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A Portrait of MWrite as a Research Program: A Review of Research on Writing-to-Learn in STEM through the MWrite Program

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Abstract

The writing-to-learn (WTL) literature is varied in how assignments are structured and implemented in the classroom, making it difficult for instructors to identify how to incorporate writing effectively. Drawing on the WTL literature, the MWrite program was established to work with STEM faculty to design, implement, and assess evidence- based WTL assignments. Herein we present a review of the WTL research generated through the MWrite program, situating our findings in a four-dimensional framework of engagement to identify how the MWrite WTL assignment design and implementation has supported students' learning. Our analysis indicates that the multi-faceted design of MWrite WTL assignments supports students' development of conceptual knowledge and disciplinary thinking. The assignments' rhetorical features (i.e., context, audience, and genre) guide how students write about content, and peer review and revision stages encourage a collaborative, knowledge building process between students and their peers.

Keywords

writing-to-learn, STEM, undergraduate, engagement

Cover Page Footnote

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The writing-to-learn (WTL) literature is varied in how assignments are structured and implemented in the classroom, making it difficult for instructors to identify how to incorporate writing effectively. Drawing on the WTL literature, the MWrite program was established to work with STEM faculty to design, implement, and assess evidence-based WTL assignments. Herein we present a review of the WTL research generated through the MWrite program, situating our findings in a four-dimensional framework of engagement to identify how the MWrite WTL assignment design and implementation has supported students' learning. Our analysis indicates that the multi-faceted design of MWrite WTL assignments supports students' development of conceptual knowledge and disciplinary thinking. The assignments' rhetorical features (i.e., context, audience, and genre) guide how students write about content, and peer review and revision stages encourage a collaborative, knowledge building process between students and their peers.

Writing-to-learn (WTL) is an instructional practice that utilizes writing assignments to support students' learning. Investigations into the ways that writing can serve to develop knowledge were conducted as early as the 1970s (Bereiter & Scardamlia, 1987; Emig, 1977; Flower & Hayes, 1980; Galbraith, 1992). However, research focused on the efficacy of writing assignments to support learning in STEM shows mixed results due in part to variation in how the assignments were implemented, what form they took, and the data gathered (Arnold et al., 2017; Rivard, 1994). A series of research syntheses focused on how writing supports learning indicates that effective WTL assignments include elements that stimulate cognition and metacognition, provide meaning-making tasks, incorporate social interactions, and contain language that directs students towards specific learning goals (Anderson et al., 2015; Bangert-Drowns et al., 2004; Gere et al., 2019; Klein, 2015). The MWrite program at the University of Michigan was developed to support the uniform implementation of WTL assignments, across a variety of STEM courses, that incorporate the aforementioned elements of effective writing assignments while also minimizing barriers to implementation (Finkenstaedt-Quinn et al., 2022; Finkenstaedt-Quinn, Petterson, et al., 2021; Moon, Gere, et al., 2018; Stroumbakis et al., 2016; Trafimow et al., 2017). The goal of this article is to present a review of the research findings from courses involved in the MWrite program, providing insight into what forms of learning the MWrite WTL assignment design can support and how the various design elements do so. The research findings are synthesized through the lens of an engagement framework (Finn & Zimmer, 2012; Fredricks et al., 2004, 2016) to extend the findings beyond what is presented in the original research articles and to better understand how the MWrite WTL assignment design can holistically support student learning across the four dimensions of engagement (i.e., the cognitive, behavioral, emotional, and social dimensions).

WTL IN STEM

Incorporating WTL in STEM can stimulate students' cognition while also appealing to affective and social elements of learning. The ability to appeal to multiple elements of learning indicates that WTL may support student engagement. While research has not yet directly addressed this potential connection between WTL pedagogy and student engagement, the WTL literature addresses elements that may be tied to the four dimensions of engagement. The existing literature describes how assignments engage students cognitively with both disciplinary concepts and disciplinary ways of thinking. A series of studies have detailed the benefits of writing assignments to improve students' scientific literacy or to elicit students' argumentation (Balgopal & Wallace, 2013; Grimberg & Hand, 2009; Klein, 2004; McDermott & Hand, 2010). The Science Writing Heuristic (SWH) specifically supports developing students' conceptual knowledge, understanding of the nature of science, and disciplinary thinking during laboratory experiences by having them make explicit their observations, claims, and the evidence supporting their claims (Grimberg & Hand, 2009; Hand et al., 2004, 2007; Keys et al., 1999; Poock et al., 2007). WTL research additionally provides insight into how students use multimodal representations in their writing and the types of learning WTL can support (Gunel et al., 2016; Hand & Choi, 2010; McDermott & Hand, 2013, 2016). These studies on different implementations of writing in STEM courses illustrate how writing can stimulate students' cognition through clear, structured writing expectations.

Many of the WTL assignments described in the STEM education literature have students write in response to a particular audience or context (Balgopal & Wallace, 2013; Doe et al., 2016; Herrington, 1985; McDermott & Hand, 2016; Rootman-Le Grange & Retief, 2018). Structuring WTL assignments such that students are writing to a specific audience can contribute to students' meaning-making while also simulating social interactions between them and the audience (Gere et al., 2019; Prior, 2006). Studies describe assignments with a range of audiences, from the general public (often framed in the context of science communication; e.g., McDermott & Hand, 2016; Rootman-Le Grange & Retief, 2018) to more discipline-specific stakeholders (such as clients for some output; e.g., Herrington, 1985). Audiences can also include the teacher, students new to the content area, peers, or family members; research indicates that the audi-

ence influences what students write about and how (Gunel et al., 2009). Writing assignments can also become meaning-making tasks when they include a context relevant to students. Contextualizing scientific and mathematic content can support students in making inferences, evaluating content, and building connections to their lives (Doe et al., 2016; Libarkin & Ording, 2012; Rathburn, 2015). For example, Balgopal and Wallace (2013) describe a style of WTL assignments implemented in biology courses where students apply their content knowledge to socioscientific issues, which are societally important issues that relate to the sciences (Balgopal et al., 2012, 2017, 2018; Balgopal & Montplaisir, 2011; Balgopal & Wallace, 2013). They found that this style of assignment supported students' scientific literacy, argumentation, and use of abstract concepts. Altogether, these studies demonstrate how the audiences and contexts incorporated into WTL assignments can support students' learning. Viewed through the lens of engagement, the meaning-making supported by WTL may promote students' cognitive, affective, and social engagement as they consider content within a relevant context and describe content for a specific audience.

Social interactions have also been incorporated into WTL assignments by having students engage in peer review during the writing process. Calibrated Peer Review (CPR) has been incorporated into a range of introductory STEM courses, primarily for laboratory-oriented and disciplinary writing (Russell, 2013). Various studies have found that students performed better on their writing and on questions associated with topics for which they engaged in CPR and demonstrated longer retention of the content in biology and chemistry courses (Cox et al., 2018; Gunersel & Simpson, 2009; Mynlieff et al., 2014; Pelaez, 2002; Russell, 2013); furthermore, students often perceive the benefits of peer review associated with CPR (Ruggiero & harbor, 2013). The structured social interactions and students' perceptions of their value indicate that peer review may support both social and affective engagement with WTL.

