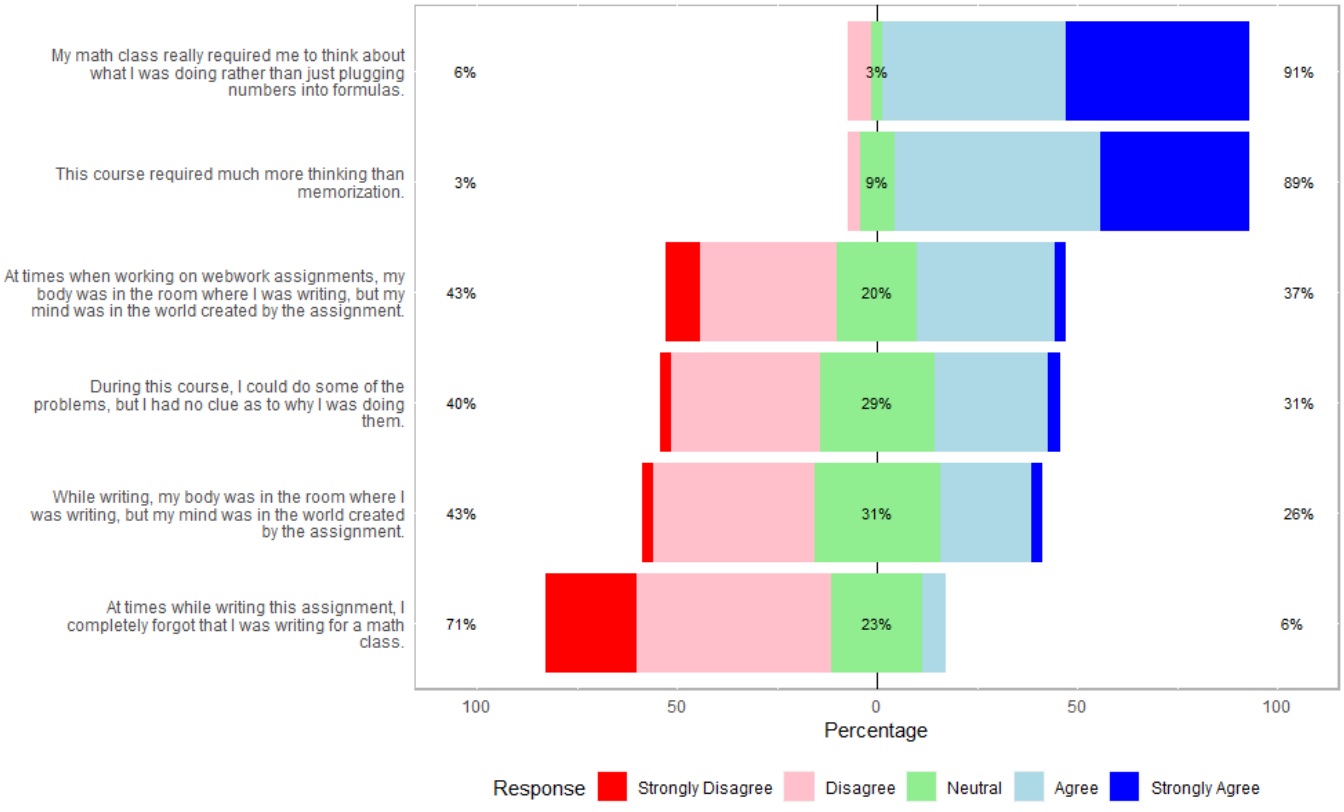

Figure 5: Post-Course Results About Student Engagement With Assignments

Measurements of Perceptions of the Course

Research Question 5 asked about students' perceptions of the course. Survey results in Table 6 and Figure 6 show good student perceptions of the course, with agreement for positive prompts and disagreement with negative prompts. While general agreement is seen in the utility of the course, it

is interesting to note that there is slightly decreasing agreement in the prompts about the usefulness of the course after college: for instance, usefulness for enabling a student to apply course ideas in the real world and usefulness for solving problems in non-mathematics courses.

