

How Faculty Discipline and Beliefs Influence Instructional Uses of Writing in STEM Undergraduate Courses at Research-Intensive Universities

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Abstract: Efforts to accelerate the pace of adoption of writing-to-learn (WTL) practices in undergraduate STEM courses have been limited by a lack of theoretical and conceptual frameworks to systematically guide research and empirical evidence about the extent to which intrapersonal attributes and contextual factors, particularly faculty beliefs and disciplinary cultures, influence faculty use of writing assignments in their teaching. To address these gaps, we adopted an ecological systems perspective and conducted a national survey of faculty in STEM departments across 63 research-intensive universities in the United States. Overall, the findings indicated that 70% of faculty assigned writing. However, the assignment of writing differed by faculty demographics, discipline, and beliefs. More specifically, faculty demographics accounted for 5% of the variance in assignment of writing. Faculty discipline accounted for an additional 6% increment in variance, and faculty epistemic beliefs and beliefs about effectiveness of WTL practices and contextual resources and constraints influencing the use of writing in their teaching together accounted for an additional 30% increment in variance. The findings point to faculty beliefs as salient intervention targets and highlight the importance of disciplinary specific approaches to the promotion of the adoption of WTL practices.

Keywords: Faculty beliefs, STEM, Writing-to-learn



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Research evidence across several decades indicates that writing can be effective in promoting student learning and engagement (Bangert-Drowns et al., 2004; Graham et al., 2020; Klein & Boscolo, 2016; Rivard, 1994). Furthermore, writing is a means for making thinking visible (Reynolds et al., 2012) and learning how to “think like” and “write like” disciplinary experts (Meizlish et al., 2013). However, writing-to-learn (WTL) practices are not always effective (Klein & Boscolo, 2016) and, similar to evidenced-based practices in general (National Research Council, 2012), WTL practices are not widely implemented in STEM education (Moon et al., 2018; Reynolds et al., 2012).

In writing research and education, writing-to-learn (WTL) is generally differentiated from learning-to-write (LTW) with regard to the learning objective. In LTW the purpose is to learn the writing conventions of particular genre or discipline, whereas in WTL the purpose is to use writing to enhance learning. WTL practices include a large number of activities. For example, a recent meta-analysis of 56 studies defined WTL as “the use of writing as a vehicle for strengthening, extending, and deepening students’ knowledge” (Graham et al., 2020, p.181). Across the studies, WTL activities included: “using writing to summarize information, compare and contrast ideas, connect new and old information, describe one or more processes, explain how something works, create a story or poem to illustrate or extend ideas, construct analogies, and build an argument. It also included taking notes about content material being learned or using writing to complete graphic organizers/mind maps to represent the conceptual or structural relationships of content information” (Graham et al., 2020, p.181).

In general, national survey findings indicate that faculty in science and engineering fields are aware of evidence-based instructional practices, but there is a gap in translating research into practice (National Research Council, 2012). This gap has led to efforts to promote adoption of evidence-based educational practices, but progress has been limited (National Research Council, 2012). Furthermore, there is limited empirical evidence regarding faculty instructional practices across STEM disciplines at the undergraduate level (National Research Council, 2012). More specifically with regard to WTL in science education, progress has been limited by the absence of theoretical and conceptual frameworks to systematically guide research and integrate findings about the factors that mediate and moderate both the effects of writing on student learning and STEM faculty assignment of writing (Reynolds et al., 2012).

Ecological systems perspectives (Bronfenbrenner, 1976) view learning and development as influenced by the mutual transactions among three factors: biological and behavioral characteristics of the person; characteristics of proximal and distal layers of the environment; and time, both historical and within the life course. Ecological systems perspectives are increasingly recognized as the necessary conceptual frameworks for investigating how intrapersonal attributes, in

transactions with educational practices, influence learning and development (Thompson et al., 2019). The focus is on the person-context transaction as the unit of analysis and the aim is to identify the mutual influence among intrapersonal attributes, such as epistemic beliefs, mastery motivations, and dispositions (Dowd et al., 2019), and contextual factors, such as task characteristics, cultural norms, and institutional resources and constraints. With regard to promoting the effectiveness and use of WTL in STEM, an ecological systems perspective identifies two interrelated research needs. First, an increased understanding is needed regarding which specific WTL practices are effective with diverse subgroups of students in specific contexts. Second, faculty WTL practices within and across STEM disciplines, and the intrapersonal attributes and contextual factors that influence faculty assignment of WTL in their undergraduate courses, need to be identified. To address this second research need, we conducted a national survey of faculty WTL practices in STEM departments across 63 research-intensive universities in the United States. Not only do research-intensive universities educate the largest number of students in the United States, they provide a particularly rich context for examining the role of institutional and disciplinary context, in transaction with faculty intrapersonal attributes, in educational practices and student learning.

1. Literature review

The literature review is selective and aims to establish the context for the research questions and conceptual frameworks for integrating findings. The review is organized in four sections: the influence of writing on student learning; the influence of faculty beliefs on instructional decision-making; sociocultural influences on faculty beliefs and educational practices; and promoting adoption of WTL in STEM.

1.1 The Influence of Writing on Student Learning

Research on the influence of writing on student learning, important in itself, has implications for promoting faculty use of WTL in their undergraduate STEM courses. Beyond persuasive evidence that writing activities can enhance students' learning of science concepts and principles, faculty interested in incorporating writing into their teaching need to know the *effective ingredients* (Klein, 2015) of writing assignments with diverse subgroups of students.

The review by Klein and Boscolo (2016) identified several trends in the methods and findings of research on writing as a learning activity that advance the identification of the effective ingredients, such as the inclusion of theories and research that integrate social and psychological processes. In addition, the use of sophisticated analytic tools, such as meta-analysis and path analysis, has resulted in consensus that writing activities improve students' reading comprehension and learning, but with small to medium effects sizes. There is also consistent evidence

of moderator effects, such as learning gains being affected by personal characteristics (Dowd et al., 2019) as well as the characteristics of the writing assignment (Anderson et al., 2015; Gere et al., 2019). In addition, metacognitive reflection has been found to be a significant mediator of the extent of learning gains from writing activities (Bangert-Drowns et al., 2004).

One of the characteristics of writing assignments associated with enhancing learning is the extent to which the writing elicits cognitive and metacognitive processes known to be associated with learning and conceptual change (Gere et al., 2019). For example, there is evidence that learning protocols, which involve writing assignment performed as a follow-up to course work activity, can be effective in enhancing learning outcomes (Berthold et al., 2007). These writing assignments provide students with an opportunity to engage in planning, drafting, and revising. However, learners may not spontaneously apply the writing learning protocol in an optimal way to realize the benefits. To optimize the impact of the learning protocols, Berthold and colleagues (2007) examined the effectiveness of prompts that aimed to elicit cognitive process (e.g. organization; elaboration), metacognitive processes (e.g. monitoring; self-regulation), or both with undergraduate psychology students. Findings indicated that learners who received cognitive or mixed prompts employed more cognitive learning strategies and learned more than those who participated in the cognitive prompts only or control conditions, and the use of cognitive learning strategies mediated the learning gains.

Efforts to delineate *effective ingredients* also examine personal factors in terms of the educational level of the students and context in terms of subject matter. In a recent meta-analysis of 56 studies, Graham and colleagues (2020) found that writing about content reliably enhanced learning (effect size ($d = 0.30$)) and was equally effective at improving learning in science ($d = 0.30$), social studies ($d = 0.33$), and mathematics ($d = 0.32$) among elementary, middle, and high school students. However, writing did not always enhance learning, as reflected in a negative effect in 18% of studies. Writing-to-learn effects were not moderated by the features of writing activities, instruction, or assessment even though there was considerable variability in effects (effect sizes ranged from 1.67 to -0.74). For example, the average weighted effect size for writing-to-learn treatments that involved analysis and interpretation of content material was 0.36, and 0.18 for writing that involved recording information, and 0.40 when the writing-to-learn treatment involved metacognitive prompting and 0.15 when it did not include such prompting, but these differences did not reach significance. This finding is in contrast to the finding in the Bangert-Drowns et al. (2004) meta-analyses that use of metacognitive prompts did moderate learning. Graham and colleagues (2020) suggests that the difference in findings may be because the Bangert-Drowns study included college students. Because of insufficient documentation Graham and colleagues (2020) were not able to examine if the social, cultural, institutional, political, and historical factors also

accounted for variability in study effects. Graham and colleagues (2020) suggested that future meta-analyses with more statistical power will be more successful in identifying factors that moderate writing-to-learn effects and also enable examination of the interactions between potential moderators.

Ecological systems perspectives incorporate a historical contextual dimension with regard to changes over time in educational practices, that influence person-context transactions and learning. For example, Russell (2002) traced the progression of writing instruction in conjunction with changes in education in the United States. Early in the history of mass education “writing was primarily thought of as a way to examine students, not to teach them, as a means of demonstrating knowledge rather than of acquiring it.” (Russell, 2002, p.6). Over time the expansion of specialized knowledge transformed the focus from general education to specialized disciplinary and profession education. Correspondingly, the view of writing progressed from a generalizable skill, as reflected in a focus on rhetoric and then general composition, to writing as central to creating new knowledge and embedded in the differentiated practices of text-based discourse communities. In accordance with Bereiter and Scardemalia’s (1987) distinction between processes of knowledge telling and knowledge transforming, writing was recognized as a means of fostering conceptual learning and acquiring ways of thinking in field (Gere et al., 2019).

