Writing in the STEM classroom: Faculty conceptions of writing and its role in the undergraduate classroom

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Abstract

Writing is widely recognized as fundamental to the construction and communication of scientific knowledge. Building on this relationship between writing and knowledge construction, writing-to-learn (WTL) activities have shown to be effective in many science classrooms, but have not been widely implemented at the postsecondary level. To address the lack of implementation, we investigated potential adopters of this pedagogy. Potential adopters, postsecondary faculty, are unique given the key role writing plays in their professional practice as researchers. Because of this unique feature and the fact that an instructor's theoretical orientation toward a construct impacts their instruction of that construct, an investigation of postsecondary faculty's conceptions of writing instruction is necessary to understand the way writing is being used in the postsecondary classroom. To this end, 33 STEM faculty across multiple disciplines and positions were interviewed about writing and its role in their classes. A phenomenographic analysis resulted in four faculty "types" consisting of unique combinations of concept and practice, organized according to compatibility with WTL. Profiles were built that describe unique conceptions, desired outcomes, and challenges for each type. These profiles provide an understanding of the relationship between faculty's conceptions and instructional practices regarding writing and lay the groundwork for understanding how writing is used in the postsecondary classroom.

Key Words: Writing to learn, undergraduate STEM, faculty conceptions, science writing, case study, phenomenography

Background

Writing is widely recognized as fundamental to the construction and communication of scientific knowledge (Halliday & Martin, 1993). Within science education, studies have explored how scientists reflect on their own writing practices (Yore, Hand, & Prain, 2002; Yore, Hand, & Florence, 2004; Yore, Florence, Pearson, & Weaver, 2006). These studies reveal the identity of a scientist as a writer, as writing has come to serve such a core role in research (Yore et al., 2002). Further, these studies elucidate how scientists write, what criteria they use to evaluate writing, and how writing influences their thinking about the topic (Yore et al., 2004; Yore et al., 2006). Undergirding all of these results is the reality that scientists consider writing to be integral to their practice as scientists. However, there is a disparity between the role of writing in the STEM classroom and the role of writing in scientific practice.

Research on writing instruction has broadly categorized writing as a skill to be learned [Learning-to-Write (LTW)] and a process that facilitates learning [Writing-to-Learn (WTL)]. In accordance with these two views of writing, writing centers at academic institutions have worked to incorporate Writing Across the Curriculum (WAC) by embedding it in introductory through disciplinary core classes (Thaiss & Porter, 2010). Like many other reforms, writing-based pedagogies have not acquired widespread adoption in large introductory STEM classes, though writing is widely recognized as an important component of doing science (Reynolds, Thaiss, Katkin, & Thompson, 2011; Henderson, Beach, & Finkelstein, 2011). Beyond general barriers for pedagogical reform in STEM—time required, lack of instructional support, resources needed for evaluation (Henderson, et al., 2011)—we believe there are barriers specific to writing-based pedagogies. In this work we argue that, in

addition to elucidating specific barriers, an understanding of instructor's *conceptions* of writing and its utility is needed to fully explain the lack of adoption. This is because faculty's conceptions of writing instruction inform their use of writing in the classroom, just as they do for primary teachers (Graham, Harris, MacArthur, & Fink, 2002). For this reason, the study presented herein serves to bridge the gap between classroom writing and STEM research writing by exploring the relationship between STEM instructors' conceptions of writing and their views of its role in the classroom.

Faculty Conceptions of Writing

Research in the area of faculty conceptions of writing has explored faculty's perspectives of their own writing practices and the way that writing is used within their own disciplines. An investigation of scientists as writers revealed that many scientists subscribed to a knowledge-telling model where writing is an opportunity to share their knowledge and results (Yore, Hand, & Prain, 2002). Building on this investigation, the authors related scientists' practices of writing with their views of the nature of science (Yore, Hand, & Florence, 2004). Generally, they found that participants considered science to consist of a "temporary explanation" that fits the current paradigms and evidence. Their writing practices and conceptions about writing did not always align with this modernist perspective of scientific inquiry (Yore et al., 2004). A similar discrepancy is present between faculty's descriptions of their disciplinary writing style and their actual disciplinary writing styles and practices (Olinger, 2014). These discrepancies may result from lack of explicit reflection on writing by faculty.

The limited reflection by faculty on their own writing may explain how scientists identify as writers while not necessarily incorporating it into their classes. That is, they

simply have not thought about extending this feature of their scientific practice to the classes that they teach. A survey of STEM faculty at a community college revealed that in courses that were not designated as writing-intensive courses (a college-specific designation), very little writing was used (Stroumbakis, Moh, & Kokkinos, 2010). This contrasted with other findings from the survey that showed faculty believed writing to be valuable for students (Stroumbakis et al., 2010). These survey results revealed little about *why* faculty considered writing to be valuable, but did not use it in their classes. Though these authors conducted follow-up interviews, they did not report the results of those interviews in this work. Interviews are, however, key to uncovering faculty's conceptions of classroom writing.

To this end, Zhu (2004) interviewed ten faculty in business and engineering departments regarding their conceptions on writing. As part of a larger study investigating English as a Second Language (ESL) students' writing experiences in college, the choice to investigate business and engineering faculty was due to these majors being frequently chosen by ESL students. Zhu (2004) identified two views on academic writing: as a set of general and transferable writing skills and as disciplinary specific skills that are built on general writing skills. Within both of these views of academic writing, faculty saw themselves as playing a role in developing students' skills, even if it was secondary to teaching the content of the course. These findings were limited to the fields of business and engineering, which constitute a small part of academic writing and themselves include unique disciplinary norms.

Writing is one of many outcomes that educators have more recently begun to include explicitly in the undergraduate curriculum. Barrie (2006, 2007) refers to these outcomes as graduate generic attributes (GGAs)—skills and knowledge beyond disciplinary content knowledge that a university graduate should ideally possess upon completing a degree.

Though there is wide consensus that there are desired graduate generic attributes (GGAs), there is ongoing discussion of what these attributes are. However, motivated to move beyond discussions of defining attributes toward conversations about conceptions and instruction about GGAs, Barrie (2006) interviewed faculty. Using a phenomenographic lens, Barrie (2006) identified four qualitatively distinct categories of conceptions about GGAs: precursory, complement, translation, and enabling. The precursory conception posits that students bring with them some basic abilities, or GGAs, and add disciplinary knowledge as they progress in their education. The complement conception posits that GGAs can complement the disciplinary learning students will do. The translation perspective views GGAs as key to the application and use of disciplinary knowledge, allowing the knowledge to be translated to new situations. Finally, the enabling perspective views GGAs as enabling the development of disciplinary knowledge (Barrie, 2006).

Building on these four conceptions of the nature of GGAs, Barrie (2007) investigated how faculty conceptualized the development of GGAs in the classroom. The outcome of this phenomenographic study was six unique perspectives of the development of GGAs: remedial, associated, teaching content, teaching process, engagement, and participatory. The remedial perspective—GGAs not taught at university—and the associated perspective—GGAs taught as discrete subset of teaching—represent supplementary and teacher-centered perspectives of GGA development. Teaching content—GGAs taught in context of disciplinary knowledge—and teaching process—GGAs taught through teaching disciplinary knowledge—still represent a teacher-centered perspective, but integrate GGA instruction into disciplinary knowledge instruction. Finally, the engagement perspective—GGAs are learned through engaging with course experience—and the participatory perspective—GGAs are learned by participating in university life—are both learner-centered and integrated with curriculum and

broader university contexts (Barrie, 2007). These differences between all of these perspectives on the nature and development of GGAs are subtle, but necessary to understand how GGAs are supported in university instruction. Given that written communication is often considered a GGA, it was expected that the study presented herein would capture a similar range of conceptions on writing and its role in the classroom.