Table 6: Survey Question Statistics About Student Perceptions of the Course

Survey Question	Mean	Median	SD
16) This course gave me thinking and problem-solving skills.	4.09	4.0	0.51
13) I believe that what I've learned in this course will be useful to me after college.	4.23	4.0	0.60
14) I feel that I can apply what I've learned in this course to real world problems.	3.97	4.0	0.75
12) I've applied what I've learned in this course to my work in non-mathematics courses.	3.46	4.0	0.98
17) This course was too abstract, not practical enough.	2.46	2.0	0.92
15) I see no practical use for what I've learned in this course.	1.89	2.0	0.76

Writing Preferences

Research Question 6 asked students what kind of writing in Multivariate Calculus they preferred and why. Qualitative coding of open-ended surveys enabled us to address this question.

In Table 7 below, we organize coding results regarding the preferences students reported when asked about writing.

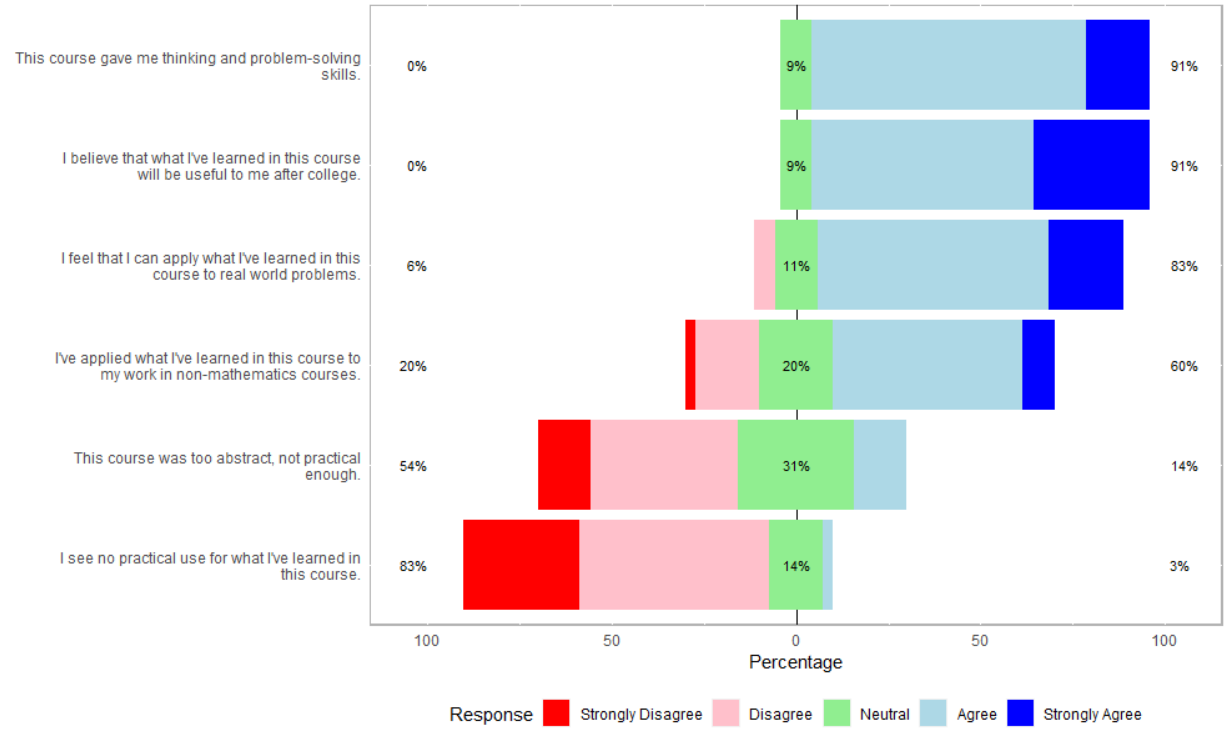

Figure 6: Post-Course Results About Students' Perception of the Course

Table 7: Pre-Intervention Responses About Writing in Math Preferences

12) If writing is used in Math, what kind of writing would you prefer and why?				
Code		**Frequency/51 (%)**		**Examples**
1.**Transactional**: Responses identifying a preference for formal academic writing featuring activities ranging from copying, to analyzing, to theorizing (Britton et al., 1975; Melzer, 2014).	1a. **Explanatory**: Writing to explain how a math problem was solved.	31 (60.8%)	12 (38.7%)	"Reasoning behind your answers because then you have to explain the process in your own words, which leads to better understanding."
	1b. **Real-World**: Writing to apply math concepts to real-world situations.		9 (29%)	"I would prefer writing that would help me see how it can be applied in the real world."
	1c. **Technical**: Writing explained as "technical."		3 (9.7%)	"Technical writing because it is precise, and it is the type of writing I will hopefully use in my career."
	1d. **Proof**: Proof writing in math.		3 (9.7%)	"Proofs are solid examples of writing used in mathematics."
	1e. **Gen. Academic**: Writing covering general academic activities, such as lab reports, research, or summarizing.		4 (12.9%)	"Research papers or projects, because they allow you to expand on what you already know."
2. **As Long as It's Short**: Responses relaying a desire to write only short compositions in Math.		8 (15.7%)		"I would prefer short paragraphs or short essays covering small topics opposed to learning large topics then having to write a long essay."
3. **Against Writing in Math**: Responses relaying an attitude against any kind of writing in Math.		7 (13.7%)		"I don't think writing should be in math."
4. **Expressive**: Responses identifying a preference for writing that lets writers express unique positions or work out thoughts (Britton et al., 1975; Melzer, 2014).		3 (5.9%)		"Possibly on my way of solving a difficult integral problem or something like that where I can explain my point of view."