Forms of knowledge, epistemic criteria for justification of knowledge claims, and processes of reasoning differ across disciplines (Sandoval, 2016). Klein and Boscolo (2016) argued that the recognition that writing is “intertwined with disciplinary forms of communication, inquiry, and argumentation” (p. 324) prompted a shift in the conception of writing from the relatively domain-neutral *Writing Across the Curriculum* (WAC) approach toward a more domain-specific *Writing in the Disciplines* (WID) approach. WID developed in recognition that disciplines are characterized not only by distinct ways of knowing and writing but also that writing is a way of knowing in a discipline (Carter, 2007). Russell (2002) argues that WAC “has always been concerned with ways knowledge is made in the disciplines” (p. 312) and that separating writing-to-learn from writing like those in the field is difficult “without sacrificing a deep understanding of the field. What counts as good writing in a course or a field is profoundly shaped its questions, goals, methods, and epistemology” (p.314). Correspondingly, there has been widespread implementation in undergraduate education of both WAC and WID programs to promote the adoption of WTL educational practices to foster domain general and domain specific student learning, respectively (Thaiss & Porter, 2010). More recently, the department-located Writing-Enriched Curriculum (WEC), draws on both WAC theories and WID research in its focus on putting faculty members in charge of aligning writing and writing instruction with learning goals. WEC engages department faculty members in a series of data-driven conversations related to

writing expectations and instructional practices. Ultimately, the faculty devises, implements, and assesses a locally-relevant approach to incorporating writing and writing instruction into its local curriculum (Flash 2016, 2020).

1.2 The Influence of Faculty Beliefs on Instructional Decision-Making

Ecological systems perspectives focus on the person-context transaction. Within an ecological systems perspective, sociocultural conceptual models add specificity regarding the influence of personal and contextual factors on behavior that are serving to guide research efforts and integrate findings about effective educational practices. In particular, there has been a focus on the role of faculty beliefs in instructional decision-making (Hora, 2014) and the Theory of Reasoned Action (TRA) (Aizen & Fishbein, 1980; Fishbein & Ajzen, 2010) is serving to elucidate the complex roles that different kinds of faculty beliefs, including epistemic beliefs about the nature of knowledge, beliefs about disciplinary norms, and beliefs about institutional resources, play in enacting educational practices.

Conceptual framework. The Theory of Reasoned Action (TRA) posits that beliefs influence behavior and are influenced by sociocultural factors. Beliefs reflect a person's representation of reality - what is held to be true whether or not evidence supports the claim (Fives & Buehl, 2016). TRA focuses on the role of three kinds of beliefs: outcome expectancies, perceived norms, and control beliefs. Outcome expectancies are the person's "positive or negative evaluation of their performing the behavior" (Fishbein & Ajzen, 2010, p. 20) and reflect their attitude - "a latent disposition or tendency to respond with some degree of favorableness or unfavorableness" (p.76). Perceived norms refer to perceived social pressure either to engage or not engage in the behavior and reflect a person's beliefs about whether important individuals or groups would approve or disapprove of their performing the behavior. Control beliefs refer to beliefs about facilitators and barriers to performing the behavior that result in a sense of high or low self-efficacy or perceived behavioral control (Bandura, 1997). Together, the attitude toward the behavior, perceived norms, and perception of behavioral control lead to the formation of a behavioral intention or a readiness to perform the behavior. The stronger the beliefs, the stronger the intention to carry out the behavior. Numerous studies have provided support for the influence of beliefs on behavior. For example, Fishbein and Aizen (2010) report that meta-analytic reviews, covering a broad range of behavioral domains, found intention-behavior correlations ranging from .45 to .62. Similarly, correlations of attitudes, perceived norms, and perceived behavioral control with intentions ranged from .59 to .66.

Types and functions of faculty beliefs. Fives and Buehl (2016; 2017) argue that three sets of teachers' beliefs shape their educational practices. Teachers hold beliefs

about teaching as student-centered or teacher-centered; epistemic beliefs about knowledge across the dimensions of certainty (unchanging or fluid), simplicity (isolated or connected), source (external authority or constructed), and justification (processes and criteria for adjudication knowledge claims); and beliefs about whether student abilities are fixed or malleable. Beliefs have influence through serving three functions (Fives & Buehl, 2017). Beliefs serve as filters through which experiences and exposure to new ideas pass and can be self-perpetuating, since events are interpreted in ways that are consistent with prior beliefs. Beliefs also serve as frames through influencing how a task is conceptualized and as guides through providing expectations and evaluative standards for when and how to act. Fives and Buehl (2017) identified teachers' epistemic beliefs in particular as influencing their decisions about educational practices and the need to examine the role of epistemic beliefs in the context of other beliefs.

Faculty beliefs about the nature of science. Yore, Hand, and Florence (2004) argued that in order to better understand the roles of writing in doing and learning science it is essential to understand scientists' ontological assumptions and epistemic beliefs about science. Yore and colleagues (2004) identified three groupings of ontological and epistemological beliefs. *Traditionalists* (realist ontology & absolutist epistemology) assume a real world exists independent of human mental activity that can be discovered and accurately described through experience and reasoning, and view scientific knowledge as a collection of absolute truths that is unchanging. *Modernists* (naïve realist ontology & evaluativist epistemology) assume that there is a real world beyond sensory perception, and view scientific knowledge as a set of temporary descriptions and explanations that best fit current understandings of the real world. Modernists do not view claims as absolute but only as supported or falsified through hypotheticodeductive reasoning. Although some claims are unlikely to change, over time claims are expected to change and more closely reflect reality. *Postmodernists* (idealist ontology, relativist epistemology) deny the existence of a reality independent of human experience, and view scientific knowledge as consisting of multiple descriptions and explanations, and only true or false for a person or group at a particular time. Postmodernists consider different explanations as of equal value and deny that verification processes can be conducted.

Using these three groupings of ontological assumptions and epistemological beliefs, Yore and colleagues (2004) examined whether STEM faculty's views about the nature of science influenced their beliefs about the role of writing in knowledge construction. The study included 16 faculty (13 scientists and 3 engineers) from multiple STEM departments at a midsize Canadian University. The 13 scientists endorsed the modernist view of science indicating that they held a naïve realists ontology and an evaluativist epistemology. The findings also indicated consistency

between faculty holding an evaluativist view of science, and engineering as design, and viewing writing as knowledge building rather than knowledge telling.

The relationship between faculty beliefs and enacted educational practices. TRA posits that beliefs influence a person's *intention* to act. Although strongly predictive of behavior, *intention* is not the same as *actual behavior*. In a critical review of the research on the teaching beliefs and practices of university academics, Kane and colleagues (2002) found that research has primarily examined professors' *espoused* beliefs about their practices and not their actual practices. Disconnects between intentions and enacted practices are a potentially fruitful area for investigation of personal and contextual factors that facilitate or inhibit faculty acting on their beliefs and intentions.

Veal and colleagues (2016) found disconnects between what secondary science teachers (N = 78) believe and say about their teaching and their actual practices. Building on the TRA, Veal and colleagues proposed the *Normative-Discursive-Practice Model* that posits three key concepts that link instructor beliefs with actual classroom practices: *normative beliefs*, what a teacher considers ought to be done; *discursive claims*, what they say they do; and *observed behavior*, what they actually do. Teachers' discursive claims were found to be a better predictor of innovative teaching practices than normative beliefs. Although desired, direct observation of educational practices is not feasible for large-scale investigations. Whereas teachers' espoused beliefs about what ought to be done may not be consistent with their enacted practices, this study provides evidence in support of teachers' discursive claims as a strong indicator of their actual practices.

Trafimow and colleagues (2017) employed the TRA to examine what differentiates faculty who assign or do not assign writing in their undergraduate courses. Faculty responded to a survey about a specific action context: *requiring writing for at least 3 assignments in the most writing-intensive course that you teach this semester*. The relationship of faculty's intention to assign writing was examined with regard to their *attitudes* (like/dislike), *perceived difficulty*, *perceived control* about requiring the writing assignments, and *normative beliefs* (e.g. to what extent do most others who are important to you think you should not or should require writing?). The strongest predictors of faculty's intention to assign writing were their attitudes and perceived difficulty in requiring writing. The most frequently endorsed disadvantages of assigning writing were "grading the papers is time consuming" and "a great deal of effort is required to give useful feedback." However, it was not beliefs about disadvantages of requiring writing but rather the belief that assigning writing is good for the students that best predicted faculty intentions to assign writing. Trafimow and colleagues (2017) argued that one implication of the findings is that interventions aiming to increase faculty assignment of writing should be designed to persuade faculty that assigning writing would be beneficial to their students.

1.3 Sociocultural Influences on Faculty Beliefs and Educational Practices

Whereas faculty beliefs, particularly epistemic beliefs, have been found to influence their enacted educational practices, a sociocultural perspective calls attention to how faculty beliefs and teaching practices are influenced by social and cultural factors in the environment in which teaching is practiced (Russ et al., 2016). For example, Hora (2014) emphasized that educational practices are influenced by a combination of personal characteristics, disciplinary affiliation, and institutional context and by “an individual’s perception of the constraints and affordances related to a specific problem or task situation” (p.38). That is, faculty beliefs about constraints and resources bridge intrapersonal psychological factors and objective features of the context that may affect the use of writing.

Disciplinary cultures in particular shape what is taught and how it is taught (Umbach, 2007) such that what counts as effective teaching is context specific (Lund & Stains, 2015). For example, disciplines differ along various dimensions such as “hardness” or “softness,” reflecting the degree of consensus regarding the underlying paradigm, and faculty in “soft” disciplines fields have been found to attach greater emphasis to active learning methods than faculty in “hard” disciplines (Umbach, 2007). Writing in particular, from a sociocultural perspective, “is conceptualized in terms of interactive processes that include socialization into the discourses and epistemological features of a discipline” (Gere et al., 2019, p. 102). Specific writing genres shape and are shaped by disciplinary conventions and practices, and writing is a way of knowing in a discipline (Carter, 2007).