The variety of research on WTL and peer review in STEM courses demonstrates the benefits of the individual elements identified as important for effective WTL (i.e., stimulating students' cognition, creating meaning-making tasks, and incorporating social interactions). In addition, the elements of effective WTL align with task features thought to support student engagement (e.g., authentic tasks that provide students with opportunity for peer interactions; Fredricks et al., 2004; Newmann et al., 1992). However, to our knowledge, there is not yet research exploring the connections between the elements of effective WTL pedagogy and student engagement with learning. The WTL assignment design developed by the MWrite program differs from the WTL implementations described previously as it attempts to incorporate all of the reported elements of effective WTL; this makes the program an ideal space for exploring how the elements of effective WTL assignments may support learning across the four dimensions of engagement. The following section provides further background information on the MWrite program itself and how it served to support these principles across a variety of STEM courses.

BACKGROUND ON MWRITE

MWrite was developed to support the implementation of WTL assignments with an evidence-based design while also attending to known barriers to faculty implementation of evidence-based practices. The MWrite program was created as part of an initiative at the University of Michigan to develop and support pedagogical innovations across the institution. Internal funding through the initiative, supplemented by two external grants, provided funding to support key personnel (i.e., instructors, writing fellows, and researchers) and develop a peer review tool to meet the needs of the program. MWrite is affiliated with the institution's center for writing, which additionally supports the program's institutionalization. Specifically, instructor and writing fellow training is conducted through the center for writing. Initially, five STEM instructors were recruited to participate in MWrite and further instructors have been recruited via word of mouth and symposia focused on pedagogical innovations within the institution. The MWrite program structure is outlined in Figure 1 and covered in more detail by Finkenstaedt-Quinn, Petterson, et al. (2021).

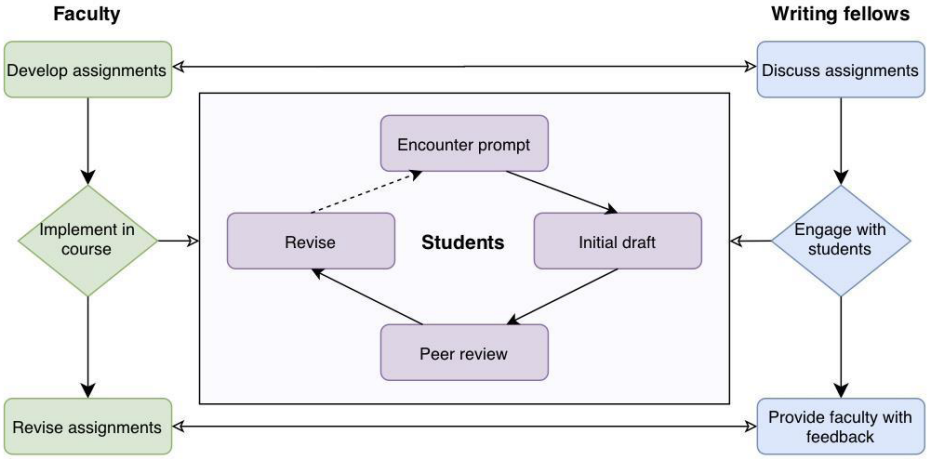

Figure 1. The MWrite Process

Note. Students encounter prompts, write initial drafts, undergo peer review, and then submit revised drafts. Faculty design and implement the WTL assignments with support from writing fellows, who provide feedback on the assignments and interact with students as they respond to the assignments. Figure used with permission from Finkenstaedt-Quinn, Petterson, Gere, and Shultz, J. Chem. Educ. 2021, 98, 5, 1548-1555. Copyright 2021 American Chemical Society.

The WTL assignment design is informed by the elements of effective WTL assignments (Anderson et al., 2015; Gere et al., 2019; Klein, 2015). Namely, assignments specify both a context and an audience to create a meaning-making task and simulated social interactions. Additionally, all MWrite courses implement the WTL assignments in a process intended to encourage students' reflection and metacognition, whereby students submit initial drafts, participate in peer review, and submit revised drafts. The MWrite program provides instructors with support for both implementing WTL in their courses and designing WTL assignments. Faculty implementing MWrite are supported by access to writing fellows and an automated peer review tool. Writing fellows are undergraduate students with prior success in the course who provide current students with support on the MWrite assignments; they take a course through the university's writing center to train them in this work, meet regularly with faculty to discuss the assignments and content, and serve as a liaison between students and faculty in a way that allows for the improvement of MWrite assignments and the MWrite experience for future courses. The peer review tool interfaces with the university's online course management system and is designed to facilitate a double-blind peer review process in which students review the initial drafts and receive feedback from typically three peers. Both the writing fellows and automated peer review tool are intended to support the implementation of WTL in large-enrollment courses.

In addition to working with faculty to develop and implement WTL assignments, the MWrite program places a large emphasis on evaluating the effectiveness of the WTL assignment design and elucidating the modes by which the design supports students' learning. The goal for this review is to examine the outcomes of the assignment design approach of the WTL pedagogy implemented through the MWrite program, since various studies of WTL often implement different variations of the pedagogical approach (Arnold et al., 2017; Bangert-Drowns et al., 2004; Gere et al., 2019; Rivard, 1994). The focus of this review specifically on MWrite research provides a summary and synthesis of the research findings coming out of this program with its standard implementation of WTL across a variety of STEM courses. Because this review is focused on the uniform design and implementation principles of WTL supported by the MWrite program, it can provide necessary insight on the types of learning instructors can support with the MWrite assignment design and how the various design components lead to and reinforce learning. This will contribute to the broader literature on WTL in STEM courses by providing insight into the ways WTL can support students' learning when implementing evidence-based assignment design principles. In addition, the synthesis of the research is guided by the framework of engagement to extend the understanding of how the MWrite assignment design supports learning across cognitive, behavioral, emotional, and social dimensions of learning.

THEORY GUIDING THIS ANALYSIS

Writing and learning have been tied by a number of theories, generally aligned with three perspectives: writing as inherently supporting learning, writing as a cognitive process that supports learning, and writing as a sociocultural process that engages the learner (Gere et al., 2019; Klein et al., 2015; Klein & Boscolo, 2016). The theories described within the literature as supporting WTL pedagogy are drawn from both cognitive and social theories of learning and of how writing can support learning. This is represented in our research as well, where the theories utilized in each MWrite research effort were dependent upon the research questions. The theories used range from purely cognitive (e.g., the cognitive process theory of writing; Flower & Hayes, 1981) to considering the social and contextual factors that influence learning and writing (e.g., the sociocultural theory of writing; Prior, 2006). The goal of this review is to synthesize the findings of the MWrite research articles across learning domains, through the lens of *engagement*, to improve our understanding of student learning with WTL pedagogy and to inform the use of WTL beyond the MWrite context.