5. **No Preference**: Responses relaying no preference regarding what to write in Math.		2 (3.9%)		"I have no preference."

Most participants identified transactional-type writing as aligned with their writing preferences. Other noteworthy answers were that the writing had to be short or non-existent in math. In Table 8 below, we organize coding results regarding the preferences students reported when asked about writing post-intervention.

Table 8: Post-Intervention Responses About Writing in Math Preferences

24) If writing is used in Math, what kind of writing would you prefer and why?				
Code		**Frequency/33 (%)**		**Examples**
1. **Transactional**: Responses identifying a preference for formal academic writing featuring activities ranging from copying, to analyzing, to theorizing (Britton et al., 1975; Melzer, 2014).	1a. **Explanatory**: Writing to explain how a math problem was solved.	24 (72.7%)	7 (29.2%)	"Explanation of why certain mathematical findings relate to the problem."
	1b. **Real-World**: Writing to apply math concepts to real-world situations.		5 (20.8%)	"I enjoy writing assignments where we apply what we are learning or have learned in the past to a real world problem."
	1c. **Technical**: Writing explained as "technical."		5 (20.8%)	"Technical writing because it'll apply to my future career."
	1d. Proof: Proof writing in math.		0 --	--
	1e. **Gen. Academic**: Writing covering general academic activities, such as lab reports, research, or summarizing.		7 (29.2%)	"I like the report-based writing where we need to research small components of our issue."
2. **Writing That Was Used in This Class**: Responses explicitly identifying the writing done over the semester as what they would like to write in Math.		7 (21.2%)		"I would say that the writing used in this course is the kind of writing I would prefer."
3. **As Long as It's Short**: Responses relaying a desire to write only short compositions in Math.		1 (.03%)		"I like the one paper a semester approach. I think it's enough writing in a math class to know how important it is in the future."
4. **Against Writing in Math**: Responses relaying an attitude against any kind of writing in Math.		0 --		--
5. **Expressive**: Responses identifying a preference for writing that lets writers express unique positions or work out thoughts (Britton et al., 1975; Melzer, 2014).		0 --		--
6. **No Preference**: Responses relaying no preference regarding what to write in Math.		1 (.03%)		"I have no preference."

As can be seen, transactional writing remained the top response for students' writing preferences; however, gone were responses coded as against math. Instead, more students identified "writing done in this class" as the kind of writing they preferred in math.

Writing Relevancy Perceptions

Research Question 7 asked what kind of writing students in Multivariate Calculus perceived as most relevant and why. Qualitative coding of open-ended surveys enabled us to address this question.

In Table 9 below, we organize coding results regarding the students' perceptions of relevant writing for them pre-intervention.