Not only do STEM disciplines differ in epistemic beliefs about the nature and justification of knowledge, there are disciplinary differences in faculty beliefs about student-centered and teacher-centered approaches to teaching and contextual factors that influence their educational practices. For example, Lund and Stains (2015) report that although STEM faculty are aware of the research regarding evidence-based instructional practices, only half report implementing one or more of these practices in their courses. Their study of faculty in the departments of chemistry ($n = 20$), biology ($n = 25$), and physics ($n = 15$) at a large research-intensive university in the USA found disciplinary differences in faculty implementation of evidence-based practices that were related to differences in faculty beliefs toward teaching approaches and perceived contextual influences. The physics faculty adopted three times more of the evidence-based practices (confirmed by observational data) than chemistry faculty and twice as many as biology faculty. The chemists were significantly higher on the information transmission/teacher-centered approach to teaching than both the physicists and biologists. With regard to influences on their teaching, chemists primarily reported impeding contextual influences (e.g. weak norms toward student-centered teaching, constraints on their time due to research expectations, and class size); physicists primarily reported supportive contextual influences; and biologists reported a balance of supportive

and impeding influences. The findings provide evidence that disciplinary differences in STEM faculty beliefs and perceptions of contextual factors influence adoption of evidence-based practices. Lund and Stains (2015) argue that one factor contributing to the research-practice gap has been the lack of attention to the fit of these practices with the variations in faculty beliefs about teaching and learning and norms across STEM disciplines.

Faculty beliefs about other contextual factors, such as barriers, rewards, and instructional resources also influence educational practices (Henderson et al., 2011). For example, a study of a large sample of college science instructors ($n = 584$) from across the USA who were trained in evidenced-based teaching (EBT) through participation in Summer Institutes for Scientific Teaching, found that perceived supports, and not perceived barriers, related most strongly to faculty report of use of EBT in their courses (Bathgate et al., 2019). Interesting, this is one of few studies that examined the influence of faculty characteristics and found that gender, ethnicity, and teaching experience (number of years) were not significant predictors of reported EBT implementation.

1.4 Promoting Adoption of WTL in STEM

Efforts at translating discipline-based education research into teaching practices “have been more effective at raising awareness of research-based practices than at changing practice” (National Research Council, 2012, p. 184). With regard to the efforts to promote change in instructional practices used in undergraduate STEM courses, Henderson, Beach, and Finkelstein (2011) reviewed 191 conceptual and empirical journal articles published between 1995 and 2008. The review identified two commonly used change strategies as ineffective in influencing instructional practices: developing and making available “best practice” curricular materials and “top-down” policy-making. Barriers to change included faculty beliefs regarding teaching and learning and institutional structures, including lack of recognition and rewards for improved instruction, lack of time, and lack of support. Henderson and colleagues (2011) argued that to be effective, change strategies must be “aligned with or seek to change the beliefs of the individuals involved; involve long-term interventions, lasting at least one semester; require understanding a college or university as a complex system and designing a strategy that is compatible with this system” (p. 952).

Efforts to change educational practices by changing beliefs have typically employed the conceptual change model (Posner et al., 1982). The model posits four necessary conditions for change: dissatisfaction with current conceptualizations plus an intelligible alternative conceptualization, from a credible source, that suggests the possibility of being useful (Murphy & Mason, 2006). Change in beliefs occur when the person, through interaction with their environment, becomes dissatisfied with their existing beliefs resulting in disequilibrium that is resolved by

restructuring their beliefs. Educational experiences have been found to promote changes in epistemic belief by evoking this conceptual change mechanism through challenging and refuting existing beliefs and providing plausible alternatives (Sosu & Gray, 2012).

The ecological systems perspective makes clear that conceptual change is not just an internal cognitive process that takes place within the individual's mind but is induced socially and the unit of analysis is the "individual's activity situated in the physical and social environment" (Mason, 2007, p. 5). Dialogue is an important catalyst for conceptual change which "is ultimately a matter of cognitive reconstruction and not merely the acquisition of membership of a community of discourse" (Mercer, 2007, p. 77). Focusing on the person-context transaction as the unit of analysis requires research that examines how personal factors, such as beliefs, and contextual factors, such as disciplinary norms and institutional resources and constraints, work together to influence faculty beliefs and decisions about educational practices.

2. Study Aims and Research Question

Faculty and program directors of teaching, learning, and writing centers, and *WAC/WID/WEC* programs interested in increasing the use and effectiveness of WTL practices in STEM education at research-intensive universities need increased understanding of both the effective ingredients of writing assignments with diverse subgroups of students and the fit of writing practices with variations in faculty beliefs and contextual factors across STEM disciplines. To address these two research needs, a multi-institutional project (University of Michigan; University of Minnesota, and Duke University), guided by an ecological systems perspective, was undertaken. The current study is the second in a series of studies addressing the second research need, examining how STEM faculty use WTL practices to promote student learning.

An initial study (currently under review) reported on the design and implementation of a faculty survey across 63 research universities in the United States that aimed to identify the types of writing practices STEM faculty report assigning in their undergraduate courses and faculty beliefs about the effectiveness of an array of writing practices for learning STEM content knowledge and beliefs about social and cultural factors influencing their assignment of writing. The majority of STEM faculty (69%) reported using writing in their undergraduate courses and viewed writing practices as generally effective. Compared with faculty who assigned writing, faculty who did not assign writing endorsed more strongly the influence of instructional constraints on their use of writing in their teaching.

The current study aimed to expand on the initial study by examining the influence of faculty demographic characteristics, discipline, and beliefs on faculty

assignment of writing. More specifically, this study addressed the following research question:

What are the independent and combined contributions to STEM faculty's decisions to assign writing in their undergraduate courses of faculty demographic characteristics, discipline, epistemic beliefs, beliefs about the effectiveness of specific writing practices, and beliefs about contextual resources and constraints that influence the use of writing in their teaching?

3. Methods

3.1 Faculty Survey Development and Item Dimensions

A faculty survey was designed by the authors with specific questions/items formulated to address the aims of the project. The survey also included demographic questions, including gender, ethnicity, discipline, number of years taught, undergraduate courses taught per year, graduate courses taught per year, and current position. The initial survey was piloted with a subset of 200 STEM faculty randomly selected from 63 research-intensive institutions ("The Carnegie Classification of Institutions of Higher Education, n.d.") and analyses were performed to identify and remove ambiguous and redundant items.

The survey included items to identify faculty at research universities who taught undergraduate students (yes/no) and among those who do, whether or not they assigned writing in their undergraduate courses (yes/no). Faculty who assigned writing were asked to identify a specific undergraduate course and were asked several questions about the size and format of the course. One question asked: *During the last academic year, how many times did you require students to engage in the following writing practices in this course* (using a scale ranging from none to 5 or more). The focus of the current study is on faculty responses about four specific writing practices: *Writing-to-learn* (i.e. writing assignments that are designed to contribute to the learning of disciplinary content); *Peer Review of Writing* (i.e. students share their writing and provide feedback to each other); *Revising Writing in Response to Feedback*; and *Scaffolding* (i.e. dividing a long piece of writing, such as a research paper, into sections so that students receive support as they complete parts). All survey respondents, both faculty who did and did not assign writing, were asked to indicate their beliefs about the effectiveness (not effective, rarely effective, somewhat effective, very effective) of these four practices *in promoting student's learning of STEM content knowledge (concepts/principles) in undergraduate science courses*.

All participants were asked to indicate the degree to which they agreed (strongly disagree, disagree, neutral, agree, strongly agree) with statements about the influence on the use of writing in their teaching of contextual factors the research literature has identified as potential resources and constraints to STEM instructional

practices (e.g. Henderson et al., 2011). The focus of the current study is on three statements related to beliefs about resources: *I have colleagues who share with me strategies and ideas about incorporating writing; I communicate with our campus center for teaching and learning about incorporating writing in my classes; and I communicate with our campus writing center about using writing in the classroom;* and four statements related to beliefs about constraints: *Covering all the material in my course does not leave instructional time to incorporate writing; My course is too large to incorporate writing; Writing is not important in my discipline; Faculty in my department are not encouraged to incorporate writing in their courses.*

One section of the survey addressed faculty's epistemic beliefs about the nature of knowledge and the process of knowing characterized along four dimensions (Hofer & Pintrich, 1997): the *certainty* of knowledge ranging from viewing knowledge as fixed and absolute to fluid, tentative, and evolving; the *simplicity* of knowledge ranging from viewing knowledge as simple, discrete, knowable facts to complex, interrelated, contingent, and contextual ideas; the *source* of knowledge ranging from transmitted from authority to constructed by the knower in interaction with texts, experiences, and others; and the *justification* for knowledge claims ranging from uncritical acceptance of facts and opinions to evaluating competing claims bases on reasoning and evidence. Based on the pattern of assumptions about these four dimensions, the focus of the current study is on faculty's personal epistemology, characterized as: *absolutist*, in which knowledge is assumed to be certain and known by authorities; *relativist* in which it is recognized that knowledge is constructed and uncertain and there are multiple views; and *evaluativist* in which knowledge is viewed as continuously evolving and justified on the basis of reasoning and evidence (Hofer & Pintrich, 1997). Characterization of respondent's epistemic beliefs was based on their response to the following prompt: *People hold different views about what constitutes knowledge about our physical and social worlds. Three general views have been identified. Please indicate which perspective best reflects your disciplined based view.* The three perspectives were constructed to reflect (a) absolutist (b) relativist, and (c) evaluativist epistemic beliefs: (a) *Knowledge is discovered and consists of facts that have been determined to be true and about which we can be certain. Knowledge claims are verifiable as right or wrong on the basis of objective evidence and standards;* (b) *Knowledge is constructed and uncertain and consists of opinions and interpretations that are subjective. People are entitled to their own opinion, and thus there are no bases on which to judge the merits of knowledge claims.* (c) *Knowledge is constructed, imperfect, and provisional and consists of objectively verifiable facts and subjective opinions and interpretations. The merits of knowledge claims can be judged against alternative claims on the basis of the quality of the arguments and evidence.*

3.2 Study sample

The study sample was generated from among faculty in STEM departments of 63 research-intensive institutions located in the United States (The Carnegie Classification of Institutions of Higher Education, n.d.) affiliated with the Reinvention Collaborative. Team members generated faculty email lists from the identified departments. Survey distribution, collection, and cleaning were performed by the University of Michigan's Institute for Survey Research.