Engagement has been defined as a three-dimensional phenomenon that includes cognitive, behavioral, and emotional realms (Finn & Zimmer, 2012; Fredricks et al., 2004, 2016). Cognitive engagement encompasses a student's psychological investment in learning and their strategic or self-regulated approach to learning, exemplified by persistence on challenging or difficult tasks, exerting effort to achieve mastery of ideas or skills, flexible approaches to problem solving, and use of metacognitive strategies, among others. Emotional engagement focuses on a student's affective domain, describing a student's feelings in an academic environment, such as interest, boredom, and anxiety. Lastly, behavioral engagement focuses on a student's behaviors in the classroom, such as effort, focus, and attention. More recently, some scholars have considered a social dimension as part of engagement, which incorporates interacting with peers in the academic context (Finn & Zimmer, 2012; Linnenbrink-Garcia et al., 2011). It is important to appeal to the multidimensional nature of engagement to create learning environments that can better support students' learning. For our purposes, we draw on the four-dimensional definition—with the cognitive, emotional, behavioral, and social dimensions—to characterize the ways in which the MWrite WTL assignments support students' engagement.

In the context of the MWrite WTL assignments, each of the four dimensions aligns with the ways in which students interact with the assignments. Cognitive engagement can be characterized by the conceptual understanding and disciplinary thinking that students demonstrate on the assignments, which serve as representations of students' persistence and effort to think critically about the content. Emotional engagement can be captured through students' reported attitudes and perceptions of the WTL assignments. Behavioral engagement can be thought of as the effort students demonstrate through completing the assignments and peer review, as well as students' self-reported effort. Lastly, social engagement is closely tied to behavioral engagement, where social engagement relates specifically to interactions with peers during the peer review process. We conceptualize social engagement as also extending to interactions with the writing fellows, interactions with peers beyond the structured review process, and choices made with respect to the audiences to whom students are writing. The four dimensions of engagement are interrelated, and individual students' experiences with the components of WTL pedagogy are likely mediated by different and multiple forms of engagement. However, by interpreting the findings of our review through the engagement framework lens, we can identify how the WTL assignments have elicited engagement across each of the four dimensions. This informs our understanding of how the WTL assignments may impact student engagement and how the elements of effective WTL contribute to supporting student learning across the four dimensions of engagement. In addition, focusing

on engagement provides insight into the ability of the assignments to provide a holistic learning experience for students. Furthermore, interpretation of the findings from the MWrite program through the engagement framework lens is part of a systematic effort to evaluate the pedagogical impacts of utilizing WTL. In addition to interpreting the research findings from MWrite through the engagement framework lens, this review can serve as a platform to bring findings from discipline-based education research into conversation with the scholarship of teaching and learning. Specifically, the synthesis of research findings across courses, assignments, and research methodologies serves to demonstrate how WTL can support learning and engagement across contexts.

METHODS

Reflexivity statement

This review synthesizes the research from the MWrite program at the University of Michigan. As this analysis is focused on research from MWrite specifically, it is important that we acknowledge our positionality as part of the MWrite program. Specifically, we are a program manager (SFQ), graduate student (FMW), and the co-primary investigators (GVS and ARG) working within the MWrite program. The co-first authors who engaged in the primary analysis for this article (SFQ and FMW) are co-authors on 12 of the 16 articles included in this analysis, and first authors on eight. This gave us familiarity with the research emerging from the MWrite program, which may have enhanced our ability to identify connections between the findings described in the articles. However, we recognize that our role in producing the research that was analyzed may have also led us to place a greater emphasis on minor findings of the articles that aligned with the themes identified in our analysis. In recognition of this potential for bias, we engaged in thematic analysis of the research articles with a consensus approach, as described in the analysis process section of the methods. In addition, prior to drafting this article, we discussed our findings with the entire MWrite team. Lastly, we sought feedback from researchers who were not affiliated with the MWrite program but are familiar with the research that has emerged from the program during the final drafting stages of this article.

Overview of articles included in the analysis

This review focuses on research articles about how students engaged with the WTL assignments implemented into classrooms using the MWrite WTL design. The analysis encompasses 16 research articles published from 2015 to 2022 (see Appendix). The articles describe research on MWrite WTL assignments implemented in biology, chemistry, materials science, and statistics courses. The research broadly characterizes students' responses to the learning objectives of the assignments, gains in learning on those objectives, and students' experiences with the assignments. The data sources used in the articles include students' writing in response to components of the assignments, students' responses to pre/post external assessments of knowledge, student interviews, and students' responses to feedback surveys about the assignments. The qualitative data sources were analyzed through coding approaches and quantitative transformation; studies based on quantitative data typically used statistical analysis. The Appendix presents the citation of each article and includes the disciplinary content area and a study overview for each article (Table A1).

Analysis process

Our review of the 16 research articles was guided by a qualitative thematic analysis approach (Braun & Clarke, 2006). The co-first authors (SFQ and FMW) separately read and wrote memos for each of the published MWrite WTL research articles with the intent to capture an overview of the study, the theoretical frameworks used, the data sources and methodologies, and the findings. Following this, we each read through our memos and identified themes in the findings across the articles. We then compared our themes and the articles we identified as contributing to each theme. The themes emerging from our independent analysis overlapped greatly, and through discussion we refined our themes into four categories, two focused on assessment of the learning objectives for the assignments (i.e., MWrite WTL assignments support students' abilities to describe content and lead to changes in content knowledge; MWrite WTL assignments engage students in disciplinary thinking practices) and two focused on how the structure of the WTL assignments support and scaffold learning (i.e., the structure of the MWrite prompts influences students' learning and affect; the peer review and revision processes support students' learning). For each theme, we additionally discussed how it aligned with the dimensions of engagement and gave insight into the mechanisms by which the WTL assignments supported learning. The final four thematic categories were discussed with the rest of the MWrite research team to confirm and finalize the analysis.

RESULTS AND DISCUSSION: MWRITE RESEARCH OVERVIEW AND ANALYSIS

Overview

Our thematic analysis of the research from the MWrite program indicates four categories drawn from the key claims and findings of the research articles. The four categories are that (1) MWrite supports students' abilities to describe content and that MWrite can lead to changes in students' content knowledge; (2) MWrite engages students in disciplinary thinking practices, specifically argumentation and reasoning; (3) the structure of MWrite assignments influences both students' learning and their affect towards the assignments; and (4) the peer review and revision process implemented with all MWrite assignments supports students' learning. The Appendix provides an overview of which articles included in the analysis present findings pertaining to each category (Table A2). For each category, we synthesize the results of our analysis of the MWrite research articles and situate them in the engagement framework.