Table 9: Pre-Intervention Responses About Perceptions of Relevant Writing[2]

5) What kind of writing do you believe is most relevant to your major?				
Code		**Frequency/53 (%)**		**Examples**
1. **Transactional**: Responses identifying a preference for formal academic writing featuring activities ranging from copying, to analyzing, to theorizing (Britton et al., 1975; Melzer, 2014).	1a. **Explanatory**: Writing to explain how a math problem was solved.	47 (88.7%)	13 (27.7%)	• "Explanation on how you came to a certain decision or solution." • "to be able to explain and idea to someone with simple instructions"
	1b. **Technical**: Writing explained as "technical."		12 (25.5%)	• "Technical." • "I believe technical writing would be most relevant to my major."
	1c. **Gen. Academic**: Writing covering general academic activities, such as lab reports, research, or summarizing.		9 (19.1%)	• "Research papers" • "Academic" • "Summarizing" • "MLA format essays"
	1d. **Scientific**: Writing described as scientific or involving reporting of a scientific process.		3 (6.4%)	• "project reports and scientific papers"
	1e. **Coding**: Writing identifying coding as a type.		3 (6.4%)	• "A lot of coding"
	1f. **Proof**: Writing identifying proof writing in Math.		3 (6.4%)	• "Proofs"
	1g. **Blueprint**: Writing of blueprints.		2 (4.3%)	• "I would say blueprints that can only be interpreted one way"
	1h. **Email/Business**: Writing in genres related to or for business.		2 (4.3%)	• "Professional letters and email"
2. **No Preference**: Responses relaying no preference regarding what to write in Math.		5 (9.4%)		• "Not sure" • "I do not have a major"
3. **Poetic**: Responses identifying a creative or literary genre, such as poetry, fiction, or creative nonfiction, as relevant (Britton et al., 1975; Melzer, 2014).		1 (1.9%)		• "The ability to write and create stories"

Most participants again overwhelmingly identified transactional-type writing as aligned with their views of the kind of writing that is relevant. In Table 10 below, we organize coding results regarding the perceptions of relevancy for writing post-intervention.

Table 10: Post-Intervention Responses About Perceptions of Relevant Writing[3]

27) What kind of writing do you believe is most relevant to your major?				
Code		**Frequency/39 (%)**		**Examples**
1. **Transactional**: Responses identifying a preference for formal academic writing featuring activities ranging from copying, to analyzing, to theorizing (Britton et al., 1975; Melzer, 2014).	1a. **Explanatory**: Writing to explain how a math problem was solved.	34 (87.2%)	9 (26.5%)	• "Describing how a system works and justifying why we went with the design we did"
	1b. **Technical**: Writing explained as "technical."		8 (23.5%)	• "Technical Writing" • "Technical"
	1c. **Gen. Academic**: Writing covering general academic activities, such as lab reports, research, or summarizing.		7 (20.6%)	• "Reports" • "Academic" • "research outlines"
	1d. **Scientific**: Writing described as scientific or involving reporting of a scientific process.		3 (8.8%)	• "Project reports and scientific papers."
	1e. **Coding**: Writing identifying coding as a type.		0 --	--
	1f. **Proof**: Writing identifying proof writing in Math.		2 (5.9%)	• "Proofs that explain the steps to solve a problem"
	1g. **Blueprint**: Writing of blueprints.		0 --	--
	1h. **Email/Business**: Writing in genres related to or for business.		5 (14.7%)	• "Email, letters and more collaborative writing."
2. **No Preference**: Responses relaying no preference regarding what to write in Math.		3 (7.7%)		• "Practical assignments that apply some of the topics we've gone over and how the topics work."
3. **Poetic**: Responses identifying a creative or literary genre, such as poetry, fiction, or creative nonfiction, as relevant (Britton et al., 1975; Melzer, 2014).		1 (2.6%)		• "creative writing"
4. **Writing That Was Used in This Class**: Responses explicitly identifying the writing done over the semester as what they find relevant.		1 (2.6%)		• "what we did in class, was beneficial. Working with designers and engineers during the summer and winter months, this is exactly what we do on a weekly basis with customers."