The survey was sent to 29,430 faculty via an online survey system, where each participant received a personalized link. Respondents indicated their consent prior to beginning the survey. The overall response rate was 23% ($n = 6,828$). Responses from only a single discipline in a university were eliminated. Using an 80% response cut-off with respect to completion of the items pertinent to the research questions guiding this study resulted in a study sample of 4,981. Some of the participants did not respond to every item, which resulted in variation in response count per question. For the current study, the sample size was 4,505 for the descriptive analyses and 3,893 for the regression models due to missing values.

Of the respondents, 3,302 (73%) identified as male and 1,203 (27%) as female. The majority of participants were white ($n = 3,246$, 72%), followed by Asian/Pacific Islander ($n = 450$, 10%), Other ($n = 176$, 3%), Hispanic or Latino ($n = 124$, 2%), and African American or Black ($n = 70$, 1%). The remaining 439 (10%) did not indicate race/ethnicity. Underrepresented minority status (URM) was characterized as any participant who self-identified as African American or Black, Hispanic or Latino, Native American or American Indian, Other, or with two or more of these racial and ethnic groups ($n = 370$, 8%). Participants who self-identified as White or Asian/Pacific Islander were not included in the URM group. Table 1 shows faculty self-reported discipline, academic rank, and years of experience.

3.3 Data Analysis Plan

Univariate analyses were conducted to identify the percentage of faculty who assigned writing and the frequency of assignment of specific writing practices. Differences between faculty who assigned writing and those who did not were examined with regard to demographic factors, discipline, and faculty beliefs about the effectiveness of writing practices, epistemic beliefs, and beliefs about contextual factors influencing their use of writing in their teaching. We used logistic regression to compare categorical data (e.g., disciplines) and independent t-tests to compare mean differences. For the logistic regressions, odds ratios (OR) were reported and for the mean differences, effect sizes (d) were reported. To examine the independent and combined contribution of these variables to faculty assignment of writing, a sequence of logistic regressions were conducted, modeling the probability of the assignment of writing. Figure 1 depicts the order of

Table 1. Discipline, Rank, and Years taught

	n	%
<i>Discipline</i>		
Biology	504	11.88
Chemistry	441	9.79
Computer Science	308	6.84
Engineering	1104	24.51
Environmental Science	145	3.22
Geosciences	296	6.57
Math	538	11.94
Physics / Astronomy	314	6.97
Other discipline	260	5.77
Missing	595	13.21
<i>Rank</i>		
Lecturer	425	9.43
Assistant Professor	772	17.14
Associate Professor	865	19.20
Professor	1879	41.71
Other (e.g., postdoc)	564	12.52
<i>Years teaching</i>		
1-5 years	766	17.00
6-10 years	640	14.21
11-15 years	571	12.67
16-20 years	459	10.19
Over 20 years	1759	39.04
Missing	310	6.88

entry of the variables into the regression analyses: faculty demographic characteristics, followed by academic disciplines, and then faculty beliefs.

4. Results

4.1 STEM Faculty Assignment of Writing in their Undergraduate Courses

Across the sample, 3,169 faculty (70%) reported assigning writing in their undergraduate courses. Differences in assignment of writing were found by gender ($\chi^2(1) = 57.41, p < .0001$) with females reporting the assignment of writing in their courses 79% of the time compared to 67% for males. Differences in assigning

writing were found by race/ethnic identity with respondents who identified as white more likely to report assigning writing (74%) compared to all others (61%, $\chi^2(1) = 67.03, p < .0001$) and respondents who identified as Asian less likely to report assigning writing (53%) compared to all others (72%, $\chi^2(1) = 67.55, p < .0001$). With regard to faculty rank, Instructors were more likely to assign writing (76%) compared to all other ranks (70%, $\chi^2(1) = 7.20, p = .0073$).

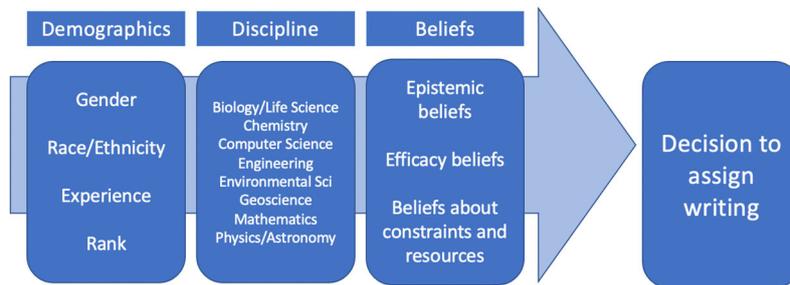


Figure 1. Order of entry of the variables into the regression analysis.

The assignment of writing also differed ($\chi^2 = 211.60, p < .0001$) by respondents' discipline. Figure 2 indicates the percentage of respondents within a discipline who reported assigning writing in their course ranging from a high of 91% of those in the Environmental Sciences ($OR = 2.54$) to a low of 59% in Mathematics ($OR = 0.37$).

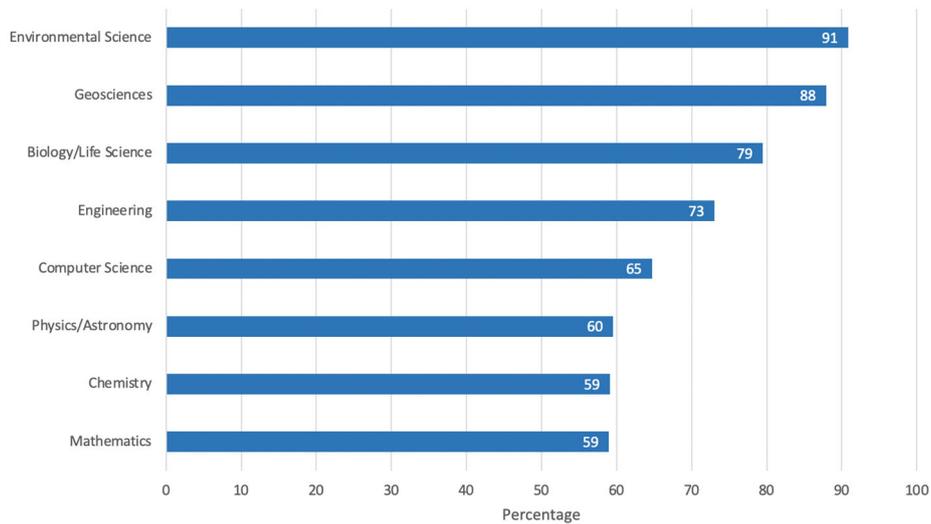


Figure 2. Percentage of faculty assigning writing by discipline.

4.2 STEM Faculty Assignment and Ratings of Effectiveness of Specific Writing Practices

All respondents to the faculty survey were asked to rate their view of the effectiveness of specific writing practices in promoting student's learning of STEM content knowledge, concepts, and principles in undergraduate science courses. Figure 3 shows the percentage of faculty who rated these practices as somewhat or very effective by whether or not they assigned writing. Faculty generally viewed each of these writing practices as effective in promoting student learning, but overall ratings of effectiveness (i.e., combined ratings of faculty who did and did not assign writing) differed by type of writing practice, with revising writing in response to feedback having the highest percentage, followed by writing-to-learn and scaffolding of writing, and peer review having the lowest.

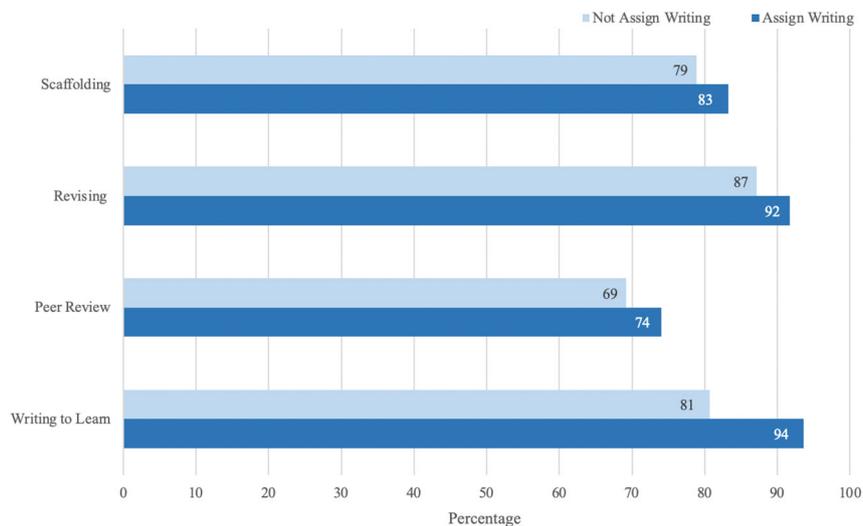


Figure 3. Faculty ratings of effectiveness of practice by assignment of writing.