Writing in the STEM classroom

Halliday and Martin's (1993) assertion that writing itself creates scientific knowledge has implications for the science classroom (Norris & Phillips, 2003). The development of scientific knowledge as a whole has been dependent on text. For this reason, learning science is inevitably related to interacting with text (Greeno, 1992; Lemke, 1990; Norris & Phillips, 2003). Given language's ability to produce science knowledge, text production is one way of engaging learners in the construction of their own knowledge (Keys, 1999). Writing assignments, then, have been embedded in science classrooms to facilitate science learning and results suggest that they have done so effectively (Bangert-Drowns, Hurley, & Wilkinson, 2004; Klein & Boscolo, 2016; Prain & Hand, 2016). There are multiple theories that explain how writing actually gives rise to the observed learning (Prain & Hand, 2016).

A cognitive perspective of writing-to-learn claims that the process of text production promotes organization of thinking and, consequently, learning (Emig, 1977; Galbraith, 2009). Additionally, the text resulting from the writing process serves to embody the writer's thoughts in a form that can be analyzed (Young & Sullivan, 1984). However, the cognitivist perspective misses the meaning making that is shaped by interaction with the tools, symbols, and norms used by a specific community—or discipline (Lemke, 1990; Vygotsky, 1978). Text production offers the learner a socialization opportunity by prompting them to draw on

the tools, symbols, and norms of the context to which they write (Prior, 2006). In contrast to the cognitive perspective where learning is a result of individual sense-making, the sociocultural perspective defines learning as a result of the individuals internalizing the meaning-making practices of the community in which they participate (Prior, 2006). Ultimately, these perspectives can complement each other in explaining how writing activity can facilitate individual knowledge construction and understanding of the unique disciplinary discursive norms (Prain & Hand, 2016).

Airey and Linder (2009, 2017) and Fredlund, Linder, and Airey (2015) contend that writing is one mode of representation within disciplinary discourse, where disciplinary discourse is multimodal and specific sets of modes of representation are needed to access specific disciplinary ways of knowing (Airey & Linder, 2009, 2017). This literacy perspective suggests that while developing discursive fluency is necessary, it is not sufficient for learning disciplinary knowledge. Airey and Linder (2009, 2017) refer to constellations of representational modes—critical combinations and proportions of modes—as different for different kinds of disciplinary knowledge. All scientific disciplines rely on a written mode of representation, but it is not well understood when writing is one of the sets of modes needed to access certain disciplinary ways of knowing.

Tasks that provide students with the opportunity to engage specifically with the writing mode of representation can be broadly categorized into Learning-to-Write (LTW) and Writing-to-Learn (WTL). As evidenced by earlier discussion, the intimate relationship between writing and learning disciplinary representational use can blur the line between LTW and WTL. Further, Reynolds and colleagues (2012) revealed a variety of learning goals for WTL activities, including critical thinking, conceptual understanding, scientific method, and

communication skills. Generally, LTW encompasses tasks aimed at developing students' writing skills. These tasks are especially important for exposing students to specific disciplinary writing and linguistic norms (Carter, 2007; Bazerman, 1992; Jones & Comprone, 1993). For this reason, LTW tasks often resemble authentic forms of disciplinary writing (e.g. journal article, research report) and are embedded in upper-level disciplinary courses or in disciplinary writing courses, especially at institutions with long-standing WAC programs (Thaiss & Porter, 2010).

WTL activities, on the other hand, can target a variety of learning goals (Reynolds et al., 2012) and take on a variety of forms (Keys, 1999). Local studies at many institutions have demonstrated success with implementing WTL tasks in math and science classes at varying levels (Connolly & Vilardi, 1989, Mason & Boscolo, 2000). Meta-analyses of WTL studies across disciplines and levels reveal that writing contributes to learning gains, but with small to medium effect sizes (Bangert-Drowns, Hurley, and Wilkinson, 2004; Klein & Boscolo, 2016). The meta-analysis identified explicit prompting for metacognitive reflection as a significant mediator of effect size—that is, the extent of the learning gains (Bangert-Drowns et al., 2004). This aligns with a cognitive perspective of writing-to-learn where writing can facilitate metacognitive reflection. However, it is likely that a cognitive perspective of writing and the resulting learning may not capture fully the possible outcomes of writing tasks, and this has prompted a marked shift in the WTL research toward considering social variables and epistemic outcomes (Klein & Boscolo, 2016). This research has identified and qualitatively investigated social variables like collaborative writing, audience, and facilitation, but more research is necessary to understand the effects. At the postsecondary level, there have been few well-studied implementations of WTL.

In an effort to capitalize on WTL, the Science Writing Heuristic (SWH) is an inquiry activity for the secondary and postsecondary science laboratory (Keys, Hand, Prain, & Collins, 1999). SWH guides students to construct scientific meaning through writing. Students are given writing prompts that model authentic science activities: research question, methods, observations, claim, evidence, negotiations, and awareness of change (Grimberg & Hand, 2009). There are opportunities to compare claims and evidence with other groups in the laboratory. In a seventh-grade biology class, students who used the SWH performed better on conceptual questions, a textbook explanation, and revealed in interviews an understanding of scientific inquiry (Hand, Wallace, & Yang, 2004). Other studies have demonstrated the positive effect of SWH on students' critical thinking skills (Quitadamo & Kurtz, 2007; Stephenson & Sadler-Mcknight, 2015). Although the emphasis of SWH is on process skills, introductory students who used SWH outperformed their traditional counterparts on a conceptual assessment of the concept of chemical equilibrium (Greenbowe, Rudd, & Hand, 2007).

Kelly and colleagues have investigated students' written argumentation in undergraduate oceanography (Kelly & Bazerman, 2003; Kelly & Takao, 2002; Takao & Kelly, 2003; Kelly, Regev, & Prothero, 2007). This course is writing-intensive, with multiple sources of scientific writing support, and the primary source of written data is technical papers characterizing geographical areas that students write as a mid-term assignment. The authors have drawn on linguistic analysis and developed an argumentation analysis framework to analyze the students' argumentation (Kelly & Takao, 2002; Kelly & Bazerman, 2003). With this analysis, researchers elucidated the relationship between rhetorical features and disciplinary values in argumentation (Kelly, Regev, & Prothero, 2007). This whole body of work has resulted in features that students can incorporate to improve their written

argumentation. Further, the writing task, course-embedded writing supports, and data set promoted students' abilities to use, assess, and critique data according to disciplinary norms. Finally, authentic participation in the discipline of geology supported an increase in science literacy generally (Kelly, Regev, & Prothero, 2007).

The SWH and oceanography writing reflect the impact of discipline on the kinds of writing tasks used at the postsecondary level. The postsecondary classroom can be a site of increased disciplinary specialization and is often taught by a disciplinary expert (Coppola & Krajcik, 2013). Given the perspective of writing as a mode of disciplinary discourse (Airey and Linder, 2009) and the relationship between conceptions about teaching and enacted instructional practices (Gibbons, Villafañe, Stains, Murphy, & Raker, 2017), we investigated postsecondary instructors' conceptions about writing in their classes to ultimately better understand how writing is incorporated into postsecondary STEM classes.

Faculty Development and Pedagogical Change

As part of a larger project aimed at developing and implementing WTL activities in introductory STEM courses, the study presented herein served to identify and understand potential adopters. In their work, *Designing Educational Innovations for Sustained Adoption*, Henderson, Cole, Froyd, Friedrichsen, Khatri, and Stanford (2015) describe considerations educational researchers must make to ensure sustained adoption of their pedagogy. One of these considerations is to develop an understanding of potential adopters. Specifically, educational researchers are tasked with understanding who might adopt a pedagogy (i.e., job position, time commitment, background) and why a potential adopter may or may not adopt a pedagogy (i.e. drivers and barriers) (Henderson et al., 2015).