As can be seen, transactional writing remained the top response for students' perceptions of transactional writing as relevant.

Summary of Findings

1. Regarding participants' perceptions of math,
    a. Binary perceptions of math as correct or incorrect diminished significantly into more nuanced perceptions;
    b. Expectations that a math instructor explicitly instruct how to do problems correctly also diminished significantly; but,
    c. Perceptions of math as helpful in everyday life did not change significantly.
2. Regarding participants' perceptions of the curriculum they studied in, no significant changes were measured.
3. Regarding participants' writerly self-efficacy, no significant changes were measured.
4. Regarding engagement with the writing process, participants did not report levels of engagement that could be described as flow states (Csikszentmihalyi, 2008).
5. Regarding perceptions of the individual course, participants reported seeing the class as practical for success in other classes and their everyday life.
6. The type of writing participants reported preferring—and seeing as most practical—in math can be described as transactional (Britton et al., 1975).

Discussion

Importantly, the findings in this study are not meant to be generalizable; instead, we aim for findings that prove transferable (Guba & Lincoln, 1981), meaning findings instructors of writing, math, and other disciplines may find applicable to other settings with other participants. Here, we attempted to measure through mixed methods the perceptions of undergraduates who encountered writing in multivariate calculus coursework. Our study featured a pre-/post-intervention design sequence, with methods of data collection gathering quantitative and qualitative information from participants' self-reports. We sought to address seven exploratory research questions, asking whether a statistically significant difference would appear between (a) perceptions of math, (b) perceptions of the curriculum, and (c) writerly self-efficacy. We also sought to describe quantitatively and qualitatively (a) the engagement participants reported regarding these writing assignments, (b) their perceptions of the course, as well as their (c) preferences and (d) perceptions of the kind of writing that should or could be included in college-level multivariate calculus. Though our inquiry was broad, we hope to have added detail to Palmquist's (2020) definition of WAC's middle ground: WTE.

For Palmquist (2020), as noted earlier, WTE represents a sort of middle ground between WTL and WID or learning-to-write. For Palmquist, WTE supports reflection, application of theory to data, and analysis of data sets or other complex information. Here, we present some evidence suggesting that WTE in multivariate calculus, for this sample of undergraduates, has the potential to change learners' perception of both writing and math coursework. In addition, while the writing intervention seems complementary for learning and engagement with the world, there was less evidence that the writing necessarily changed learners' self-efficacy beliefs as writers or prompted the kind of engagement perhaps more common in poetic (i.e., creative) or autobiographical writing

(Nicholes, 2016). Poetic writing, however, was not apparently perceived as either relevant or preferred among this sample. Instead, a clear trend of participants valuing transactional writing (Britton et al., 1975) is reported.

What makes these findings especially noteworthy, we argue, is the statistically significant movement participants reported regarding their perceptions of math in binary terms (correct, incorrect) and the role of math instructors to explain correct approaches to complete math problems. Viewed through the lens of Perry's (1999) stages of development, these movements show evidence that students are moving away from dualism and toward multiplicity. Whether this was related to writing or positive experiences in the class cannot be teased out of the results at this time, but this raises interesting questions to be explored in future studies. Another noteworthy finding is that participants reporting coming to see the class as more relevant and worth their time.

While ultimately raising additional questions, these findings extend earlier scholarship on WTE and writing to support persistence in college. First, our findings, albeit exploratory in nature, add some additional empirical evidence to clarify possible outcomes associated with WTE (Palmquist, 2020). Though future studies will be required to fill in the picture, here it seems possible that a preliminary description of WTE is not so much that students learn math content (which WTL accomplishes as well) but that participants engage both with content and with the field and its relationship to participants' present and future lives. This, then, adds to another possible outcome of WTE relevant to college persistence efforts. That is, here we provide some evidence suggesting that WTE helps learners see the relevance of the course they are taking. Perceptions of the curriculum remains an important variable used to explain the larger picture of college-student persistence (Tinto, 2017).