Ratings of effectiveness also differed by whether faculty assigned or did not assign writing: (Writing to Learn: $\chi^2(1) = 165.70$, $p < .0001$; Peer Review: $\chi^2(1) = 10.90$, $p = .001$; Revising Writing: $\chi^2(1) = 21.61$, $p < .0001$; and Scaffolding: $\chi^2(1) = 11.63$, $p = .0006$). Faculty who assigned writing had higher mean ratings of the effectiveness of each of the four practices than faculty who did not assign writing, ranging from medium effect sizes for writing-to-learn ($d = 0.56$), to small effect sizes for revising writing in response to feedback ($d = 0.24$), scaffolding of writing ($d = 0.21$), and peer review ($d = 0.13$).

Faculty who assigned writing were asked to report how many times during the last academic year they required students to engage in specific writing practices in their course. The frequency of assignment differed by type of writing practice with writing to-learn as the most frequently assigned practice (75%), followed by revising writing in response to feedback (48%), peer review (32%), and scaffolding of writing (28%).

4.3 Faculty Epistemic Beliefs

Faculty epistemic beliefs were characterized based on their indication of which of three general perspectives best reflected their discipline-based view about what constitutes knowledge about our physical and social world: relativist (n = 64, 1%), evaluativist (n = 2880, 60%), and absolutist (n = 1817, 38%)¹. Figure 4 presents the percentage of faculty within each discipline who endorsed absolutist, relativist, and evaluativist epistemic beliefs. There were differences in faculty epistemic beliefs by discipline. A logistic regression was conducted, modeling the probability across all disciplines of endorsing evaluativist beliefs. Biology faculty (OR = 1.33) were more likely to endorse evaluativist epistemic beliefs whereas faculty in Chemistry (OR = .67), Engineering (OR = .56), Physics (OR = .55), and Mathematics (OR = .30) were more likely to endorse absolutists epistemic beliefs.

Figure 5 shows the percentage of faculty who assigned writing by both their discipline and by whether they endorsed evaluativist or absolutists epistemic beliefs. Faculty who endorsed evaluativist epistemic beliefs were significantly ($\chi^2 (1) = 70.36, p < .0001$) more likely to assign writing (76%) compared to faculty who endorsed absolutist epistemic beliefs (64%).

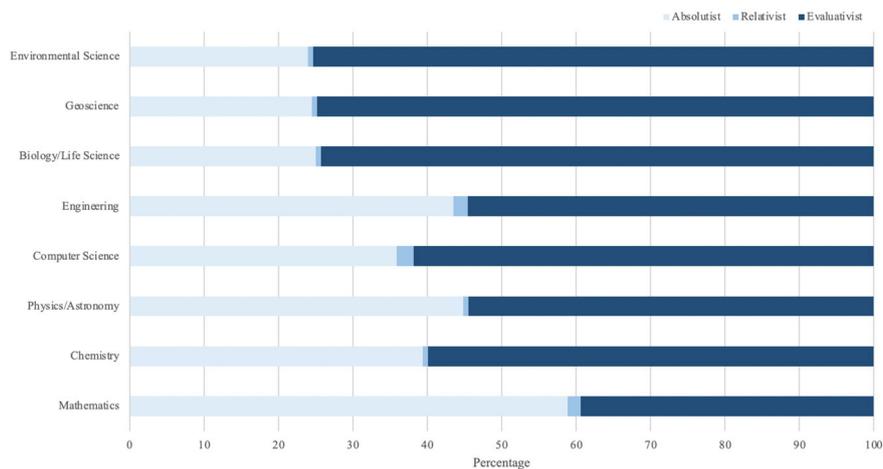


Figure 4. Percentage of faculty who endorsed absolutist, relativist, and evaluativist epistemic beliefs by discipline

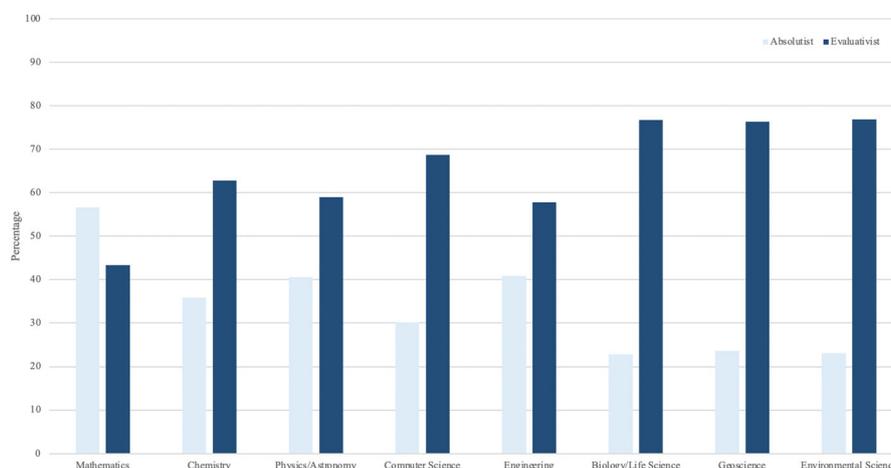


Figure 5. Percentage of faculty who assigned writing by absolutist and evaluator epistemic beliefs within each discipline.

4.4 Faculty Beliefs about Contextual Factors

Faculty views about contextual factors that influence the use of writing in their teaching differed significantly between faculty who did and did not assign writing. Faculty who assigned writing had higher levels of endorsement of use of three resource, with medium effect sizes for: *I have colleagues who share with me strategies and ideas about incorporating writing* ($d = 0.51$); and *I communicate with our campus Center for Teaching and Learning about incorporating writing* ($d = 0.43$); and small effect size for: *I communicate with our campus Writing Center about using writing in the classroom* ($d = 0.38$).

Faculty who did not assign writing had higher levels of endorsement of constraints with large effect sizes for: *Covering all the material in my course does not leave instructional time to incorporate writing* ($d = -0.82$); *My course is too large to incorporate writing* ($d = -0.85$); and *Writing is not important in my discipline* ($d = -0.77$); and medium effect size for *Faculty in my department are not encouraged to incorporate writing in their courses* ($d = -0.48$).

4.5 Independent and Combined Contributions to STEM Faculty Assignment of Writing

A set of logistic regression models were conducted, assessing the probability of faculty assigning writing in their undergraduate STEM courses. Model 1 includes demographic characteristics; Model 2 includes Model 1 variables and adds all discipline dummy variables; and Model 3 includes all variables from Model 2 and adds epistemic beliefs, and then adds those belief variables that significantly improve the model from the following list: faculty beliefs regarding effectiveness of

writing practices and contextual resources and constraints influencing the use of writing in their teaching. Table 2 shows the Wald estimate² and odds ratios for significant results across all 3 models.

Table 2. Logistic regression models assessing the assignment of writing

	Model 1		Model 2		Model 3	
	<i>X</i> ²	<i>OR</i>	<i>X</i> ²	<i>OR</i>	<i>X</i> ²	<i>OR</i>
<i>Demographics</i>						
Female	43.27***	1.76	23.23***	1.54	11.90**	1.45
Asian	60.38***	0.43	48.47***	0.46	18.26***	0.56
URM	3.58		4.18*	0.77	0.17	
<i>Rank</i>						
Instructor	0.08		0.06		1.79	
Assistant	0.02		0.47		0.01	
Associate	0.00		0.65		0.19	
Full	3.39		5.49*	0.66	1.24	
<i>Experience</i>	7.34**	1.10	6.98**	1.10	0.58	
<i>Discipline</i>						
Chemistry			23.23***	0.39	17.79***	0.37
Computer Science			11.89**	0.49	3.76	
Engineer			1.34		1.32	
Environmental Science			6.63*	2.51	2.86	
Geoscience			9.03**	2.14	3.62	
Biology			0.03		2.18	
Mathematics			22.37***	0.41	10.44**	0.47
Physics			20.87***	0.42	13.70**	0.42
<i>Epistemic beliefs</i>						
Absolutist					6.88**	0.79
<i>Effectiveness</i>						
Writing to Learn					73.31***	1.83
Peer review					8.15**	0.84
Scaffolding					5.92*	0.85

Table 2. Continued

	Model 1		Model 2		Model 3	
	χ^2	<i>OR</i>	χ^2	<i>OR</i>	χ^2	<i>OR</i>
<i>Constraints</i>						
Course too large					313.78***	0.50
Writing not important					150.76***	0.52
Not encouraged					13.10**	0.85
<i>Resources</i>						
Help from colleagues					27.45***	1.24
Teaching and Learning Center					19.65***	1.22
<i>R</i> ²	.05		.11		.41	
χ^2	130.80***		308.22***		1324.08***	
<i>Df</i>	8		16		25	

Note. * $p < .05$; ** $p < .01$; *** $p < .0001$

In Model 1, faculty demographic characteristics of gender, race, faculty rank, and years of experience were entered and together accounted for 5% of the variance in faculty assignment of writing. Three variables significantly affected the model. Being an Asian faculty member was associated with less likelihood of assigning writing ($OR = .43$) and being a female faculty member was associated with more likelihood of the assignment of writing ($OR = 1.76$). There is a positive linear relationship between years of experience and writing, with those who have been teaching longer slightly more likely to endorse writing ($OR = 1.10$).