MWrite WTL assignments support students' abilities to describe content and lead to changes in content knowledge

A primary aim of the WTL assignments developed by the MWrite program is to support conceptual learning of STEM content in large introductory courses. Thus, much of the early research through the MWrite program focused on assessing whether this aim was achieved as students responded to the assignments. Eight articles describe research in this area, six of which each focused on a single writing assignment (Brandfonbrener et al., 2021; Finkenstaedt-Quinn et al., 2017, 2020; Finkenstaedt-Quinn, Polakowski, et al., 2021; Moon, Zotos, et al., 2018; Schmidt-McCormack et al., 2019) and two focused on multiple writing assign-

Table 1. **Articles pertaining to each theme related to how MWrite WTL assignments support students' abilities to describe content and lead to changes in content knowledge**

Article	Disciplinary content area	Themes				
		Analyses of student responses demonstrated students were able to describe content targeted by the WTL assignments	The MWrite WTL design supports students' abilities to describe new or difficult concepts	The WTL assignments support students' application of content knowledge to real-world problems	Analysis of initial and revised drafts provides evidence of students' cognitive engagement	Students demonstrated learning via improvements on external assessments
Finkenstaedt-Quinn et al., 2017	Materials science and engineering	X			X	X
Moon, Zotos, et al., 2018	Physical chemistry	X	X		X	X
Gere et al., 2018	Introductory statistics	X		X		
Schmidt-McCormack et al., 2019	Organic chemistry	X			X	X
Finkenstaedt-Quinn et al., 2020	Physical chemistry	X		X	X	
Finkenstaedt-Quinn, Polakowski, et al., 2021	Introductory statistics	X	X		X	
Brandfonbrener et al., 2022	Organic chemistry	X	X			
Marks et al., 2022	Materials science and engineering	X	X		X	X
Totals for each theme		8	4	2	6	4

ments in a single course (Gere et al., 2018; Marks et al., 2022). Across assignments, disciplines, and courses, there was evidence of students successfully describing content and demonstrating learning gains, as captured through the analysis of students' writing and/or revisions and through external assessments of students' knowledge (specific themes are presented in Table 1).

Across articles, students demonstrated the ability to describe the content targeted by the WTL assignments (Table 1). In a majority of the articles, students' written responses to specific assignments were analyzed using rubrics that aligned with the learning objectives for the assignments (Finkenstaedt-Quinn et al., 2017, 2020; Finkenstaedt-Quinn, Polakowski, et al., 2021; Gere et al., 2018; Marks et al., 2022; Moon, Zotos, et al., 2018; Schmidt-McCormack et al., 2019). For example, Finkenstaedt-Quinn et al. (2017) characterized students' responses to a WTL assignment implemented in an introductory materials science course focused on students' knowledge of material properties. The assignment tasked students with extending their understanding of stress-strain properties of metals and ceramics to polymers, which are not discussed in as much detail in the course, and applying that knowledge to an authentic application. The analysis of students' writing indicated that students successfully extended their knowledge to the new material (Finkenstaedt-Quinn et al., 2017). In Brandfonbrener et al. (2021), rather than characterizing students' responses using a rubric developed to align with the assignment objectives, the responses were characterized using an analytical framework developed from learning objectives for the fundamental chemistry concept of resonance (Carle & Flynn, 2020). The analysis indicated that students were incorporating descriptions of the concept in line with the established learning objectives. However, the results also indicated that some students' descriptions reflected surface-level conceptual understanding. This analysis also demonstrates the potential for WTL to elicit students' knowledge of difficult concepts when they are presented with challenging tasks, indicating students' cognitive engagement. Instructors can use the elicited knowledge to adapt their teaching of the material in an effort to move students from learning to mastery of the material.

Evidence indicating the potential of the MWrite WTL design to support students' learning is also found across MWrite studies. Specifically, studies indicate that the MWrite WTL design supports students' abilities to describe new or difficult concepts and that the assignments support students' application of content knowledge to real-world problems (Table 1). Supporting students in making connections between course content and real-world applications is a challenging learning goal to achieve in STEM education contexts (Gilbert, 2006). Not only have we identified that students apply content knowledge to real-world problems in their writing, but students themselves recognize that the WTL assignments support them to build these connections (Petterson et al., 2022). This also demonstrates cognitive engagement with the assignments as students are applying effort to not only successfully describe new and difficult content in line with the learning objectives of the WTL assignments, but they are also applying content to real-world problems.

Further evidence of students' cognitive engagement was present in the articles in which both initial and revised drafts of students' writing were analyzed and compared (Table 1). The analyses demonstrated that students improved their descriptions of content upon revision. The improvement between drafts further demonstrates that the revision component of the assignments engaged students on the cognitive dimension, as revisions indicate students' persistence in the task and problem solving as they decide what feedback to incorporate as they revise. The improvement between the initial and revised drafts may also indicate students' behavioral engagement with the WTL assignments, as it demonstrates that students made an effort to revise their drafts. Learning from responding to the assignments is also demonstrated by improvements seen on the external assessments in a subset of the studies (Table 1). In these articles, students who responded to the WTL assignments demonstrated greater gains on specific concepts targeted by the assignments than students in a control

group who had not responded to the WTL assignments (but completed another activity related to the target concepts, such as a traditional problem set). The increase in students' conceptual knowledge through the MWrite WTL assignments aligns with findings from other implementations of WTL, such as the SWH (Hand et al., 2004, 2007; Poock et al., 2007). Ultimately, the findings regarding students' learning gains on targeted course concepts provide evidence that the MWrite WTL design led to students' cognitive and behavioral engagement.

MWrite WTL assignments engage students in disciplinary thinking practices

Beyond engaging students in describing content and improving their content knowledge, another trend in the MWrite research is that the WTL assignments engage students in disciplinary thinking practices. Disciplinary thinking is a construct derived from the National Research Council's *A Framework for K-12 Education* that emphasizes the need for teaching in STEM classrooms to present science as a set of scientific and engineering practices, crosscutting concepts, and disciplinary core ideas (National Research Council, 2012). The construct of disciplinary thinking relates to broader scientific and engineering practices, such as "analyzing and interpreting data," "constructing explanations," and "engaging in argument from evidence," using disciplinary concepts and ideas. While many MWrite research articles analyze students' construction of explanations within specific content areas, four MWrite research articles examined topics related to cognitively engaging students in other disciplinary thinking practices (Table 2).

Analysis of students' writing and a pre/post survey in the study by Shultz and Gere (2015) indicated the capacity of the MWrite WTL assignments to support students in the scientific practices of asking questions and developing and using models, which is related to students' conceptions of the nature of science. The scores of students' writing significantly increased from the initial to revised drafts for the learning objectives focused on describing and comparing scientific theories. However, students faced more challenges with comparing theories versus describing or summarizing a single theory. Results from a pre/post survey measure of students' conceptions of the nature of science indicated that students exhibited more sophisticated conceptions after the assignment, particularly for the idea that alternative theories in science exist. Hence, the study indicated that the MWrite WTL assignment was able to cognitively engage students in considering more deeply the scientific practices related to understanding the nature of science, in alignment with findings from the implementation of writing assignments through the SWH (Keys et al., 1999).