This study's methodological strengths included the collection of a wide range of information. This helped us to explore writing and a number of possible outcomes in multivariate math. Of course, our findings here have to be considered in light of the study's limitations. Self-reported data must always be understood as participant performance and not naively reflective of how participants feel. The sample size is also small, opening the door to errors and a host of possible lurking variables we were unable to capture in this single study. We urge future studies to build on this work. For instance, studies at multiple institutions or across larger samples and timeframes would help fill gaps. In addition, qualitative studies on the phenomenon of writing in math seem warranted to fill in the picture of the emotional and cognitive experience we attempted to measure in broad, exploratory strokes here.

Appendix A: Pre-Intervention Survey

1. Rate how much you agree with these statements:

   (5 = Strongly Agree, 4 = Agree, 3 = Neither Agree Nor Disagree, 2 = Disagree, 1 = Strongly Disagree)

- Math problems can be done correctly in only one way. [Perception Math 1]
- Good mathematics teachers show you the exact way to answer the math questions you'll be tested on. [Perception of Math 2]
- I understand why this course is part of my academic program. [Perception of Curriculum 1]
- I see a strong connection between what I am learning in this class and my future career possibilities. [Perception of Curriculum 2]
- This class is important to help me be successful in my major. [Perception of Curriculum 3]

- This class is important to help me be successful in my possible future career paths. [Perception of Curriculum 4]
- I can articulate my strengths and challenges as a writer. [Writerly Self-Efficacy 1]
- I can be recognized by others as a strong writer. [Writerly Self-Efficacy 2]
- I can write a paper without experiencing overwhelming feelings of fear or distress. [Writerly Self-Efficacy 3]
- In general, writing about a subject is an effective way to learn the subject. [Perception of Writing in Math 1]
- Writing is helpful for really learning how to apply math in the real world. [Perception of Writing in Math 2]

2. If writing is used in Math, what kind of writing would you prefer—and why?
3. What is your desired future career?
4. What is your major?

- Math
- Non-Math _____

5. What kind of writing do you believe is most relevant to your major?
6. What year are you in college?

- First Year
- Sophomore
- Junior
- Senior

7. How do you self-identify regarding gender?

- -Male
- -Female
- -Non-binary/third gender
- -Prefer not to say

8. How do you self-identify regarding ethnicity?

- White/Caucasian
- African American/Black
- Asian
- Hispanic/Latin@
- American Indian/Alaskan Native
- Hawaiian/Pacific Islander
- Two or More Races _____-
- International

- Prefer Not to Answer

9. What best describes your course format for Calculus 1?

- In-Class Face to Face
- Online Synchronous (with scheduled face-to-face online time)
- Online Asynchronous (without specific online meeting times)
- Hybrid (half in-class face to face, half online)

10. What best describes your course format for Calculus 2?

- -In-Class Face to Face
- -Online Synchronous (with scheduled face-to-face online time)
- -Online Asynchronous (without specific online meeting times)
- -Hybrid (half in-class face to face, half online)

Appendix B: Post-Intervention Survey

1. Rate how much you agree with these statements:

   (5 = Strongly Agree, 4 = Agree, 3 = Neither Agree Nor Disagree, 2 = Disagree, 1 = Strongly Disagree)

- I've applied what I've learned in this course to my work in non-mathematics courses. [Perception of Course 1]
- I believe that what I've learned in this course will be useful to me after college. [Perception of Course 2]
- I feel that I can apply what I've learned in this course to real world problems. [Perception of Course 3]
- I see no practical use for what I've learned in this course. [Perception of Course 4]
- This course gave me thinking and problem-solving skills. [Perception of Course 5]
- This course was too abstract, not practical enough. [Perception of Course 6]
- My math class really required me to think about what I was doing rather than just plugging numbers into formulas. [Perception of Course 7]
- During this course, I could do some of the problems, but I had no clue as to why I was doing them. [Perception of Course 8]
- This course required much more thinking than memorization. [Perception of Course 9]
- Math problems can be done correctly in only one way. [Perception of Math 1]
- Good mathematics teachers show you the exact way to answer the math questions you'll be tested on. [Perception of Math 2]
- At times while writing this assignment, I completely forgot that I was writing for a math class. [Engagement 1]
- While writing, my body was in the room where I was writing, but my mind was in the world created by the assignment. [Engagement 2]