In Model 2, faculty disciplines were added to the model and the amount of variance accounted for increased to 11%. Faculty in Chemistry ($OR = .39$), Computer Science ($OR = .49$), Mathematics ($OR = .41$), and Physics ($OR = .42$) were less likely to assign writing while those in Environmental Science ($OR = 2.51$) and Geosciences ($OR = 2.14$) were more likely to assign writing.

In Model 3, faculty epistemic beliefs were added first and then faculty beliefs about the effectiveness of specific writing practices and resources and constraints influencing their assignment of writing were added in a stepwise approach with competitive order of entry based on significant increment in amount of variance

accounted for in the assignment of writing. The overall model is significant and the R^2 improves to .41, indicating that we can account for 41% of the variance in STEM faculty assignment of writing through the utilization of all of the variables in the model. Some of the earlier variables that were significant are no longer significant; however, being female ($OR = 1.45$) is still associated with more likelihood of assigning writing and being Asian ($OR = .56$) is still associated with a lower likelihood of the assignment of writing. Being faculty in Chemistry ($OR = .37$), Mathematics ($OR = .47$), and Physics ($OR = .42$) still indicated less likelihood of the assignment of writing. Adding the faculty belief variables increased the amount of variance accounted for in faculty assignment of writing by 30%. Endorsing absolutist beliefs was significantly associated with less likelihood of assignment of writing ($OR = .79$). Faculty beliefs about the effectiveness of writing-to-learn ($OR = 1.83$) was positively associated with the assignment of writing, whereas peer review ($OR = .84$) and scaffolding of writing ($OR = .85$) were negatively associated with the endorsement of writing. Faculty beliefs about constraints related to the use of writing in teaching were all negatively associated with the assignment of writing. These included beliefs that: *My course is too large to incorporate writing* ($OR = 0.50$); *Writing is not important in my discipline* ($OR = 0.52$); and *Faculty in my department are not encouraged to incorporate writing in their courses* ($OR = 0.85$). Faculty beliefs about resources for pedagogical practices are significantly associated with the assignment of writing, and include: *I have colleagues who share with me strategies and ideas about incorporating writing* ($OR = 1.24$); and *I communicate with our campus Center for Teaching and Learning about incorporating writing* ($OR = 1.22$).

5. Discussion

The current study adopted an ecological systems perspective to guide the efforts to promote the use of WTL practices by STEM faculty in their undergraduate courses and examined the influence of intrapersonal attributes and contextual factors, particularly faculty beliefs and disciplinary cultures, on faculty assignment of writing in their undergraduate courses across STEM disciplines at research-intensive universities. More specifically, the study aimed to identify the independent and combined contributions of faculty demographic characteristics, discipline, epistemic beliefs, beliefs about the effectiveness of specific writing practices, and beliefs about contextual resources and constraints to STEM faculty's decisions to assign writing.

5.1 STEM Faculty Practices

The findings of this national study indicate that 70% of faculty assign writing in their undergraduate STEM courses, which would seem to suggest that the gap in translating research into practice (National Research Council, 2012) may be

narrowing. The findings also provide additional support for the role of disciplinary cultures in influencing educational practices (Umbach, 2007). Whereas previous work by Lund and Stains (2015) found differences in the adoption of evidence-based practices across three STEM disciplines within a single university, the current study expanded the scope by identifying differences between eight STEM disciplines across 63 research intensive universities. The assignment of writing ranged from a high of 91% of faculty in Environmental Sciences to a low of 59% in Mathematics. However, a majority of faculty in each discipline reported assigning writing. Although faculty who assigned writing had higher ratings of the effectiveness of writing practice (particularly WTL), even faculty who *did not* assign writing viewed these practices as effective for developing student's learning of STEM content knowledge, concepts, and principles.

5.2 Personal and Contextual Factors Influencing Faculty Assignment of Writing

Beyond providing empirical evidence of STEM faculty WTL practices, this study contributes to our understanding of the influences of personal and contextual factors on STEM faculty assignment of writing. Faculty demographic factors, discipline, and faculty beliefs in particular all matter in faculty decisions to assign writing in their classes. Variables associated with an increased likelihood of assignment of writing included: being female; faculty beliefs about the effectiveness of WTL; and faculty beliefs about resources, including having colleagues who share strategies and ideas and communicating with their campus center for teaching and learning about incorporating writing in their classes.

Variables associated with a decreased likelihood of assignment of writing included: being Asian; being faculty in Chemistry, Mathematics, and Physics; endorsing absolutist epistemic beliefs; and faculty beliefs regarding constraints, including having too large of a class, the lack of importance of writing in their discipline, and not being encouraged to conduct writing in the classroom. Counterintuitively, belief about the effectiveness of Peer Review and Scaffolding were also associated with less likelihood of assigning writing, perhaps because these are more challenging practices to implement in the classroom.

Together the variables accounted for 41% of the variance in faculty assignment of writing in STEM undergraduate courses. The regression models show how a variable that contributes when examined individually no longer does so when its effects are subsumed by another variable and the resulting independent and combined contribution of variables. The major findings of the current study are that over and above the contribution of faculty demographics and disciplinary background, faculty epistemic beliefs and beliefs about effectiveness of WTL practices and contextual resources and constraints accounted for an additional 30% increment in variance in the assignment of writing. The evidence of the

contribution of faculty beliefs to the assignment of writing adds to the evidence that beliefs are a strong influence on faculty instructional decision making (Hora, 2014; Fives & Buehl 2016; 2017). Furthermore, the findings indicate that faculty beliefs are salient and meaningful intervention targets in the efforts to promote the adoption of WTL practices.

Although the ecological systems perspective emphasizes a focus on transactions among variables, we did not examine the transactions among the variables by testing interactions. The number of interaction terms to be tested in a model with such a large number of variables is overwhelming (on the order of 135 tests). Rather, this analysis can be viewed as serving the function of reducing the number of variables of interest to those that have been found to make a significant, independent, contribution to the assignment of writing; subsequent studies could test the interactions of selected variables that are specifically hypothesized to be mutually influencing. Examining interaction effects with regard to the influence of gender and discipline on faculty assignment of writing may be especially warranted as illustrated by post hoc analyses. For example, the main effects of being female was associated with a significant increased likelihood of assigning writing ($OR = 1.45$) while being a faculty member in Chemistry ($OR = 0.37$) or Physics ($OR = 0.42$) was associated with a significant decreased likelihood of assignment of writing. However, examining the interaction of discipline with gender yields a more nuanced finding. Female faculty members in Chemistry and Physics did not differ from their male counterparts but were less likely to assign writing than both males and females in other disciplines. Similarly, gender differences, with small effect sizes, were also found with regard to faculty beliefs.

With regard to faculty beliefs about contextual resources, female faculty had higher mean ratings than males for *I have colleagues who share with me strategies and ideas about incorporating writing* ($t = 3.85, p < .001, d = 0.14$); *I communicate with our Campus Center for Teaching and Learning about incorporating writing in my classes* ($t = 5.15, p < .001, d = 0.19$) and *I communicate with our campus Writing Center about using writing in the classroom* ($t = 4.23, p < .001, d = 0.14$). With regard to constraints, female faculty had lower ratings than males for *Writing is not important in my discipline* ($t = -7.52, p < .001, d = -0.24$), and *Covering all the material in my course does not leave instructional time to incorporate writing* ($t = -5.43, p < .001, d = -0.20$). Faculty demographics also were associated with faculty epistemic beliefs. Females were less likely ($OR = 0.79$) to self-categorize as Absolutists, whereas Asian ($OR = 2.10$) and URM ($OR = 1.66$) faculty and those in Chemistry ($OR = 1.50$), Engineering ($OR = 1.68$), Mathematics ($OR = 3.23$), and Physics ($OR = 1.74$) were more likely to be categorized as Absolutist.

5.3 Relationship of Faculty Epistemic Beliefs with Discipline and the Assignment of Writing

Faculty epistemic beliefs were characterized based on their discipline-based view regarding what constitutes knowledge about our physical and social world. Most faculty endorsed evaluativist epistemic beliefs (60%), followed by absolutist beliefs (38%), with a very few endorsing relativist beliefs (1%). In the descriptive statements used in this study, both evaluativist and absolutist epistemic views included evaluating claims on the basis of evidence. The primary difference in the statements were with regard to the view of the nature of knowledge as constructed and provisional (evaluativist) versus discovered and verifiable as right or wrong (absolutist). Of faculty who assigned writing, 65% endorsed evaluativist epistemic beliefs, which is consistent with the findings of Yore and colleagues (2004) of an association of an evaluativist view of science and viewing writing as knowledge building rather than knowledge telling.

There also were differences in STEM faculty epistemic beliefs by discipline with faculty in Environmental Sciences, Geosciences, and Biology more likely to endorse evaluativist beliefs whereas faculty in Mathematics, Physics and Engineering more likely to endorse absolutist beliefs. These findings are consistent with the evidence that academic disciplines differ in their epistemological foundations (Muis et al., 2006) and in the extent to which the discipline has a clearly delineated paradigm or a unified body of theory and methodologies. In disciplines with “hard” paradigms, knowledge is well-structured with regard to certainty, source, and justification and can be conceptualized as more “absolute” than in “softer” disciplines (Rosman et al., 2017). The findings of the current study are consistent with previous findings that absolutist beliefs about what constitutes knowledge are more prevalent in “hard” disciplines (Muis et al., 2006). The percentages of faculty endorsing absolutist epistemic beliefs across discipline (see Figure 4) ranged from a high in Mathematics (59%), Physics (45%) and Engineering (44%), through Chemistry (40%) and Computer Science (36%), to a low in Geosciences (25%), Biology (25%), and Environmental Sciences (24%).