In a critical review of the literature on undergraduate STEM pedagogical reform, Henderson, Beach, and Finkelstein (2011) identified two barriers common in unsuccessful change efforts: institutional barriers and failure to align change with existing faculty beliefs. These beliefs have the potential to operate as both drivers and barriers. For a pedagogy to be sustainably adopted, the instructor must understand how it fits with her own conceptions about teaching, learning, and writing (Henderson et al., 2011). The extent to which the outcome of the pedagogy is predetermined shapes the role the potential adopter plays in the change. A prescribed outcome will involve less input and fewer decisions by the adopter, while an emergent outcome relies heavily on choices that the adopter will make (Henderson et al., 2011; Henderson et al., 2015). It is likely that institution and department culture and individual faculty beliefs are related. As a result, this work directly investigated faculty beliefs and indirectly explored departmental, institutional, and disciplinary cultures as they emerged in the context of individual beliefs.

We have deliberately conceptualized Writing-to-learn (WTL) to fall in the middle of the prescribed-emergent spectrum. The structural components of the pedagogy—drafting, peer review, and revising—are heavily prescribed as they are grounded in the sociocultural theory underpinning WTL (Vygotsky, 1978; Prior, 2006). The writing task is emergent in that it requires the instructor to make decisions about the content, genre, length, depth, audience, and writer's identity, which all influence student outcomes (Henderson et al., 2011). As the success of WTL activities hinges upon the decisions made by faculty in designing them, we must understand what conceptions about writing and its utility that faculty bring with them.

Research Question

To understand the relationship between scientists' conceptions of writing and the extension of those conceptions to instruction, this study aimed to answer the following research question.

Research Question: How do STEM instructors at research-intensive institutions conceive of writing and its role in the classroom?

Methods

Phenomenography and Writing-to-learn (WTL)

The aim of this research was to understand STEM faculty's conceptions of the phenomenon of writing and its role in the classroom. Regarding this phenomenon we aimed to develop qualitatively different categories of conceptions held by faculty, acknowledging that there are a finite number of qualitatively distinct ways a specific phenomenon can be conceived (Marton, 1981; Marton, 1986). Further, the power of a phenomenographic lens lies in revealing an understanding of the meaning of and relationship between the conceptions elicited (Entwistle, 1997; Orgill, 2007). For this study, this informed a desire to not just understand differing conceptions of writing held by faculty, but also how these conceptions related to faculty approaches to their instruction. This theoretical lens assumes that there are no correct or incorrect conceptions. The aim of the study was to elicit and understand the conceptions, which are then evaluated according to existing theoretical positions (described below).

As stated earlier, the motivation for this study comes from an effort to develop and implement writing-to-learn activities in introductory STEM classes. The theory underlying writing-to-learn is that writing is a social activity through which participants can develop

understanding (Vygostky, 1985; Prior, 2006). This theoretical commitment influenced data analysis by directing analytical attention to the relationship between writing and learning and factors that may affect adoption of writing-to-learn strategies. Conceptions of classroom writing were organized hierarchically based on how closely they resonated with the use of writing to support learning. The outcome space (Akerlind, 2012), then, of this study is structured to include profiles organized according to level of agreement or overlap with WTL.

Participants and Setting

Interviews conducted in this study followed a nationwide survey on faculty conceptions and practices of writing in their classes. The survey was sent to all STEM faculty at very high research activity institutions that are members of the Reinvention Collaborative, "a national consortium of research universities dedicated to strengthening undergraduate education" (http://reinventioncollaborative.colostate.edu/). The survey was developed to determine how frequently writing is being used in the STEM classroom, what types of writing are used, and what factors impact faculty' use of writing. At the end of the survey, the participants indicated willingness to participate in an interview; 748 survey respondents marked that they would participate in follow up interviews (748 out of the 5027 total responses). A stratified sample was selected from all participants who indicated agreement to participate. In accordance with phenomenography, the stratified approach aimed to capture the variety of perspectives by sampling according to varying demographic information. The sample strategy (Robinson, 2014) considered reported writing use, position, gender, and discipline. In an effort to capture a variety of conceptions, we aimed to interview a subset of STEM faculty that represented the range of experiences present in academia. We expected

some of these identifiers to possibly give rise to differing conceptions among participants. Given the literature showing how discourse can be bound by discipline, it was possible that discipline might play a role in faculty's conceptions of writing—a mode of discourse (Airey & Linder, 2009). We also expected that faculty who use writing in their classes will have at the very least thought about it more than their counterparts who do not use writing in their classes. Finally, given the relationship between instructional practices and academic rank, we expected that rank could give rise to conceptual differences (Walter, Henderson, Beach, & Williams, 2016). Table 1 shows the representation of faculty by discipline and rank. A total of 33 interviews were conducted. IRB approval was obtained for this study and all participants were given pseudonyms to maintain anonymity.

[Insert Table 1 here]

Data Collection

Semi-structured interviews were used to add to the survey by eliciting a deeper understanding of conceptions of the same phenomenon from each interviewee and still capturing the uniqueness of each interviewee's conceptions. Participants were recruited individually by email. Interviews were conducted via Skype, telephone, or Google Hangout and lasted approximately 30 to 60 minutes. There were no noticeable differences in interviews conducted via differing media. The interviews were semi-structured and a full interview protocol can be found in the supplemental information, which is annotated to distinguish main and sub-questions. There was some variation in the protocol depending on whether the participant reported using writing or not in their survey response. If a participant reported using writing, there were questions targeting how and why writing was used. If a participant did not, questions targeted hypothetical views of writing in the classroom and

possible types of writing that could be used. During the interview, quite a bit of flexibility was employed to follow any interesting veins that could reveal conceptions of writing.

Writing was not defined for participants in the interviews. Many genres of writing were included in the survey to which they responded; including research proposals, poster presentations, abstracts, short in-class writing, writing in response to prompts, short answer essays, lab reports, scientific paper, research reviews, thesis, field notes, annotated bibliography, and online discussion. These genres surely informed the types of writing that participants considered during their interviews. The interviews themselves revealed that participants included many forms of writing in their definition. In addition to the genres listed above, participants discussed generating graphs, labeling figures, reviewing peers, note-taking, as well as numerous types of technical writing (e.g., memos, manual pages). When participants discussed writing in the context of their own scholarship and disciplines, writing almost always referred to academic publishing and grant proposal writing. The inclusion of so many forms of writing reveal a broad and liberal definition of writing and aligns with our definition of writing as any text resulting from a meaning-making task (Norris & Phillips, 2003; Fredlund, Linder, & Airey, 2015).

Data Analysis

Interviews were transcribed verbatim and grammatical errors that did not affect the meaning of the quote were removed in the quotes presented below. Interviews were first open-coded using an exploratory, constant comparison approach in QSR NVivo 11 (Kolb, 2012). This involved iteratively reading interviews and comparing to other interviews to produce codes that began to repeat, condense, and group. These codes described conceptions of writing, the types of writing that were used, drivers and barriers to adoption, and details

about how classroom writing was evaluated. After codes were generated and refined, each interview transcript was categorized according to their reported use of writing in the classroom into users (no or very little writing) or non-users (writing embedded in some or all classes). The two groups (users and non-users) were further divided into categories based on their conceptions of classroom writing (i.e. value of writing for students, role of writing in their classroom). Once all sources were coded for practice and conceptions of writing in the classroom, an initial model was generated. This model included four faculty "profiles" with unique combinations of classroom writing practices and conceptions. This model was then tested against the data by iteratively assigning each interviewee to a profile and refining the characteristics of each profile. This continued until all interviewees were assigned, after which analysis served to build the profiles by considering only interviews from each specific profile. From this stage of analysis, themes in justifications for reported practices and conceptions of classroom writing emerged. There were a few participants that initially did not seem to fit into any profile; however, considering both conceptions and practices allowed for assigning these faculty. In addition to these profiles, there were themes in conceptions of writing that emerged from all interviews; particularly regarding the value of writing in their respective disciplines and features of good writing.