The writing analysis in the other articles indicated that the MWrite assignments also support students' reasoning (Table 2), aligning with the scientific practices of constructing explanations and arguments. For example, the study by Moon et al. (2019) identified that students were able to make a variety of cognitive operations in their writing (e.g., observation, comparison, cause and effect) which could be characterized to determine the overall cognitive complexity in students' responses. The study suggested that the measure of cognitive complexity is indicative of students' reasoning abilities. The two studies in organic chemistry focused on mechanistic reasoning, a specific type of scientific reasoning that requires explanation at a level lower than the observed phenomena (Russ et al., 2008). Watts et al. (2020) analyzed features in students' writing necessary for this type of reasoning and identified that students were able to engage in multi-component, process-oriented reasoning, which is typically challenging for students (Bhattacharyya, 2008; Bhattacharyya & Bodner, 2005). Watts et al. (2022) expanded on this work by examining how students reason on a meaning-making task reflective of the epistemic practices of organic chemists. They found that the students who were more successful exhibited reasoning more aligned with how organic chemists would reason. In all three studies, the researchers separated correctness of content from identifying students' reasoning skills, suggesting that the WTL assignments are able to elicit both reasoning and content knowledge (as described in the previous section), in alignment with findings from implementations of the SWH (Grimberg & Hand, 2009). This separation of content from reasoning skills further emphasizes how the WTL assignments can serve to cognitively engage students beyond developing their conceptual understanding and into engaging with disciplinary thinking, which can be a higher order task.

Table 2. **Articles pertaining to each theme related to how MWrite WTL assignments engage students in disciplinary thinking practices**

Article	Disciplinary content area	Themes	
		The MWrite assignments support students' reflection on the nature of science	The MWrite assignments support students' reasoning
Shultz & Gere, 2015	General chemistry	x	
Moon et al., 2019	General chemistry		x
Watts et al., 2020	Organic chemistry		x
Watts et al., 2022	Organic chemistry		x
Totals for each theme		1	3

The structure of the MWrite assignments influences students' learning and affect

Various MWrite studies included specific findings about how the rhetorical features of the assignments—including the genres, contexts, and audiences—influence students' cognitive and social engagement with course content. The rhetorical framing of the assignments is a key aspect of MWrite WTL assignments, intended to support the writing activity as a meaning-making task. Studies across multiple course contexts demonstrated findings related to how the assignments' rhetorical features support students' learning and affect (Table 3).

Studies have indicated that the audience or genre can influence the language students use and the degree to which students incorporate their content knowledge (Table 3). For example, one study explored students' responses to two WTL assignments in a statistics course with different audiences and genres (Gere et al., 2018). The findings indicated that the amount of statistics knowledge students incorporated differed between the two assignments, suggesting that the audience and genre can constrain how students incorporate their knowledge. Students recognize that the audience requires them to consider the detail of their explanations; this supports their perceived learning and can be a productive challenge for some students (Gupte et al., 2021; Petterson et al., 2022). Thus, the audience and genre may influ-

Table 3. **Articles pertaining to each theme related to how the structure of the MWrite assignments influences students' learning and affect**

Article	Disciplinary content area	Themes			
		The audience or genre can influence the language students use and the degree to which students incorporate their content knowledge	**The assignment context supports students in making connections between concepts**	**Rhetorical framing is linked to students' perceptions of the relevance of content and their emotional engagement**	**Interview and survey data indicate that students often experience an increase in confidence due to WTL**
Finkenstaedt-Quinn et al., 2017	Materials science and engineering	X			X
Moon, Zotos, et al., 2018	Physical chemistry				X
Gere et al., 2018	Introductory statistics	X			
Schmidt-McCormack et al., 2019	Organic chemistry				X
Finkenstaedt-Quinn et al., 2020	Physical chemistry		X		
Gupte et al., 2021	Organic chemistry	X	X	X	
Petterson et al., 2022	Organic chemistry	X	X	X	X
Marks et al., 2022	Materials science and engineering		X	X	
Totals for each theme		4	4	3	4

ence the level of cognitive engagement with the course content, social engagement with the simulated audience, and behavioral engagement with the assignment itself.

Beyond the influence of the audience and genre on students' engagement, studies have demonstrated that the assignment context supports students in making connections between concepts targeted by the assignments, further eliciting students' cognitive engagement (Table 3). For example, two studies describe how the rhetorical context of specific WTL assignments supported students in making connections between concepts across microscopic and macroscopic scales (Finkenstaedt-Quinn et al., 2020; Marks et al., 2022), which can be challenging connections for students to make (Bain et al., 2014; Bain & Towns, 2016; Justi, 2002). Additionally, two studies indicated how the different contexts of WTL assignments supported students in making connections to content from prior courses, within the course itself, and within concurrently taken courses (Gupte et al., 2021; Petterson et al., 2022). For example, interviews indicated that assignments with medically relevant contexts supported students' perceived learning of the specific concepts targeted by the assignments (Petterson et al., 2022). The findings across the MWrite WTL implementation regarding the influence of the rhetorical context on student responses reflect similar findings from other implementations of WTL involving specific rhetorical contexts (Balgopal et al., 2012, 2017; Balgopal & Montplaisir, 2011; Balgopal & Wallace, 2013; Doe et al., 2016; Libarkin & Ording, 2012; Rathburn, 2015). However, it is necessary to note that some students do not necessarily recognize the connections to outside courses, and that the context of the WTL assignments can influence whether students identify connections to content both within the course and from other sources, which can impact their cognitive engagement (Gupte et al., 2021; Petterson et al., 2022).

The rhetorical framing is also linked to students' perceptions of the relevance of content and their emotional engagement, such as their affect, motivation, and confidence, with the assignments (Table 3). For example, interviews in an organic chemistry course revealed students' positive affective experiences with the role, genre, and audience assignment components because they contributed to the authenticity of the assignments and demonstrated the relevance of the content (Petterson et al., 2022). The relevance of the assignments supported students' motivation for learning and their identification of connections to fields of interest for future career possibilities. In addition, interview and survey data across studies have revealed that students often experience an increase in confidence due to WTL (Table 3). The increase in confidence has been further demonstrated when comparing to a control group engaged in a non-WTL, traditional homework activity (Moon, Zotos, et al., 2018) or when controlling for overall differences in academic ability (Schmidt-McCormack et al., 2019). The influence of the rhetorical framing on students' affect is similarly reported for other implementations of WTL (Doe et al., 2016; Libarkin & Ording, 2012; Rathburn, 2015). However, studies within the MWrite context indicate that different students do have different affective experiences with assignment components (Gupte et al., 2021; Marks et al., 2022; Petterson et al., 2022). For example, students may not always recognize the relevance of assignments, which can influence a negative affective experience for aspects of the WTL assignments that other students experience with positive affect (Gupte et al., 2021). Hence, attention within the WTL pedagogical approach must consider the fact that students will have different affective experiences that can influence their engagement.

The peer review and revision processes support students' learning

Peer review and revision are important stages of the MWrite WTL assignments that are intended to provide students with the opportunity to learn from their peers and revisit their own thinking. Our analysis indicates a few modes by which the two stages support students' learning and engagement. Ten of the MWrite WTL studies included some evaluation of the peer review and revision elements of the WTL assignments (Table 4). Examination of the findings across the studies indicates that the peer interactions occurring during the peer review process provide additional sources of knowledge for students that can lead to primarily content-focused revisions.