Further evaluation of faculty views about the characteristics of their discipline is necessary to elucidate the relationship between discipline and epistemic beliefs and the implications for efforts to promote the adoption of WTL practices. Important in this regard is that even though there is an association of epistemic beliefs and discipline, faculty epistemic beliefs contributed to assignment of writing over and above the contributions made by discipline.

5.4 Limitations

The limitations of this study are those common to large-scale survey studies. More specifically, direct observation of faculty enacted teaching practices is not feasible and thus reliance on self-report measures is a necessity. Given that the survey used

in this study asked faculty to report what they did, and not what they intended to do or believed ought to be done, the measure reflected faculty's discursive claims about their practices with regard to the assignment of writing, which can be considered a proxy for direct observation of enacted practices (Gibbons et al., 018). Relatedly, future studies could examine the relationship of objective characteristics of courses, such as class size and faculty beliefs about contextual constraints to their assignment of writing.

Response rate is another common limitation of survey studies. The overall response rate was 23% and it is recognized that the obtained relationships among variables obtained may not generalize to faculty practices in STEM overall. The response rate, however, is a function of the number of faculty invited to participate. The approach to identifying STEM faculty to participate in the study was extensive and resulted in an invitation to a very large number of STEM faculty ($N = 29,430$) to complete the survey and yielded a large number of respondents ($n=6,828$) with representation across 63 institutions and 9 STEM disciplines. Furthermore, even with a criterion of 80% completion of survey items, the resulting study sample ($n = 4,981$) was large and sufficient for the data analytics employed.

Pilot testing indicated that survey length was a limiting factor with regard to response rate resulting in a trade-off between the number of variables included and the number of items allocated to the measurement of a variable. For example, faculty beliefs about the efficacy of various WTL practices, their personal epistemology, and the contextual resources and constraints were examined but other beliefs of potential influence such as faculty's beliefs about student's backgrounds, characteristics, and capacities as writers and learners were not included in the survey. Faculty beliefs about students need to be included in the continuing efforts to examine the influence of personal factors, in transaction with contextual factors, on educational practices. Similarly, measures of variables were constructed of items based on concepts in the literature and the reliability and validity of these measures will need to be ascertained over subsequent studies. The actual wording of items has been included in this report to facilitate examination and replication.

Another limitation stems from the commitment to an ecological systems perspective that requires an initial examination of sets of personal factors and contextual factors which result in a large number of variables and multiple analyses. Interpretations of complex findings are provisional and confirmation of hypothesized relationships will necessitate subsequent experimental studies that test the effectiveness of initiatives to promote the adoption of WTL practices by enhancing the "fit" of the characteristics of the intervention with personal and contextual characteristics.

5.5 Implications for Subsequent Research

With 59% of the variance in faculty assignment of writing unaccounted for by the variables in this study, the next step is to identify additional variables that are potentially likely to influence the assignment of writing. The findings that the largest proportion of variance was accounted for by faculty beliefs about contextual resources and constraints suggest that it would be fruitful to include faculty beliefs about additional contextual factors, such as institutional recognition and reward structures identified by Henderson, Beach, and Finkelstein (2011) as barriers to change in educational practices. It is also important to examine the relationship of faculty beliefs about resources and constraints, as intrapersonal psychological factors, with objective measures of contexts, such as class size and extent of support services available to faculty.

The interrelationships of the variables identified as accounting for significant amounts of variance in the assignment of writing need to be examined for evidence of underlying or latent constructs. Furthermore, cluster analysis can be employed to delineate profiles that reflect specific patterns or constellations of interrelationships among variables across a number of dimensions (Dowd et al., 2019). With regard to faculty personal factors, for example, different meaningful faculty profiles could emerge such as absolutist epistemic beliefs coupled with low efficacy beliefs and strong beliefs about contextual constraints or perhaps evaluativist epistemic beliefs coupled with high efficacy beliefs and strong beliefs about contextual resources.

The final step in the research on promoting the adoption of WTL practices is the same as with research on enhancing the specificity of effectiveness of WTL practices. Experimental studies are needed of interventions that are specifically designed to fit meaningful faculty subgroups based on patterns of personal and contextual factors. Furthermore, experimental intervention studies undertaken to increase the use of writing assignments will enable examination of the personal and contextual factors that moderate and mediate the effects of the intervention on enacted practices.

5.6 Implications for Promoting STEM Faculty Incorporation of WTL in their Teaching

The findings of the current study indicate that 30% of STEM faculty do not currently assign writing in their undergraduate courses. Fishbein and Ajzen (2010) argue that the first determination is whether the intervention should be directed at influencing intentions or at helping people act on the intentions they already hold by ensuring that they have the necessary skills, social support, and resources. For example, a recent study by Moon et al. (2018) identified a subgroup of faculty who view writing as fundamentally related to knowledge and understanding but who do not use writing in their classes. These faculty would be a particularly salient target

for intervention. If the objective is to change intentions, then intervention targets can be designed by “identifying behavioral, normative, and control beliefs that discriminate between individuals who perform the behavior of interest and individuals who do not” (Fishbein & Ajzen, 2010, p.23). The major findings of this study point to faculty beliefs as the most salient intervention targets.

Furthermore, there is considerable evidence from the research on conceptual change that beliefs are malleable. The ecological systems perspective makes clear that conceptual change is not just an internal cognitive process that takes place within the individual’s mind but also is a social activity that takes place in a socio-cultural context. Dialogue is an important catalyst for conceptual change, which “is ultimately a matter of cognitive reconstruction and not merely the acquisition of membership of a community of discourse” (Mercer, 2007, p. 76). This suggests that efforts to promote the adoption of WTL practices should include institutional commitment to supporting structures and processes that facilitate dialogue, such as centers for teaching, learning, and writing, WAC/WID/WEC programs, and fostering the development of communities of discourse within and across STEM departments of faculty interested in incorporating writing into their teaching practices. Differences in disciplinary practices and norms highlight the importance of disciplinary specific approaches to the promotion of the adoption of WTL practices. As the review by Henderson and colleagues (2011) made clear, institutional policies are also likely to matter, particularly with regard to the incentive and reward policies in support of effective teaching.

We have argued that interventions to promote the use of WTL in STEM education need to be attuned to enhancing the “fit” of the characteristics of the practices with variations in personal and contextual characteristics. The findings of this study indicate the importance of the fit of WTL practices with disciplinary differences in faculty epistemic beliefs about science and beliefs about contextual resources and constraints. Faculty in Chemistry, Mathematics, and Physics, disciplines with clearly delineated (“hard”) paradigms, were less likely to assign writing, more frequently endorsed absolutist epistemic beliefs about knowledge being verifiable as right or wrong, and more frequently endorsed the beliefs that writing is not important in their discipline and that faculty in their department are not encouraged to incorporate writing in their courses. Perhaps the association of absolutists epistemic beliefs with the view of writing as knowledge telling rather than knowledge building may help to explain the relative lack of importance and value accorded to writing. One implication would be to foster faculty beliefs about writing as knowledge construction as a prerequisite to promoting the adoption of WTL practices in these disciplines.

At the outset, we argued that the two lines of research, enhancing the effectiveness of WTL practices and the faculty adoption of WTL practices, are interrelated. An interesting example supporting this interrelationship was the

finding by Trafimow and colleagues (2017) that faculty intentions to assign writing were best predicted by the belief that assigning writing is good for the students. One implication is that interventions aiming to increase faculty assignment of writing in STEM should be designed to make more salient that assigning writing will be beneficial to their students. Moreover, if the studies provide evidence about the differential effectiveness of specific WTL practices with diverse subgroups of students, this evidence would likely motivate faculty concerned with science education equity and preparing all students for success in the 21st century to adopt such beneficial WTL practices.

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Notes

1. Because of the small number with relativist epistemic beliefs, subsequent analyses only contrasted evaluativist and absolutist groups.
2. A Wald statistic is used to test the individual estimates of the model and is compared to the chi square distribution to assess significance (Bewick et al., 2005).

References

- Ajzen, I. & Fishbein, M. (1980). *Understanding Attitudes and Predicting Social Behavior*. Englewood Cliffs, NJ: Prentice Hall.
- Anderson, P., Anson, C. M., Gonyea, R. M., & Paine, C. (2015). The contributions of writing to learning and development: Results from a large-scale multi-institutional study. *Research in the Teaching of English*, 50(2), 199-235.
- Bandura, A. (1997). *Self-efficacy: The exercise of control*. New York: Freeman.
- Bangert-Drowns, R. L., Hurley, M. M., & Wilkinson, B. (2004). The effects of school-based writing-to-learn interventions on academic achievement: A meta-analysis. *Review of Educational Research*, 74, 29-58. <https://doi.org/10.3102/00346543074001029>
- Bathgate, M. E., Aragón, O. R., Cavanagh, A. J., Waterhouse, J. K., Frederick, J. & Graham, M. J. (2019). Perceived supports and evidence-based teaching in college STEM. *International Journal of STEM Education*, 6(11), <https://doi.org/10.1186/s40594-019-0166-3>
- Berthold, K, Nückles, M, & Renkl, A. (2007). Do learning protocols support learning strategies and outcomes? The role of cognitive and metacognitive prompts. *Learning and Instruction*, 17(5), 564-577. <https://doi.org/10.1016/j.learninstruc.2007.09.007>
- Bereiter, C., & Scardemalia, M. (1987). *The Psychology of Written Communication*. Hillsdale, NJ: Lawrence Erlbaum.