Results

Results will be separated into two sections: faculty conceptions of writing and classroom writing conceptions and practices. The former section will include themes that emerged across the faculty regarding writing. These themes are consistent with previous findings on scientists' conceptions of writing (Yore et al., 2002; Yore et al., 2004). The trends across faculty serve to lay the foundation for highlighting the distinctions between faculty

regarding conceptions and practices of classroom writing. The latter section, then, will describe the variety of classroom writing practices and conceptions held by faculty. This variety will be captured in the form of faculty typologies that will be ordered according to compatibility with writing to learn; that is, from least compatible (no classroom writing) to most compatible (classroom writing for learning).

Faculty conceptions of writing

Faculty ubiquitously saw the important role that writing played in their discipline and science as a whole. As all faculty perceived writing as an important part of their research, the variety of ways in which writing was incorporated (or not) in the classroom was unexpected. Writing academic publications was highlighted as the primary product of their work and means of communicating their findings to their communities. For this reason, many viewed writing as constituting the bulk of their research activity.

> *Papers is the currency of what we do. The ability to write clearly is just as important as the ability to do important science. There are some people we all know who are brilliant, but write papers that are so opaque that they have far less impact than they otherwise would. Scientific communication, be it through one's writing, through one's talk at big meetings and stuff, is a major aspect of the impact of your work.* -Ruben (Neuroscience)

Ruben equates the importance of writing to the importance of doing science. The fact that faculty so widely recognized the important role that writing plays in their own scientific practice has direct implications for the STEM classroom. That is, if writing is a preeminent component of scientific practice, it deserves explicit emphasis in the STEM classroom. Not only was writing considered to be important, there was also broad consensus on the features

of good writing, across all typologies and disciplines. Namely, good scientific writing is clear, precise, and persuasive. These features of good writing were often voiced in the context of discussing weaknesses of student writing. Regarding clarity, Lena explains that to achieve clarity in writing, one must consider the perspective of the reader, a move that is sometimes foreign to students.

> *I think getting familiar with the idea that it's about communicating clearly. I think that they [students] don't always ... And that communicating clearly requires that you get out of your head and get into someone else's and read through someone else's eyes what you've written and it being understandable.* -Lena (Biology)

This quote points to clarity as a distinguishing feature of scientific writing. Regarding precision, many commented on the value of using language precisely in their writing (and speaking) to best represent what they were trying to say. This value of precision was tied to the value of clarity, but participants provided more insight into characteristics of precision. This quality was concerned with how words were used; that is, words were to be used to mean exact things and in exactly appropriate contexts. This value of precision arose for multiple writing genres, from research papers to manual pages in an engineering class.

> *The first one is I try to use English like a scalpel. You can tell the way I talk. I try to use English precisely, concisely, exactly, etc.*-Roger (Computer science)

In support of this effort voiced by Roger, one interviewee discussed a specific example of a published paper in which two words (i.e., reflectance and reflectivity) were used interchangeably and thus, inappropriately.

Across all disciplines and typologies, instructors considered the ability to craft an argument as essential to science.

> *To me, so much of business, so much of academics, so much of almost anything is an argument. You're trying to convince somebody of something. To me, the ideal world would be always talking about how to write an argument with clarity and conciseness.* -Colin (Biology)

Not only for academics, but for everyone, there is a need to write good arguments. Olivia claims that argumentative skill associated with writing is required for success in any future endeavors a student might pursue. She voiced this in response to a question on the role of writing in her discipline. The fact that this feature of being argumentative and convincing emerged in a response on writing generally speaks to how integral it is to scientific writing.

> *Once you get to any professional level of it, whether that's graduate school or beyond if you're going into intellectual property or industry or anywhere else along the career path, then writing good, argumentative, compelling writing is really important to succeeding in any of those areas because you have to be able to convince people to give you the research for what you're trying to do, whether that's in academia or other areas*. -Olivia (Biology)

The consideration of crafting good arguments as a key scientific skill emerged later in interviews as a criterion for evaluating students' writing, agreeing with prior literature on scientists' writing (Yore et al., 2006).

Faculty identified clarity, precision, and argument as features of effective writing. Though there seemed to be broad consensus in how faculty conceive of writing in their own

research practices, there was a variety of ways these conceptions were extended to the STEM classroom. The next section will characterize these variations in conceptions and practices of classroom writing. It is necessary to understand the variety of ways writing is used in the classroom *because* of the widespread agreement on the importance of writing amongst STEM faculty.

Faculty classroom writing conceptions and practices

[Insert Figure 1 here]

An overview of the four qualitatively distinct types of faculty positions on writing in the classroom and the relationships between them are presented in Figure 1, including the number of participants that fell into each category. These typologies will be used to designate participants throughout the results section. The faculty are positioned along two axes: Use of writing in the classroom (do or do not use) and goals of using writing (WTL or LTW). The assignment of faculty along each axis and the names given to types emerged from analysis, once we understood some of the unique features for each profile. Evident in Figure 1 is the overlap in practices between Writers and Utilitarians and the overlap in goals between the Idealist and Writer. A detailed description of each profile will be presented, but some demographic information is included in Table 2. There are a variety of disciplines and positions represented in each profile, evident in Table 2, which further justifies the need to understand the potential adopter's conceptions as an important factor that affects adoption.

[Insert Table 2 here]

The Traditionalist

As can be seen in Figure 1, this faculty type was the least represented in the interviews conducted for this study. What distinguished this group was the belief that for some reason, writing fell outside the scope of the STEM class for which they were the instructor. Though they recognized that writing was inherent to professional scientific practice, they did not see any writing as inherent to the scientific content that they were teaching. Brian explains this in the context of introductory physics.

> **Interviewer**: *Mm-hmm (affirmative). One of the things I've heard you say is that physics is really math-intensive and problem-solving-intensive. Do you think this is somewhat incongruent with writing?*
>
> **Brian**: *That's a nice question. I think I'm going to vote "Yes." Yeah, that's actually a pretty good way of stating what I think my personal opinion would be. I'd be happy if they could do the math. I'd be happy if, in 5 lines, they could answer my question thoroughly enough. I think any given physics instructor has had plenty of math, and so they know how you could in 5 lines represent a whole page of writing as far as what the physics content is concerned with. Yeah, incongruent's not a bad way to say that.* (Traditionalist, Physics)

According to Brian, the mathematics is the primary learning objective and writing is viewed as actually detracting from the concision that mathematics offers. This prioritizing of mathematics means that writing has no place in the introductory physics curriculum. Kathy, an introductory mathematics instructor, argued that writing actually served as a distraction from the mathematical skills that are important for her students to develop in introductory mathematics. The mathematical skills are what students will need for their further coursework, while writing is not. A primary reason, then, for not using writing in these

introductory physics and mathematics courses was the view that writing did not fit into the curriculum, as it was not part of the skills that these two instructors desired as outcomes for their students. Kathy extended this reasoning to argue that incorporation of writing in introductory mathematics detracted from students' mathematical skill building.

> *They weren't really developing any [mathematical] skills and so that was my objection to the verbal aspects of the course. Interpreting writing, what is this graph doing, what is this function doing, where is it increasing, where is it decreasing? Say in your own words, what is the average rate of change mean in the context of this problem? What domain makes sense in the context of this problem? I thought a decent student who had moderate skills in written language would be able to do that and there was no need to make a space for it on an exam, but they put a big part of the credits in those non-mathematical areas.* -Kathy (Traditionalist, Mathematics)

Based on the examples of verbal aspects provided, Kathy considers the ability to communicate and explain one's understanding to be easily completed once the content ability is achieved. This perspective does not align with research that has demonstrated the difficulty associated with the practice of constructing explanations and communicating results (NRC, 2013; Soto, 2015).