Table 4. **Articles pertaining to each theme related to how the peer review and revision processes support students' learning**						
Article	**Disciplinary content area**	**Themes**				
		Students can provide constructive, content-focused feedback to their peers, aligned with the peer review rubrics	**Students make revisions associated with peer feedback they receive**	**Students find reading peers' drafts useful for identifying whether they understood or explained content correctly**	**Reading peers' drafts is statistically associated with content-focused revisions, exerting more influence than peer feedback received**	**Peer review and revision reduced students' anxiety associated with the assignments and supported students' confidence**
Finkenstaedt-Quinn et al., 2017	Materials science and engineering			X		
Moon, Zotos, et al., 2018	Physical chemistry	X	X			
Halim et al., 2018	Introductory biology	X	X			
Finkenstaedt-Quinn et al., 2019	General chemistry	X	X			
Schmidt-McCormack et al., 2019	Organic chemistry		X			
Finkenstaedt-Quinn et al., 2020	Physical chemistry	X	X			
Gupte et al., 2021	Organic chemistry		X	X		X
Finkenstaedt-Quinn, Polakowski, et al., 2021	Introductory statistics				X	
Petterson et al., 2022	Organic chemistry		X	X		X
Watts et al., 2022	Organic chemistry		X		X	
Totals for each theme		4	8	3	2	2

Qualitative analyses of the peer review comments across multiple studies reveal that students can successfully provide constructive, content-focused feedback to their peers that aligns with the peer review rubrics students receive to guide the feedback process (Table 4). The alignment indicates that students are socially engaged during the peer review process, as well as cognitively engaged in the process of identifying content that merits revision and articulating feedback to their peers. Findings within Petterson et al. (2022) additionally indicate students' behavioral and social engagement with peer review, as interviewed students described putting more effort into their initial drafts so as to get the maximal benefit from peer feedback. Some students also noted that if they produced a good first draft their peers could also benefit from reading their response.

A key theme related to peer review and revision was that peer feedback prompted students to make revisions on their drafts (Table 4). Relatedly, two studies characterized the features of peer review comments and revisions using logistic regression, finding that revisions were most associated with peer review comments that identified areas for improvement or that presented disagreements with their peers' reasoning (Finkenstaedt-Quinn et al., 2019; Watts et al., 2022). These findings indicate cognitive engagement, as providing and utilizing feedback on content requires students to think about the material. Furthermore, analyses of student interviews and feedback surveys indicate that students describe peer feedback as helpful for identifying areas in their initial drafts that need improvement (Finkenstaedt-Quinn et al., 2020; Gupte et al., 2021; Petterson et al., 2022). The studies also indicate social engagement during the revision process, as students are actively considering the feedback they received from their peers.

The importance of reading peers' drafts on students' revisions was also present in a subset of the studies. Analyses of student feedback survey responses and interviews indicated that students found reading peers' drafts to be beneficial for identifying whether they understood or explained content correctly (Table 4). Peers' drafts thereby serve as another source of knowledge, demonstrating an intersection between social and cognitive engagement with the WTL assignments. This finding is further supported by studies which used logistic regression to examine the relative influence of peer feedback and reading peers' drafts during the peer review process, which found that reading peers' drafts was statistically associated with content-focused revisions (Table 4). The impact of reading peers' drafts on students' own revisions indicates that students were socially and cognitively engaged while providing feedback to their peers. However, these studies suggested that peer feedback effected less influence on students' revisions relative to reading peers' drafts (Table 4).

A theme arising from more recent MWrite WTL research is the benefits of the peer review and revision stages of the assignments on student affect. Analysis of students' perceptions of the assignments indicate that both the peer review and revision stages of the MWrite process reduced students' anxiety associated with the assignments and supported students' confidence in their responses (Table 4). Students described how receiving feedback and reading their peers' responses made them feel more confident about their own responses. The positive affective responses to peer review align with the findings on students' perceptions of CPR as beneficial (Ruggiero & Harbor, 2013). In addition, Petterson et al. (2022) identified that the opportunity to revise can serve to reduce students' anxiety about the assignments more generally; students knew they could revise if they initially responded to the assignments incorrectly, which enabled them to take risks on their initial drafts. In general, the inclusion of peer review and revision typically led to students' positive emotional engagement with the MWrite WTL assignments.

CONCLUSIONS AND IMPLICATIONS

This article analyzes the findings across the 16 research articles extending from the MWrite program at the University of Michigan. The review encompasses impacts of the various aspects of the MWrite WTL implementation (i.e., assignment design, peer review, and revision) in a variety of introductory STEM disciplines, including chemistry, materials science, biology, and statistics. The findings from these articles were analyzed in alignment with the dimensions of cognitive, behavioral, emotional, and social engagement. Through analyzing the findings across articles from the MWrite program, this study extends the literature on WTL by focusing on students' engagement when WTL is uniformly implemented across STEM courses. That is, prior analyses and meta-analyses indicate that the design principles, implementation, and support structures of WTL assignments often varies across disciplines and courses. MWrite, however, provides instructional support for designing evidence-based, effective WTL assignments along with support for a peer review and revision process that is standard across MWrite courses. Hence, analyzing the set of findings extending from research on the MWrite program serves to provide insight into the ways that WTL, when implemented in classrooms following the principles behind MWrite, can support students' engagement in STEM.

We identified four key findings regarding how MWrite WTL supports students' engagement: (1) MWrite WTL assignments support students' abilities to describe content and lead to changes in content knowledge; (2) MWrite WTL assignments engage students in disciplinary thinking practices, specifically reasoning and argumentation; (3) the structure of MWrite assignments influences students' learning and affect; and (4) MWrite's peer review and revision processes support students' learning. The first two of these findings demonstrate the ways in which MWrite supports students' cognitive and behavioral engagement; the findings indicate that students are behaviorally engaged in the different aspects of WTL (i.e., drafting, peer review, and revising) which support their cognitive engagement with both content and disciplinary thinking practices. The third finding relates largely to students' emotional and social engagement, describing how the MWrite assignment design influences students' affective experiences and engagement with rhetorical contexts and audiences in ways that support their learning. The final finding relates to students' behavioral and social engagement, detailing how students participate in the peer review process which is grounded in the social aspects of receiving peer feedback and reading/responding to their peers' writing. Altogether, the findings illustrate how the multiple dimensions of engagement can be supported through MWrite WTL to create a more holistic learning experience for students.

The review points to a number of implications for instructors wishing to implement WTL in their courses and for stakeholders in programs seeking to support WTL across multiple courses and disciplines (such as writing across the curriculum or writing in the disciplines initiatives that seek to include WTL-specific support structures). The findings indicate that the design principles used for developing MWrite assignments created learning experiences that cognitively engaged students with both content and disciplinary thinking (such as scientific reasoning or arguing from evidence). This finding points to principles instructors should keep in mind when designing assignments, along with the benefits of implementing college- or university-wide programs like MWrite that can support students' learning through WTL assignments. In addition, the analysis indicates the potential for the WTL assignments to support learning in areas where students are known to struggle, such as building connections between concepts, connecting course content to real world applications, and engaging in complex reasoning. Furthermore, since WTL assignments such as those developed through MWrite elicit students' knowledge and disciplinary thinking, students' responses can serve as a valuable tool for formative assessment that can allow instructors to access what students know and understand about specific content areas. Lastly, the findings emphasize the value of implementing peer review and revision processes to support students' learning with WTL assignments. The various studies analyzed indicate the value of these processes for supporting students' learning, where both reading peers' writing and receiving feedback can inform content-focused revisions. Peer review and revision can additionally create positive affective experiences, such as increasing students' confidence.