- At times when working on webwork assignments, my body was in the room where I was writing, but my mind was in the world created by the assignment. [Engagement 3]
- I understand why this course is part of my academic program. [Perception of Curriculum 1]
- I see a strong connection between what I am learning in this class and my future career possibilities. [Perception of Curriculum 2]
- This class is important to help me be successful in my major. [Perception of Curriculum 3]
- This class is important to help me be successful in my possible future career paths. [Perception of Curriculum 4]
- I can articulate my strengths and challenges as a writer. [Writerly Self-Efficacy 1]
- I can be recognized by others as a strong writer. [Writerly Self-Efficacy 2]
- I can write a paper without experiencing overwhelming feelings of fear or distress. [Writerly Self-Efficacy 3]
- In general, writing about a subject is an effective way to learn the subject. [Perception of Writing in Math 1]
- Writing is helpful for really learning how to apply math in the real world. [Perception of Writing in Math 2]

2. If writing is used in Math, what kind of writing would you prefer—and why?
3. What is your desired future career?
4. What is your major?

- Math
- Non-Math _____

5. What kind of writing do you believe is most relevant to your major?

Appendix C: Writing Assignments

Leonard Purcell
CEO
Duncan Hills Coffee
1618 Phi Street

October 6, 2021

Blue Devil Consulting
314 Pi Street
Menomonie, WI 54751

Do you folks like coffee? Real coffee from the hills of Colombia? At Duncan Hills Coffee we make the best coffee in the world. Our coffee is so good we sell thousands of bags every day to stores and coffee shops all over the world.

This volume of sales has created a problem. When we started as a small company, we had individual contracts with each of the few stores and shops we sold to, but now individual contracts are too much of a hassle. We want to streamline our operations. We primarily sell two types of coffee, a Colombian roast and a dark roast. We want to move away from individual contracts and just sell one package with a set number of bags Colombian and dark roast beans. We hope you can

help us determine what the best number of each roast should be in this package. Due to shipping constraints we need to keep the total bags at five hundred or fewer. We have data from our recent sales attached to this letter. Would anything change if we were able to double the size of our shipping constraint?

Please provide your report before we have our next sales event. We need this by 11:59 PM on November 1, 2021. The executives who will read this report are a bright bunch, but it may have been a while since they have been in calculus. Some who read this may not have been hired yet and won't understand the issues presented here so make sure to give a thorough introduction. Dr. Skorczewski is one of our consultant liaisons. He can answer any and all related questions you may have regarding technicalities or requirements related to your effort. Please do not hesitate to contact him. We are eagerly awaiting your reply.

Our coffee is the best. Prepare for the ultimate flavor!

Sincerely,

Leonard Purcell
CEO
Duncan Hills Coffee

Things you need to do

- Write a report that introduces the problem, sets up your methodology to solve that problem, answers the questions and interprets them.
- Include a two to three bullet point Executive Summary at the beginning of your report, before the introduction, that summarizes your main results.
- While a conventional professional report wouldn't show all the math used, you still need to do this. (This is still an assessment for the course, after all.) Put this work in an appendix and refer to it in the body of the report, e.g. `the solution to equation ZZZ is AAA (appendix A).' The amount of mathematical formula you should show in the appendix is the same amount as a textbook example.
- The due date here (November 1) is when I expect you to turn in a draft of your report. It should be near completion. At the end of the draft please include an Author's Note section. A typical in-process author's note attends to the following types of questions: What are some struggles you've encountered, and how have you dealt with them? Where are you still struggling? What do you have left to do? Where you do you most need another set of eyes? If the instructor only has a limited amount of time to look at each draft, can you prioritize what kind of feedback is going to be most helpful for you at this point?
- The first draft will count for 40 points and the final draft will count for 30 points. After I read the first drafts, I will put students with similar ideas and levels of work into groups. Each group's task will be to take the feedback from their individual drafts and merge them into one final draft due November 23.

Notes/Hints/Thoughts

- There is a rubric below to help you organize your thoughts about the assignment.
- You should use math learned in this course to solve this problem. You can expect to earn less than full credit if you use techniques outside of this course.
- What does it mean to find `optimal' here if no function is given?