Though all Traditionalists recognized that writing was an important skill for students and that their students possessed weaknesses with respect to writing, they firmly believed that it need be taught elsewhere.

> **Cleo:** *How do I view the role of writing? I think the role of writing has to be accomplished before they get into the class.*

Interviewer: *You're saying that some of these reading and writing skills need to be established before they come into your class?*

Cleo: *Yeah, definitely. Way before they come in. (Traditionalist, Chemistry)*

An assumption underlying the claim that writing must be taught elsewhere is that the writing completed in STEM disciplines is sufficiently supported by the writing training a student might receive in high school or Freshman English. This assumption does not hold in light of the vast body of work recognizing unique disciplinary writing norms and expectations (Olinger, 2014; Rempel, 2010; Hinton, 2010; Swales, 1990; Carter, 2007). However, the discussion of who teaches disciplinary writing and how they teach it is ongoing. Some Traditionalists argued that incorporating this type of writing was not within their role as a STEM instructor.

Melinda: *It depends on how the professor sees his role. I am not a writing professor.*

Interviewer: *How do you see your role?*

Melinda: *I think I am a professional cell biologist so I help teach cell biology. I can tell the students what are the current paradigms in the field. (Traditionalist, Biology)*

This position voiced by faculty contradicts findings by Zhu (2004) in which some business and engineering faculty argued that they had a responsibility to teach writing within their discipline, even if it was secondary to their responsibility to teach content. For the Traditionalist, the conception that guides their perspective on writing in the classroom is that it is outside the scope of the curriculum and/or their role as an instructor. This serves as an insurmountable barrier to incorporating any writing as they do not see it as having a place in

their classes, regardless of its importance in scientific inquiry. The result of this thinking is a persistent discrepancy between faculty's conception of the role of writing within their disciplines and the role of writing within the classroom.

The Idealist

Like the Traditionalist, the Idealist does not use writing in their classes (or uses very little). The Idealist's conceptions of writing are similar to the Writers' conceptions, however. They see writing as fundamentally related to their knowledge and understanding. Though they do not use writing in their classes, they explicitly consider the value of writing for promoting understanding. This recognition of the capacity of writing to promote understanding sources from faculty's own scholarship and experiences. Danielle, a mathematician, explicitly explains this relationship.

> *I'm a big believer of writing to think. A lot of this derives from the way that I approach my own research and scholarship, that sometimes I don't know what I think or my ideas are until I start trying to capture them. I don't know where I'm going until I start trying to describe where I'm going…if you're asking them to put something in writing, that is kind of asking them to teach themselves to explain it to themselves. If you can't put it in writing, then you don't understand it yet.* -Danielle (Idealist, Mathematician)

Danielle emphasizes how the act of writing guides her own learning and understanding and extends this potential to the classroom. Olivia, a biologist, further explains this relationship between writing and understanding, citing her work with her graduate students.

Part of it is that it seems like there's a connection between your ability to communicate in written form and your ability to have a mental model of what you're trying to do and why. If you're struggling to build that mental model or if you're struggling to communicate it well, that's usually because those two things are linked, in my observation with my students. -Olivia (Idealist, Biologist)

Olivia argues that the ability to communicate the knowledge is connected with actually knowing.

One of the unique outcomes facilitated by writing is a conceptual understanding, which Idealists cited as a challenge they encounter in teaching. Lena, an evolutionary biologist, describes the challenge of developing students' conceptual understanding, especially for an abstract topic like evolution.

I think that we are asking them to do a lot less memorizing and a lot less assimilation of facts and a lot more understanding of some pretty abstract ideas. I think that that just doesn't happen. In part, it's just the nature of the topic. I think evolution is by definition ... seen as pretty abstract from the student's perspective. -Lena (Idealist, Biology)

Given the Idealists' value of writing for building understanding, it is important to understand what barriers to incorporation of writing into the classroom exist. A unique feature of interviews with the Idealist was that when they reflected on their teaching, they raised challenges with teaching that recurred later in the interview as barriers to incorporating writing. This pattern points to the Idealist as reflective about their teaching practices and consistent with their considerations of challenges. In Peter's case, the rigid course structure

placed limitations on the instructors. He expanded on how this rigid class structure impacts his teaching.

> *We run our general chemistry courses here as departmental courses which basically means all the sections have to have the same syllabus and the syllabus is written by the department and you can't really make changes to it without getting everyone to agree to those changes. That sort of limits the flexibility in how you teach things and what order you do the topics and everything like that.* -Peter (Idealist, Chemistry)

Peter references this challenge again in the context of incorporating writing into a chemistry classroom.

> *One as I mentioned is that the syllabus is departmental and I certainly could propose changes to the syllabus but we'd have to get all the faculty that are teaching the course and the department leadership on board with those changes which may or may not be possible. I haven't really honestly tried yet at this early stage in my career*. -Peter (Idealist, Chemistry)

In addition to institutional barriers like course structure, Idealists echoed barriers to incorporating writing in the classroom reported elsewhere. Logistical challenges with grading, scale, and lack of graduate instructor support all contributed to the infeasibility of incorporating writing.

> *I think the main reason was, there was such a large class size…I knew that I wasn't going to have enough time to actually grade ... Yeah, assess everything that was being written.* -Kyle (Idealist, Physics)

There aren't any good tools for doing automated grading of more extensive writing, and we just don't have the resources within ourselves or the TA resources and staffing resources to help with that. Even though I would love to be able to do something like that, it's just not feasible. -Olivia (Idealist, Biologist)

The Idealists quoted above expressed a desire to incorporate writing into their classes (Kyle expressed this desire elsewhere in the interview), but recognized the logistic challenges that made that impossible. Specifically, grading student writing was not feasible. Part of what made this infeasible was finding enough support for grading (i.e., teaching assistants). Even if instructors were able to secure support, many faculty across types and discipline voiced that they did not think teaching assistants were qualified to evaluate writing effectively. To incorporate writing into the Idealist's classroom, then, these barriers must be overcome. However, the Idealist's demonstration of reflective teaching practices and tendency to relate their instruction to their own scholarship makes a discussion about incorporating writing more accessible.

Utilitarian

Both the Utilitarian and Writer used writing in their classes to some degree, though the Utilitarian used it less and more selectively than the Writer. The Utilitarian's desired outcomes can be separated into two goals: developing skills associated with science (separate from the content) and developing students' technical writing and communication skills. To achieve both of these goals, students must be taught how to write effectively (LTW). Colin summarizes this perspective when he explains his opposition to the term "writing-to-learn."

Writing is a tool…If I want to become a better scholar the tool is the writing. That's my tool and I need to use that tool, hone that tool, use it right...Once you're ready to

go, ready to learn then you're going to acquire all the tools you need to be a scholar or be a fill out the blank whatever that is. It's part of your tool set, writing is...I don't know if writing forces you to learn. Writing is a tool. Writing is your hammer. It's your hammer in your tool belt. It's not the thing that's going to drive you to learn. - Colin (Utilitarian, Biology)

This language (i.e., "tool") was used frequently by Utilitarians for describing writing. One implication of this language is that it is one of many tools used by scientists. This was reflected in Utilitarians' claim that writing was not a unique way to achieve desired outcomes in their classrooms. John, an engineering instructor, considered writing to be a useful, but not a unique skill due to its ubiquitous use in science. For this reason, though other tools could achieve the same goal for students, writing is perhaps more important to teach students because they will use it again in the future.

Another distinguishing feature of the Utilitarian, then, was the view of writing in the classroom as a tool for achieving some outcome other than content learning. There was a variety of outcomes desired from writing tasks. In his introductory chemistry class, Hank assigned writing tasks that required students to, for example, generate a "plot of the changing CO_2 over the last 50 years and explain why that's evidence for human influence on the planet system." Hank perceived the ability to construct arguments as the desired outcome of this type of prompt.