The review additionally points to several avenues for further research into both WTL and the MWrite program specifically. Of particular need is research on whether and how the MWrite WTL assignment design may differentially impact groups of students and how the implementation and effectiveness of our WTL design changes in different classroom and institutional contexts. It is necessary to understand how students who are English language learners or who identify as belonging to minoritized groups experience the WTL assignments and the MWrite program. This direction for future research is especially merited given the findings that students express different experiences with different assignment components (such as the rhetorical contexts or peer review), both in terms of affect and in terms of their learning (e.g., the finding that not all students identify connections between assignment content and prior knowledge). Tied to research on the differential impact of WTL, more attention is required to understand the impacts of the WTL assignments on the affective domains, such as motivation and meaningful learning. For example, students may have different affective responses to the assignment components meant to demonstrate the relevance of course content (e.g., context and audience).

It is also important to study aspects of the MWrite program other than students' learning and engagement with the WTL assignments. Specifically, research focused on the impact of being involved with MWrite on both instructors and writing fellows is merited. As the MWrite program progresses, it is becoming increasingly apparent that there are unexpected benefits to the writing fellows and faculty involved (e.g., enculturation with disciplinary norms and increasing the use of evidence-based practices, respectively). Studying how being involved in a large-scale effort such as MWrite may influence pedagogy and disciplinary knowledge could inform our communities' efforts to create and support pedagogical change more broadly.

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APPENDIX

***Table A1*. Overview of articles included in the review**	
Shultz, G.V., & Gere, A. R. (2015). Writing-to-learn the nature of science in the context of the Lewis dot structure model. *Journal of Chemical Education, 92*(8), 1325-1329.	
Disciplinary content area	General chemistry
Study overview	Researchers implemented a WTL assignment where students read and wrote about a fundamental article presenting a model for depicting structures in chemistry, comparing it to the conventional model taught in lecture. Students' responses to a pre-post survey indicated changes in their conceptions of the nature of science.
Finkenstaedt-Quinn, S. A., Halim, A. S., Chambers, T. G., Moon, A., Goldman, R. S., Gere, A. R., & Shultz, G.V. (2017). Investigation of the Influence of a Writing-to-Learn Assignment on Student Understanding of Polymer Properties. *Journal of Chemical Education, 94*(11), 1610-1617.	
Disciplinary content area	Materials science and engineering
Study overview	Researchers examined how a WTL assignment supported students' learning of polymer properties through analyzing students' writing with a content-focused rubric. The study additionally used a multi-tiered assessment and interviews to identify students' conceptual understanding and experiences with the writing process. The study found that WTL promoted students' understanding and identified aspects of WTL that supported their learning.
Moon, A., Zotos, E., Finkenstaedt-Quinn, S., Gere, A. R., & Shultz, G. (2018). Investigation of the role of writing-to-learn in promoting student understanding of light–matter interactions. *Chemistry Education Research and Practice, 19*(3), 807-818.	
Disciplinary content area	Physical chemistry
Study overview	Researchers investigated how students understand central concepts in physical chemistry through analyzing students' responses to a WTL assignment connecting the concepts to a real-world context. Using a quasi-experimental design and a pre-post assessment, the study identified learning gains associated with the WTL assignment. Findings were triangulated with interviews and feedback surveys and indicated that students improved their explanations of the concepts.
Halim, A. S., Finkenstaedt-Quinn, S. A., Olsen, L. J., Gere, A. R., & Shultz, G.V. (2018). Identifying and Remediating Student Misconceptions in Introductory Biology Via Writing-to-Learn Assignments and Peer Review. *CBE - Life Sciences, 17*(2), ar28.	
Disciplinary content area	Introductory biology
Study overview	Researchers examined four WTL assignments in an introductory biology course to identify the types of misconceptions elicited and how peer review and revision can remediate or propagate misconceptions. The study identified misconceptions in students' responses to all four assignments, and researchers generated six profiles to characterize how misconceptions were addressed through peer review. Findings indicated that directed peer review comments were the primary mode of remediating misconceptions, while students revealed further misconceptions when revising in response to more general peer review comments.
Gere, A. R., Knutson, A.V., Limlamai, N., McCarty, R., & Wilson, E. (2018). A Tale of Two Prompts: New Perspectives on Writing-to-Learn Assignments. *The WAC Journal, 29*, 147-188.	
Disciplinary content area	Introductory statistics
Study overview	Researchers analyzed students' responses to two WTL assignments in a statistics course, with a focus on how the amount and type of learning was influenced by the differences in genre and audience for the assignments. Responses were scored on a rubric to identify students' learning and interviews with students were conducted to identify the influence of genre and audience. The findings indicate that students' explanations differ based on the genre and the need to align the genre with the level of explanation targeted by the assignment.
Finkenstaedt-Quinn, S. A., Snyder-White, E. P., Connor, M. C., Gere, A. R., & Shultz, G.V. (2019). Characterizing Peer Review Comments and Revision from a Writing-to-Learn Assignment Focused on Lewis Structures. *Journal of Chemical Education, 96*(2), 227-237.	
Disciplinary content area	General chemistry
Study overview	Researchers investigated the relationships between peer review and revision through analyzing students' peer review comments and revisions in their responses to the WTL assignment described in Shultz and Gere (2015; see above). Peer review comments were characterized by their usefulness and connected to associated revisions in students' writing. The findings indicate that students provided detailed feedback that focused on concepts while also making editorial comments.
Schmidt-McCormack, J. A., Judge, J. A., Spahr, K., Yang, E., Pugh, R., Karlin, A., Sattar, A., Thompson, B. C., Gere, A. G., Shultz, G.V. (2019). Analysis of the role of a writing-to-learn assignment in student understanding of organic acid–base concepts. *Chemistry Education Research and Practice, 20*(2), 383-398.	
Disciplinary content area	Organic chemistry
Study overview	Researchers investigated a WTL assignment that required students to consider two theories of acid-base chemistry. The study included an external assessment administered to a treatment and comparison group, finding that students who completed the WTL assignment demonstrated a greater increase in their conceptual understanding. The results were triangulated with interviews and provide details about how students explained and connected the acid-base theories.
Moon, A., Moeller, R., Gere, A. R., & Shultz, G.V. (2019). Application and testing of a framework for characterizing the quality of scientific reasoning in chemistry students' writing on ocean acidification. *Chemistry Education Research and Practice, 20*(3), 484-494.	
Disciplinary content area	General chemistry
Study overview	Researchers investigated a WTL assignment focused on accessing students' scientific reasoning. The study provides a framework for assessing students' argumentative writing about ocean acidification, which was used to estimate the quality of students' reasoning. The findings suggest strategies for identifying reasoning in students' writing that can be used by instructors for formative assessment.
Finkenstaedt-Quinn, S. A., Halim, A. S., Kasner, G., Wilhelm, C. A., Moon, A., Gere, A. R., & Shultz, G.V. (2020). Capturing student conceptions of thermodynamics and kinetics using writing. *Chemistry Education Research and Practice, 21*(3), 922-939.	
Disciplinary content area	Physical chemistry