- Some of the terms here might be vague and/or ill-defined. This is intentional. In the real world people come to mathematicians and engineers with ill-formed problems all the time. (Nobody ever gives a professional a textbook and asks them to work through problem 7.) You may need to define what any of these terms mean. Make sure to justify how you define these if you can.
- You won't need anything more complex than linear or quadratic terms.
- Ask questions if you get stuck. Don't wait to start. Your procrastination is not someone else's emergency. Extensions are \emph{very, very unlikely}.

Count Chocula
Chief Sales Officer
Tyler Chocolates, LLC
1618 Phi Street

October 6, 2021

Blue Devil Consulting
314 Pi Street
Menomonie, WI 54751

Dear Blue Devil Consulting,

We at Tyler's Chocolates have a simple goal. We want to make the best dark and milk chocolates that money can buy. We sell these chocolates to specialty stores and chocolatiers around the world. While we make several kinds of specialty chocolates, but focus on one milk chocolate and one dark chocolate variety for much of our bulk sales.

While we pride ourselves on the quality of our chocolates, our sales intuition is unfortunately a bit lacking. This is where we would like your help. We need to know where to price our boxes of milk and dark chocolates. We know that the prices affect the number sold and that changing the price of one of the chocolate varieties affects the sales of both. It costs us \$10 to make a box of milk chocolate and \$15 to make a box of dark chocolate. Furthermore, we have just signed a new deal with our shipping partner where we get a preferred rate if the total combined amount of boxes is no more than 100 and we want to stay in these bounds. We have data on the prices and numbers of boxes sold for many recent orders. Can you help us find the ideal prices?

Please provide your report before we have our next sales event. We need this by 11:59 PM on November 1, 2021. The executives who will read this report are a bright bunch, but it may have been a while since they have been in calculus. Some who read this may not have been hired yet and won't understand the issues presented here so make sure to give a thorough introduction. Dr. Skorczewski is one of our consultant liaisons. He can answer any and all related questions you may have regarding technicalities or requirements related to your effort. Please do not hesitate to contact him. We are eagerly awaiting your reply.

Sincerely,

Count Chocula
Chief Sales Officer
Tyler Chocolates LLC

[Same ‘Things To Do’ as previous prompt]

Appendix D: Rubric

Topic	Excellent	Good	Poor
INTRODUCTION	Topic is introduced so that audience without prior knowledge understands what the problem is and why it is important.	Topic is introduced, but not reasons for studying it – or – problem is not introduced in a way that assumes no prior knowledge.	Topic is not introduced.
METHODOLOGY	Approaches to problems/questions are clearly laid out; all assumptions are stated; model is introduced/developed/ explained.	Approach to problem is mostly laid out; most assumptions stated; model explained but perhaps not clearly.	Approach to problem is not laid out; assumptions not stated; model appears from nowhere.
SUBJECT KNOWLEDGE; RESULTS	Expansive – all points clearly made/claims justified; mathematical results correct and interpreted back to problem; figures look professional and are referred to in text of manuscript.	Sufficient – topic generally understood. Some extraneous info included. Mathematical results mostly correct and somewhat related back to problem; some figures missing/not referred to in text of manuscript.	Insufficient – topic not clearly explained. Irrelevant info presented; mathematical results not correct; figures missing/never referred to in text.
ORGANIZATION	Audience can follow because it has a logical sequence; one coherent narrative presented.	Audience can follow with some exceptions; mostly one coherent narrative.	Audience cannot understand the presentation; clear this is the work of several different people stitched together.
OVERALL IMPRESSION	Paper reads well; varied sentence structure; correct grammar.	Paper reads fairly well; some grammar issues; somewhat repetitious sentence structures.	Consistently unclear sentences; several grammar issues.
BOTTOM LINE	Company paying for this work would be thrilled, hire you again, and recommend you to other clients.	Company paying for this work may or may not hire you to perform more work for them.	Company paying for this work would want its money back.

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Notes

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[2] Participants sometimes mentioned more than one type.

[3] Participants sometimes mentioned more than one type.

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