I'd like them to be comfortable making their own arguments from observations about the world. I'd like them to be comfortable reading other people's, and evaluating whether or not they're persuasive. I think one of the ways you get a sense of whether

other people's arguments are persuasive is by trying to make them yourself. -Hank (Utilitarian, Chemistry)

Hank's assignments and desired outcome demonstrate the Utilitarian's view of their interest in teaching skills in addition to content. Other instructors cited goals such as developing students' understanding of where scientific knowledge comes from or learning about students' interests in chemistry. For these types of desired outcomes, writing was one way of achieving them. In contrast to the Traditionalist, the Utilitarian voiced having a responsibility to teach skills important for doing science.

More explicitly in agreement with Learning-to-Write (LTW), Utilitarians frequently voiced the desire to develop students' technical writing and communication skills. They viewed writing assignments as training for these skills. Chester expresses this view as motivation for participating in the interview.

I think that writing, and in general, just communication skills is really critical and we need to keep working to find more effective ways and more efficient ways to help our students get better at that, so I think it's really important. -Chester (Utilitarian, Engineering)

Chester taught upper-level engineering courses that were very applied and he frequently commented on his effort to assign writing tasks that were authentic to the practice of engineering. In line with this, he viewed the inclusion of writing in the curriculum as training the students to become better communicators.

For many Utilitarians, a goal was to teach formal disciplinary writing based on the view that scientific writing was a key feature of their discipline. Dominick, who teaches a

reformed laboratory course for which students generate and research their own questions, sees the outcome of the writing as developing students' understanding of scientific writing.

> *I definitely want them to get a much better understanding of formal science writing. I think there are two ways to go about doing that. One is to read things and the other is to actually do writing. I think writing themselves and having their writing critiqued is the best way for them to start to understand what formal science writing is, but it's a lot of work for me and them.* -Dominick (Utilitarian, Biology)

Dominick's perspective treats science writing as the learning outcome. The best way to achieve this learning outcome is to engage in science writing. Inherent in this view of the utility of classroom writing tasks is the belief that technical writing is a unique skill, deserving its own training. This finding has been documented previously by Zhu (2004) who demonstrated faculty's view of writing as a set of discipline-specific skills.

As Utilitarians' goal for writing was the development of technical writing and communication skills, they evaluated writing with broad quality criteria that were expressed above as consensus features of good scientific writing: clarity, precision, and argumentation.

> *The level of language, the level of writing, which is a bit different. What I call by writing here is the structure, how convincing the arguments are, the structure of the essay as compared to the level of language, then originality of the content…that you can tell fairly easily from the essay.* -Curtis (Utilitarian, Physics)

Within these broad qualities of persuasiveness or language, Utilitarians voiced ambiguous quality criteria as a frustrating challenge when evaluating writing. With non-writing users, challenges were perceived as barriers to the incorporation of writing into their classes. With

writing users, challenges provide insight into the quality of the instructor's experience with using writing. This insight contributes to an understanding of the relationship between an instructor's conceptions and practices of classroom writing. In the case of Curtis, returning to teaching courses with no writing provided relief. He considered evaluating writing to be the hardest part of using it in his classes. The ambiguity made the grading even more time-consuming. In Curtis' case, the challenges he encountered impacted both his practices and conceptions of classroom writing use by eventually moving him away from using writing. Declan echoes the challenge of ambiguity.

> *Like the one I mentioned before about how do I come up with an objective grading criteria that the student can follow…Grading writing, I'll admit, I'm not the best at it. It's really difficult to take two papers and give an objective grade to both of them based on what they wrote. I'm a huge fan. I really try and build a lot of writing into my course. It's a pain in terms of grading, because it's hard to grade objectively, and it's a lot of work.* -Declan (Utilitarian, Statistics)

Both Curtis and Declan worry about not being objective in their writing. Part of this feeling may source from the broad qualities they desire from students in their writing, like argumentation or clarity. However, these features align with the Utilitarian's desire to develop students' technical writing and communication skills. Narrowing down the learning goals associated with writing tasks may help alleviate the ambiguity experienced while grading.

Ultimately, the Utilitarian viewed writing as a tool that students could use to engage in science. This tool could help students develop skills like argumentation or an understanding of the nature of science. More broadly, this tool itself required explicit

training. That is, the Utilitarian instructor perceived her role as helping students develop the writing and communication skills they would need to progress in their disciplines. This role was still shaped by challenges associated with incorporating writing. For the Utilitarian, a primary challenge was the lack of objectivity associated with evaluating writing.

The Writer

This type of faculty related writing to conceptual understanding, like the Idealists, and saw conceptual understanding as a desired outcome of the writing tasks that they assigned into their classes. The Writer, then, aligns closely with Writing to Learn (WTL) in both conception and practice. In contrast to any of the other faculty type, Writers did not view writing as a skill, but rather a process that broadly encompassed their practice as a scientist, thereby inseparable from scientific knowledge. Elliot illustrated this by equating writing to the act of discovery.

> *Without writing, we don't really know what it is we discovered, writing is part of thinking. Physics is hard enough that people rarely have, correctly, in their mind, what it is they've done until they write it up, and as part of writing it up, read what other people have written in draft and go back and refine it…Because you really don't know what you've done until you've finished the paper."* -Elliot (Writer, Physics)

Walter, a chemist, and Elizabeth, a computer scientist, justified the equation of writing with discovery based on a view of science as a social activity. Based on this view, Elizabeth believed her role as a computer science instructor was to teach students computer science by teaching them writing. The scientists above perceived writing and communicating as an integral part of the science that they do. For Writers, this view of writing as integral to the practice of science motivated their incorporation of it into their classes, illustrating how

faculty's conceptions of writing inform their practice. Walter explained how his view of the role of writing in science extends to his perspective of the role of writing in his classes.

> *Therefore, it is important that…you the student need to be able to communicate both orally, informally, formally and in writing. It's a substantial part of the work that the students do in my course is to work on communication.* -Walter (Writer, Chemistry)

Writers incorporate writing into their classes because they see it as necessary to teach science. For this reason, they connect students' writing with their understanding of science. This relationship between writing and content understanding is the most distinguishing feature of a Writer. As with the Utilitarians, conceptions of writing emerged from faculty's discussion of their desired outcomes for writing tasks in their classes. For some faculty, writing served as an effective form of assessment, while for others, writing is the means to developing that understanding. For some Writers, these two goals were not separate. Elliot incorporated authentic physics writing with research proposals and peer review into his classes for two reasons. He viewed writing tasks as a way to reveal students' understanding (assessment) but also discusses how the act of writing prompts students to "understand things at a deeper level." Ed further expands on the capacity of writing to fulfill both an assessment and knowledge-building goal.

> *Part of what I want them to be able to do is reason their way through a problem, is connecting concepts that they're learning from other parts of the course, or they had walking into the course, with new knowledge. Writing is a very straightforward way… to find out if they can do that. From an assessment standpoint, a question where I can get them to write a little bit is actually much more effective for me in terms of knowing I've accomplished what I want to accomplish than just a multiple-choice question or a*

true/false, or some of the quick and easy that are more common in big, big courses. To the degree that I can make that happen, I try to because that's how I know I've actually gotten where I want to get to. -Ed (Writer, Earth Science)

Ed views writing as a way to help students "reason their way through a problem" and build new knowledge, while serving to inform him of whether or not students have developed that knowledge and problem-solving ability. Underlying this view of writing as a means of achieving learning is a priority of conceptual learning, which "punching buttons on their calculator" or "multiple choice question(s)" fail to assess effectively. One characteristic, then, of the Writer is ultimately a desire to promote students' conceptual understanding with their instruction. Roger, a computer scientist, shows how this goal for writing tasks directly contradicts the Utilitarian perspective.