- Bewick, V., Cheek, L., & Ball, J. Statistics review 14: Logistic regression. *Critical Care*, 9(1), 112-118. <https://doi.org/10.1186/cc3045>
- Bronfenbrenner, U. (1976). The experimental ecology of education. *Educational Researcher*, 5(9), 5-15. <https://doi.org/10.2307/1174755>
- Carter, M. (2007). Ways of knowing, doing, and writing in the disciplines. *College Composition and Communication*, 58(3), 385-418.
- Dowd, J., Thompson, R. J., Jr., Schiff, L., Haas, K., Hohmann, C., Roy, C., Meck, W., Bruno, J., & Reynolds, J. (2019). Student learning dispositions: Multi-dimensional profiles highlight important differences among undergraduate STEM honors thesis writers. *CBE-Life Sciences Education*, 18(2), ar28. <https://doi.org/10.1187/cbe.18-07-0141>.
- Fishbein, M. & Ajzen, I. (2010). *Predicting and changing behavior: The Reasoned Action Approach*. New York: Psychology Press, Taylor & Francis Group. <https://doi.org/10.4324/9780203838020>
- Fives, H. & Buehl, M. M. (2016). Teacher's beliefs, in the context of policy reform. *Brain and Brain Sciences*, 3(1), 114-121. <https://doi.org/10.1177/2372732215623554>
- Fives, H. & Buehl, M. M. (2017). The functions of beliefs: Teacher's personal epistemology as the pinning block. In G. Schraw, J. L. Brownlee, L. Olafson, & M. V. Veldt Brye (Eds.), *Teachers' personal epistemologies: Evolving models for informing practice* (pp 25-54). Charlotte, NC: Information Age Publishing, Inc.
- Flash, P. (2016). From Apprised to Revised: Faculty in the disciplines change what they never knew they knew. In K.B. Yancey (Ed.), *A Rhetoric of Reflection* (pp 227-249). Utah State University Press. <https://doi.org/10.7330/9781607325161.c011>
- Flash, P. (2020). Writing-Enriched Curriculum: A portable model for provoking and sustaining change. In C.M. Anson and P. Flash (Eds), *Writing-Enriched Curricula: Models of Faculty-Driven and Departmental Transformation*. The WAC Clearinghouse.
- Gere, A. R., Limlamai, N., Wilson, E., Saylor, K. M., & Pugh, R. (2019). Writing and conceptual learning in science: An analysis of assignments. *Written Communication*, 36(1), 99-135. <https://doi.org/10.1177/0741088318804820>
- Gibbons, R. E., Villafane, S. M., Stains, M., Murphy, K. L., & Raker, J. R. (2018). Beliefs about learning and enacted instructional practices: An investigation in postsecondary chemistry education. *Journal of Research in Science Teaching*, 00, 1-23. <https://doi.org/10.1002/tea.21444>
- Graham, S., Kiuahara, S. A., & MacKay, M. (2020). The effects of writing on learning in science, social studies, and mathematics: A meta-analysis. *Review of Educational Research*, 90(2), 179-226. <https://doi.org/10.3102/0034654320914744>
- Henderson, C., Beach, A., & Finkelstein, N. (2011). Facilitating change in undergraduate STEM instructional practices: An analytic review of the literature. *Journal of Research in Science Teaching*, 48(8), 952-984. <https://doi.org/10.1002/tea.20439>
- Hofer, B. K., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research*, 67(1), 88-140. <https://doi.org/10.3102/00346543067001088>
- Hora, M. T. (2014). Exploring faculty beliefs about student learning and their role in instructional decision-making. *The Review of Higher Education*, 38(1), pp. 37-70. <https://doi.org/10.1353/rhe.2014.0047>
- Kane, R., Sandretto, S., & Heath, C. (2002). Telling half the story: A critical review of research on the teaching beliefs and practices of university academics. *Review of Educational Research*, 72(2), 177-228. <https://doi.org/10.3102/00346543072002177>
- Klein, P. D. (2015). Mediators and moderators in individual and collaborative writing to learn. *Journal of Writing Research*, 7(1), 201-214. <https://doi.org/10.17239/jowr-2015.07.01.08>
- Klein, P. D., & Boscolo, P. (2016). Trends in research on writing as a learning activity. *Journal of Writing Research*, 7(3), 311-350. <https://doi.org/10.17239/jowr-2016.07.3.01>

- Lund, T. J., & Stains, M. (2015). The importance of context: an exploration of factors influencing the adoption of student-centered teaching among chemistry, biology, and physics faculty. *International Journal of STEM Education*, 2(1), 1-21. doi:10.1186/s40594-015-0026-8
- Mason, L. (2007) Introduction: Bridging the Cognitive and Sociocultural Approaches in Research on Conceptual Change: Is it Feasible? *Educational Psychologist*, 42:1, 1-7. <https://doi.org/10.1080/00461520709336914>
- Meizlish, D., LaVaquer-Manty, D., Silver, N., & Kaplan, M. (2013). Think like/write like: Metacognitive strategies to foster students' development as disciplinary thinkers and writers. In Thompson, R. J. (Ed.), *Changing the conversation about higher education* (pp. 53–73). Lanham, MD: Rowman & Littlefield
- Mercer, N. (2007) Commentary on the reconciliation of cognitive and sociocultural accounts of conceptual change, *Educational Psychologist*, 42:1, 75-78. <https://doi.org/10.1080/00461520709336920>
- Moon, A., Gere, A.R., & Shultz, G.V. (2018). Writing in the STEM classroom: Faculty conceptions of writing and its role in the undergraduate classroom. *Science Education*, 102,1007–1028. <https://doi.org/10.1002/sce.21454>
- Muis, K. R., Bendixen, L. D., & Haerle, F. (2006). Domain-generality and domain specificity in personal epistemology research: Philosophical and empirical reflections in the development of a theoretical framework. *Educational Psychology Review*, 18, 3–54. <https://doi.org/10.1007/s10648-006-9003-6>
- Murphy, P. K. & Mason, L. (2006). Changing knowledge and changing beliefs. In P. A. Alexander & P. Winne (Eds.), *Handbook of educational psychology* (2nd ed., pp. 305–326). Mahwah, NJ: Lawrence Erlbaum.
- National Research Council. (2012). *Discipline-based education research: Understanding and improving learning in undergraduate science and engineering*. Washington, DC: The National Academies Press
- Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education*, 66(2) 1–227. <https://doi.org/10.1002/sce.3730660207>
- Reynolds, J. A., Thaiss, C., Katkin, W., & Thompson, R. J. (2012). Writing-to-learn in undergraduate science education: A community-based, conceptually driven approach. *CBE Life Sciences Education*, 11(1), 17–25. <https://doi.org/10.1187/cbe.11-08-0064>
- Rivard, L. P. (1994). A review of writing to learn in science implications for practice and research. *Journal of Research in Science Teaching*, 31, 969-983. <https://doi.org/10.1002/tea.3660310910>
- Rosman, T., Mayer A. K., Kerwer, M., & Krampen, G. (2017). The differential development of epistemic beliefs in psychology and computer science students: A four-wave longitudinal study. *Learning and Instruction*, 49, 166-177. <https://doi.org/10.1016/j.learninstruc.2017.01.006>
- Russ, R. S., Sherin, B. L., & Sherin, M. G. (2016). What constitutes teacher learning. In D. H. Gitomer & C. A. Bell (Eds.), *Handbook of research on teaching* (5 ed., pp. 391-438): American Educational Research Association. https://doi.org/10.3102/978-0-935302-48-6_6
- Russell, D. R. (2002). *Writing in the academic disciplines: A curricular history*. 2nd Ed. Carbondale: Southern Illinois University Press.
- Sandoval, W. A. (2016). Disciplinary insights into the study of epistemic cognition. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *Handbook of epistemic cognition* (pp. 184-194). New York: Routledge. <https://doi.org/10.1007/s11191-019-00061-1>
- Sosu, E. M., & Gray, D. S. (2012). Investigating change in epistemic beliefs: An evaluation of the impact of student teachers' beliefs on instructional preference and teaching competence. *International Journal of Educational Research*, 53, 80–92. <https://doi.org/10.1016/j.ijer.2012.02.002>

- Thaiss, C., & Porter, T. (2010). The state of WAC/WID in 2010: Methods and results of the U.S. Survey of the International WAC/WID Mapping Project. *College Composition and Communication*, 61(3), 534–570.
- The Carnegie Classification of Institutions of Higher Education (n.d.). About Carnegie Classification. <http://carnegieclassification.iu.edu>
- Thompson, R. J., Jr., Díaz Pearson, A. & Shanahan, S. (2019) Promoting community and political engagement through undergraduate educational practices: The role of identity formation. *Journal of College and Character*, 20(2), 97-122. <https://doi.org/10.1080/2194587X.2019.1591284>
- Trafimow, D., Ruckel, L.M., Stovall, S. & Raut, Y. J. (2017). Predicting faculty intentions to assign writing in their classes, *International Journal for the Scholarship of Teaching and Learning*, 1(2), Article12. <https://doi.org/10.20429/ijstl.2017.110212>
- Umbach, P. D. (2007). Faculty cultures and college teaching. In R. P. Perry and J. C. Smart (Eds.), *The scholarship of teaching and learning in higher education: An evidence-based perspective* (pp. 263–317). New York: Springer. https://doi.org/10.1007/1-4020-5742-3_8
- Veal, W. R., Riley Lloyd, M. E., Howell, M. R., & Peters, J. (2016). Normative beliefs, discursive claims, and implementation of reform-based science standards. *Journal of Research in Science Teaching*, 53(9), 1419-1443. <https://doi.org/10.1002/tea.21265>
- Yore, L. D., Hand, B. M., & Florence, M. K. (2004). Scientists' views of science, models of writing, and science writing practices. *Journal of Research in Science Teaching*, 41(4), 338–369. <https://doi.org/10.1002/tea.20008>