Study overview	Researchers identified students' conceptions of two central concepts in physical chemistry through a WTL assignment that applied the concepts to a real-world context. The study focused on the content in students' writing and the peer review feedback, finding that students demonstrated improvements in describing and connecting the concepts. The findings indicate that content-focused peer review and revision supported students' responses to the assignment.
Watts, F. M., Schmidt-McCormack, J. A., Wilhelm, C. A., Karlin, A., Sattar, A., Thompson, B. C., Gere, A. R., Shultz, G.V. (2020). What students write about when students write about mechanisms: analysis of features present in students' written descriptions of an organic reaction mechanism. *Chemistry Education Research and Practice, 21*(4), 1148-1172.	
Disciplinary content area	Organic chemistry
Study overview	Researchers analyzed features in students' writing in response to a WTL assignment about an organic chemistry reaction mechanism. The analysis adapted an analytical framework based in the philosophy of science to identify evidence of mechanistic reasoning in students' writing. Researchers analyzed the co-occurrences of features in students' writing to make inferences about students' reasoning, identifying empirical evidence for the hierarchical nature of mechanistic reasoning and the variations in students' reasoning.
Gupte, T., Watts, F. M., Schmidt-McCormack, J. A., Zaimi, I., Gere, A. R., & Shultz, G.V. (2021). Students' meaningful learning experiences from participating in organic chemistry writing-to-learn activities. *Chemistry Education Research and Practice, 22*(2), 396-414.	
Disciplinary content area	Organic chemistry
Study overview	Researchers examined students' meaningful learning experiences from three WTL assignments in an organic chemistry laboratory course. The study analyzed students' responses to open-ended feedback surveys and interviews conducted after each assignment to understand if and how the assignments promoted students' meaningful learning across affective and cognitive domains. Findings indicated different ways the assignments connected to students' existing knowledge and the specific assignment components that supported students' meaningful learning.
Finkenstaedt-Quinn, S. A., Polakowski, N., Gunderson, B., Shultz, G.V., & Gere, A. R. (2021). Utilizing Peer Review and Revision to Support the Development of Conceptual Knowledge Through Writing. *Written Communication, 38*(3), 351-379.	
Disciplinary content area	Introductory statistics
Study overview	Researchers analyzed a WTL assignment, with a focus on identifying whether engaging in peer review and revision resulted in changes in how students write about the content elicited by the assignment. The findings demonstrate that students made content-focused revisions, including an increase in explaining content correctly. Furthermore, the study indicates that students benefit from reading peers' work during the peer review process.
Petterson, M. N., Finkenstaedt-Quinn, S. A., Gere, A. R., & Shultz, G.V. (2022). The Role of Authentic Contexts and Social Elements in Supporting Organic Chemistry Students' Interactions with Writing-to-Learn Assignments. *Chemistry Education Research and Practice, 23*(1), 189-205.	
Disciplinary content area	Organic chemistry
Study overview	Researchers investigated WTL assignments in organic chemistry, with a focus on their inclusion of relevant contexts and social elements. Through analyzing interviews and feedback surveys, the study examined how the rhetorical elements of the WTL assignments demonstrated the relevance of organic chemistry and how peer review supported students' affective experiences. The findings indicated that assignments with relevance and social interactions support students' affective experiences and perceived learning.
Brandfonbrener, P. B., Watts, F. M., Shultz, G.V. (2022). Organic chemistry students' written descriptions and explanations of resonance and its influence on reactivity. *Journal of Chemical Education, 98*(11), 3431-3441.	
Disciplinary content area	Organic chemistry
Study overview	Researchers examined students' responses to a WTL assignment focused on a concept in organic chemistry that is fundamental for representing and determining the reactivity of molecules. Through analyzing students' responses, the study identified how students explained the concept and how it influences reactivity. The analysis identified the features of the concept that students found important for their explanations, including the analogies and examples students generated. The findings indicated the ways students conceptualize the phenomenon.
Marks, L., Lu, H., Chambers, T., Finkenstaedt-Quinn, S., Goldman, R. S. (2022). Writing-to-learn in introductory materials science and engineering. *MRS Communications, 12*, 1-11.	
Disciplinary content area	Materials science and engineering
Study overview	Researchers analyzed the influence of four WTL assignments on students' conceptual understanding for specific, targeted content areas. The researchers used scoring rubrics to analyze students' initial and revised drafts, finding statistically significant improvements in scores. The highest effect sizes were for the WTL assignments that required synthesizing qualitative data into quantitative formats. The researchers also used pre/post concept-inventory style assessments to identify that WTL supported students' learning beyond traditional pedagogies.
Watts, F. M., Park, G. Y., Petterson, M. P., Shultz, G.V. (2022). Considering alternative reaction mechanisms: Students' use of multiple representations to reason about mechanisms for a writing-to-learn assignment. *Chemistry Education Research and Practice, 23*(2), 486-507.	
Disciplinary content area	Organic chemistry
Study overview	Researchers examined students' responses to a WTL assignment focused on how students utilized two representations fundamental in organic chemistry to determine and explain which pathway an organic chemistry reaction would follow. Through analyzing students' responses, the study identified how students explained their choice of reaction pathway and the changes in their explanations following revision. The analysis also identified the relative importance of the peer feedback students received and the peers' initial drafts that they read.

Table A2. **Overview of articles pertaining to each category presented in the Results and Discussion**				
Article	**Themes**			
	MWrite WTL assignments support students' abilities to describe content and lead to changes in content knowledge	**MWrite WTL assignments engage students in disciplinary thinking practices**	**The structure of the MWrite assignments influences students' learning and affect**	**The peer review and revision processes support students' learning**
Shultz & Gere, 2015		X		
Finkenstaedt-Quinn et al., 2017	X		X	X
Moon, Zotos, et al., 2018	X		X	X
Halim et al., 2018				X
Gere et al., 2018	X		X	
Finkenstaedt-Quinn et al., 2019				X
Schmidt-McCormack et al., 2019	X		X	X
Moon et al., 2019		X		
Finkenstaedt-Quinn et al., 2020	X		X	X
Watts et al., 2020		X		
Gupte et al., 2021			X	X
Finkenstaedt-Quinn, Polakowski, et al., 2021	X			X
Petterson et al., 2022			X	X
Brandfonbrener et al., 2022	X			
Marks et al., 2022	X		X	
Watts et al., 2022		X		X
Total	8	4	8	10