I'm trying to both reinforce the learning, and measure them. That's the purpose of the exam, or the assignment. I'm trying to get them, ultimately part of what they're supposed to learn in class is what, but a much bigger part of what I try to teach them is why. I'm trying to literally reinforce or determine levels of comprehension with all the homework assignments, the programming assignments, and the exams. There's very little of what I teach that is a skill that I'm teaching them per se. It's all about comprehension. -Roger (Writer, Computer Science)

Roger claims explicitly that his objective is not to teach students a skill, but rather that writing is a means to support and reveal their comprehension. This is not to say that Writers did not value the same features of writing that were valued by other faculty (clarity, precision, and argumentation), but that these features pointed to a better understanding of the content itself.

Mark, who taught abstract algebra with a large emphasis on proof writing, specifically discussed how proof writing tasks in introductory mathematics courses could improve comprehension.

There definitely should be. There definitely should be because I think one of the big changes in common core is math has really been here is the algorithm you apply to multiple 2, 3 digit numbers together. You do this, you do this, you do this, without real comprehension of what's going on behind the scenes and that makes it much less sticky. If you really understand what you're doing on a more theoretical level, I don't know that you need to prove every statement, but if you understand what's going on behind the scenes, it makes it much easier to remember. -Mark (Writer, Mathematics)

Mark believes that developing proof-writing skills (as he describes earlier in his interview) promotes comprehension. In the context of mathematics, writing could be a way of moving students beyond algorithmic problem solving to building a conceptual understanding. Underpinning this view of the potential of writing tasks for achieving learning is the value assigned to conceptual understanding.

It is clear that the Writer sees many benefits of using writing that ultimately motivates them to implement it in their classes. However, they still report challenges that they encounter in using writing. One of the primary challenges is the time it requires to evaluate students' writing. Trevor, an engineering instructor, succinctly explains that "It's fundamentally a scaling problem." For this reason, time becomes a very significant constraint for large introductory classes.

I don't use writing exercises much or at all in 101, because the classroom is too big. I don't have the teaching assistants to help me grade it, so I very rarely get them to

write...The other part of that is in terms of time, is that I'm still pre-tenure. In practice, what that means is that I can't afford to spend hours on grading because I have to be writing my own stuff. -Alexandra (Writer, Geology)

Alexandra specifically cites the difficulty of other time constraints that she faces, including her own scholarship and pre-tenure obligations. For the Writer, part of what makes grading time-consuming is the difficulty of grading writing well. Trevor discusses this challenge in his engineering courses.

Interviewer: *Do you feel like you're able to evaluate all of the writing assignments the way that you would like?*

Trevor: *No, there's absolutely no time to do that. I can only do it during, the assignments basically have to be turned in the week that there is no classes, so then in essence takes the entire Thanksgiving week to try and grade them.*

[Questioned about motivation for using writing]

Trevor: *Critical thinking. So much of what we do is, it's easy to grade stuff that's [not] real learning, but to have students actually do original work, you're going to end up with things that then become very, very difficult to grade and to provide good feedback to the student.* (Writer, Engineering)

Trevor's claim that "it's easy to grade stuff that's not real learning" perhaps best summarizes the Writer's perspective that writing is an activity resulting in "real" learning. The nature of writing tasks intended to help students build knowledge makes them inherently more difficult to evaluate. For Writers, writing is valuable for revealing students' understanding and this often justifies the effort required to grade. This driver does have limitations, such as large

introductory classes. For both Utilitarians and Writers, these obstacles are significant enough to making implementing writing tasks infeasible in some cases.

Limitations

As faculty self-selected to participate in these interviews (by indicating willingness on their survey and responding to recruiting emails), it is likely that faculty with existing and potentially strong opinions about writing chose to participate. That is, this study represents people who "had something to say." A strength of this study is the consideration of faculty from research-intensive institutions. However, we recognize that both their conceptions of writing and the extension of those conceptions to the classroom are shaped by their roles at these institutions. The typologies presented in this work likely do not fully encompass either faculty's conceptions of writing or practices of classroom writing at less research-intensive, primarily undergraduate, or liberal arts institutions. Finally, the categorization of writing users as LTW or WTL was an artifact of our analysis. That is, we are not claiming that the faculty themselves would subscribe to those conceptualizations of writing. The results presented above do not characterize faculty's conceptions of LTW or WTL. We propose this typology as a powerful tool for understanding potential adopters, but recognize that not all faculty may fit entirely into one type.

Discussion and Implications for Research and Practice

This study was motivated by the goal of incorporating writing into the postsecondary classroom by understanding the conceptions of writing held by potential adopters in the STEM classroom. The core conceptual difference between writing non-users (Traditionalists and Idealists) and users (Utilitarians and Writers) is a difference between additive and transformative perspectives of writing (Barrie, 2006), where an additive perspective considers

writing as additional to disciplinary knowledge and transformative perspective considers writing as having the potential to transform disciplinary knowledge. This difference was identified by Barrie (2006) in the context of faculty conceptions of generic graduate attributes (GGAs), which are non-disciplinary knowledge related skills students should possess upon completing a degree. Written communication is often considered to be a GGA, so it is not surprising our study elicited a similar range of conceptions. In our study, for both the Traditionalist and the Idealist, writing is an external component that can be added in or removed from the curriculum without affecting what is considered key knowledge within that course. In the case of the Traditionalist, writing is completely extraneous as it should have been taught before students enter university or through other coursework within the university. For the Idealist, however, writing can, but is not necessary to, support learning. Therefore, in working with faculty of this type, we should aim to support a conceptual shift from an additive to a transformative perspective by showing ways in which writing is a key tool for understanding content and by minimizing practical barriers that inhibit this conceptual shift. For example, Idealists are less likely to think deeply about ways in which writing can be useful for supporting their students' learning when confronted with a large course for which evaluating writing is too high an instructional burden.

Though conceptual change from additive to transformative perspectives of writing can lead to the incorporation of more writing in the classroom, there are still challenges to using it effectively as well as a wide variety of ways writing is viewed as valuable. Both the Utilitarian and Writer adopt a transformative perspective, evidenced by their deliberate incorporation of writing into their classes. We believe the variety of ways writing is conceived of and used by writing users can be explained by their view of the relationship between writing and disciplinary knowledge (Barrie, 2007). For the Utilitarian, writing is one

of multiple tools that can support application of disciplinary knowledge in the form of effective communication, better argumentation, or increased clarity, to name a few (Reynolds et al., 2012). There were two perspectives captured by the Writer. The first was that writing is equivalent to disciplinary knowledge, which reflects a rather sophisticated view of the role of writing in science (Halliday & Martin, 1993; Keys, 1999; Norris & Phillips, 2003). The second perspective posited by the Writer was the view of writing as a domain-general mode of learning, aligning with cognitivist perspectives of writing (Emig, 1977; Galbraith, 2009). Both of these perspectives align with the enabling perspective elicited by Barrie (2007), where writing enables learning of disciplinary knowledge.

Despite these conceptual differences, there were some consistencies across faculty that we believe come with increasing disciplinary specialty (Coppola & Krajcik, 2013). Namely, participants showed a consensus on what was considered good writing and a view of writing as a multimodal activity. Interviewees identified features of good writing as clarity, precision, and persuasiveness. Faculty did not, however, expand on how to identify this in text. In fact, the Utilitarian specifically demonstrated a conflict between perceiving these features as learning outcomes of writing tasks, but being frustrated with the lack of objectivity in grading essays for these features. We argue that while there was broad consensus on what is desirable in writing, faculty have under conceptualized how to identify good writing, relying on their intuition and tacit knowledge and that this may contribute to difficulty grading. The view of writing as multimodal was evidenced by the consistent inclusion of more than just text production when discussing writing. Instructors discussed figure captions, graph explanations, laboratory reports, mathematical proofs, computer code, manual pages, presentations, and then, of course, more traditional text forms—term projects, thesis writing, literature reviews, and extended response. Most of these forms include multiple modes of

representation (e.g., graphical visuals, equations, data). More importantly, there were a variety of writing forms considered within and across faculty types. This evidence demonstrates that increased disciplinary specialty includes indistinguishable use of multiple modes of representation (Airey & Linder, 2009, 2017; Lemke, 1990) though even very young students rely on multiple modes when free to write as they wish to complete a task (Bjorkvold & Blikstad-balas, 2017), which further justifies a shift in the writing-to-learn community towards multimodal and multimedia tasks (Klein & Boscolo, 2016; Prain & Hand, 2016). Aligning with Airey and Linder's (2009) assertion that discursive fluency is inherently multimodal, we argue that faculty consider writing to be inherently multimodal and that to support disciplinary discursive fluency in students, there must be repeated practice opportunities (Airey & Linder, 2009, 2017; Prain & Hand, 2016; Klein & Boscolo, 2016).

The results from this work—differing conceptions of the relationship between writing and disciplinary knowledge—will inform how these repeated practice opportunities are offered. The perspective espoused by the Utilitarian that writing is one tool used within a discipline resulted in the implementation of a variety of writing tasks with a variety of learning goals. One challenge voiced by Utilitarians was the lack of objectivity in evaluating writing. This challenge sources from broad and potentially vague learning goals (e.g., students will become better communicators) and a misalignment between learning goals and writing assignments. To overcome this challenge and improve incorporation of repeated practice opportunities in these faculty's classes, we recommend professional development specifically supporting the delineation of clear and achievable learning goals and design of writing assignments that develop students along those goals.

The perspective voiced by Writers in which writing was equated to the construction of disciplinary knowledge aligns with the view of WTL posited by Kelly and colleagues (Kelly & Takao, 2002; Kelly & Bazerman, 2003; Kelly, Regev, & Prothero, 2007; Takao & Kelly, 2003). In this ongoing inquiry, authors used extensive and authentic disciplinary writing (i.e., mid-term papers using geological data to make claims) as a way of supporting students' epistemic reasoning. By giving students the opportunity to do extensive writing in a deeply disciplinary way, they were able to develop an understanding of how disciplinary knowledge is constructed and justified (Kelly & Takao, 2002; Kelly et al., 2007). The value of this perspective is the provision of rich, deeply disciplinary activities in the classroom, but as the Writers said, these sorts of tasks are not feasible for large, introductory classes. For these faculty, then, we recommend relaying the value of smaller writing tasks that achieve smaller learning goals in order to ensure the repeated practice opportunities suggested by Airey and Linder (2009). Finally, the Writer who views writing as the key way to support "real learning" is at risk of believing that any writing task can support learning, which is contradicted by the mixed results from WTL studies (Klein & Boscolo, 2016). To ensure the design of activities that maximize student outcomes, we recommend supporting these faculty by sharing the variables that mediate WTL effectiveness (Klein, 2015) and the disciplinary enculturation that can be supported by writing (Prain & Hand, 2016).

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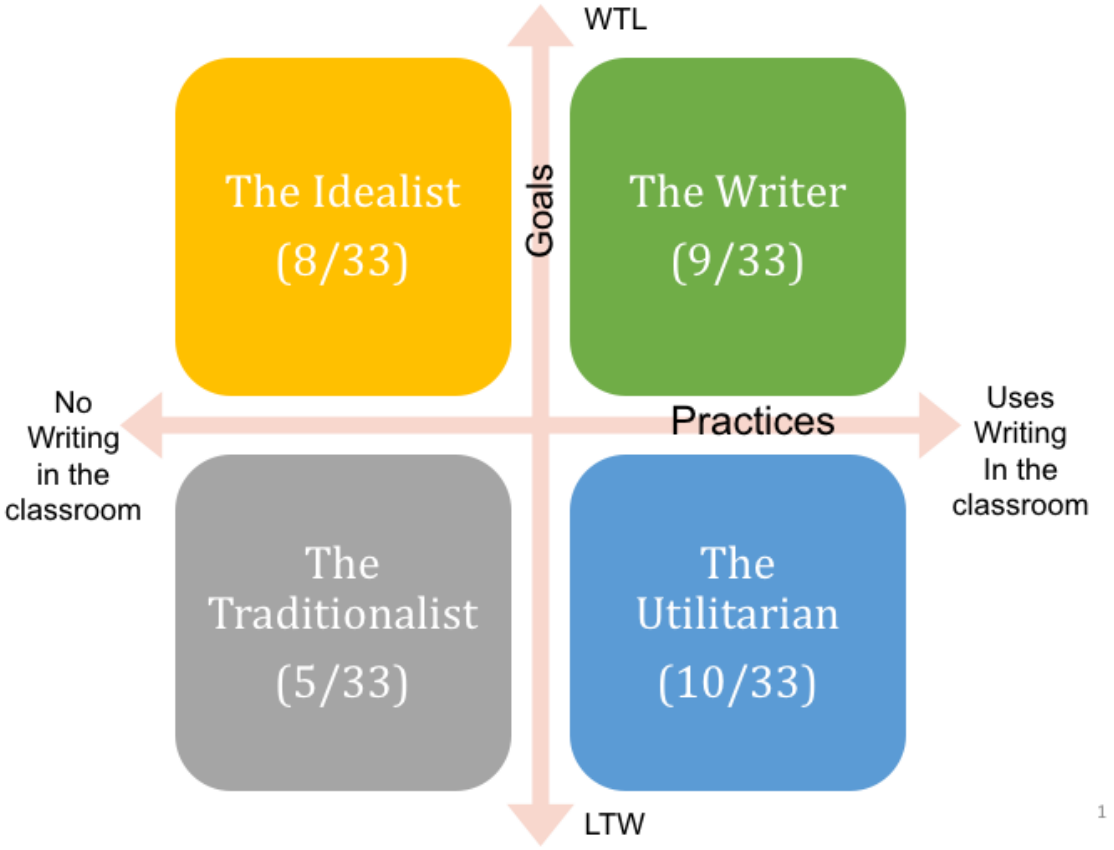
Figure 1. Placement of each faculty typology along two axes—goals and practices—with the number of faculty from this study that were categorized in each.



Tables and Figure Caption

Table 1. Discipline and position demographics of participants

		Discipline						
		Computer Science	Biology	Physics	Engineering	Chemistry	Mathematics	Earth Science
Position	Lecturer	2	1	1	2	0	1	0
	Assistant Professor	0	1	2	2	1	3	1
	Associate Professor	1	1	0	1	1	1	0
	Professor	1	2	1	1	3	0	0
	Non-tenure Faculty	0	0	0	0	1	1	0

Table 2. Demographic information, discipline and position, about participants in each faculty profile.

Idealist		Writer	
Disciplines	**Position**	**Disciplines**	**Position**
Engineering	Lecturer	Engineering	Lecturer (2)
Computer Science	Assistant professor (3)	Computer Science (2)	Assistant professor (2)
Biology	Associate professor	Earth Science (2)	Associate professor (2)
Chemistry (2)	Professor (2)	Physics	Professor (2)
Physics	Non-tenure	Mathematics (2)	Non-tenure
Mathematics (2)		Chemistry	
Traditionalist		**Utilitarian**	
Disciplines	**Position**	**Discipline**	**Position**
Biology	Lecturer (2)	Engineering (3)	Lecturer (2)
Physics	Professor (3)	Chemistry (3)	Assistant professor (5)
Mathematics		Biology (3)	Associate professor (2)
Chemistry		Mathematics	Professor (2)
Computer Science		Physics	