

How Exposure to and Evaluation of Writing-to-Learn Activities Impact STEM Students' Use of Those Activities

JUSTIN NICHOLS

That writing, “a knowledge-making activity,” aids learning represents accepted knowledge in writing studies (Estrem, 2015, p. 19). Research has established that writing is linked to important educational outcomes in higher education (Arum & Roksa, 2011; Astin, 1992; Light, 2001) and that specific features of writing assignments most effectively facilitate deep learning (Anderson, Anson, Gonyea, & Paine, 2015, 2016). Traditionally occupying one end of McLeod’s (1992/2000) writing-across-the-curriculum (WAC) approach continuum, writing-to-learn (WTL) approaches generally reflect a view of writing as a mode of thought (Arnold et al., 2017; Emig, 1977; Estrem, 2015) and may include assignments such as journaling, class-note summaries, and imaginary dialogues (Fulwiler, 1982; Young, 1984/2011) and other ungraded writing assignments aimed at promoting “learning” defined not simply as memorization but as “*discovery*, as a way of objectifying thought, of helping separate the knower from the known” (McLeod, 1992/2000, p. 3). Much of the literature on WTL outcomes, though, has used a more specific measurement of learning, specifically *learning achievement*, defined as and measured by recall of course content.

What is known about WTL experiences in relation to learning achievement is that WTL has produced modest but positive effects (Bangert-Drowns, Hurley, & Wilkinson, 2004). Short in-class WTL experiences have had greater effects than longer experiences, feedback on WTL assignments has generated no visible impact, and metacognitive WTL tasks have been more effective than personal writing (Bangert-Drowns et al., 2004). In exploring cognitive processes involved in WTL activities, Arnold et al. (2017) found that essay-like responses measuring recall of content led to better achievement, suggesting, as did Newell (1984), that WTL may be most effective when it leads to elaboration upon and reorganization of material. Nevid, Ambrose, and Pyun (2017) found that brief higher-order WTL assignments, defined as assignments “in which students needed to apply [a] particular concept to an example or to use the concept to analyze a process or mechanism” versus assignments that asked only for definitions or descriptions, were most impactful (p. 2). In their study of calculus students in a challenging R1 setting, Doe, Pilgrim, and Gehrtz (2016) found that students in a traditional lecture class were outperformed by students in a class where lecture time was reduced to make room for mainly writing and discussion, with the

writing-class group doing better both on conceptual understanding and mathematical procedural knowledge. Finally, Gingerich et al. (2014) found that the effects of writing about course content was significantly greater than the effects of copying lecture slides in class, and recall of course content was still greater eight weeks after the WTL intervention.

Generally, then, writing as an activity and WTL in particular have been established as beneficial for learning achievement, yet a topic that remains less investigated in WTL literature is how students evaluate these experiences and how those evaluative judgments may relate to exposure to and adoption of WTL activities. Steffens (1991) argued for using WTL journaling in large history lecture classes and provided student reflections on the WTL experience, which showed students reporting that writing forced engagement with content and was useful for learning. In a paper that looked at learning achievement and student perceptions, Schurle (1991) found that, although writing substituting for homework did not help students outperform another group of students on college math tests, students perceived that writing enhanced their conceptual understanding of the material. Elder and Champine (2016) recently enhanced our understanding further of how college students understand WTL experiences: They reported that mathematics students judged problem-solving writing, or “writing to clarify student’s thinking,” as more useful for learning new content than narrative-mode writing (Conclusion section, para. 1). In the present study, I have aimed to add to WTL literature on students’ evaluative judgments of WTL experiences in STEM (science, technology, engineering, mathematics) majors by measuring the degree to which STEM students’ exposure to and evaluative judgments of WTL activity use in their STEM major were associated with voluntary use of those activities. While WAC/WID researchers have long emphasized the need to focus on observable learning outcomes rather than student or faculty perceptions of learning (Ochsner & Fowler, 2004), this study follows in the footsteps of researchers who have looked at how student writers’ dispositions and writing-experience evaluations may be made manifest in self-directed learning behavior, such as strategy adoption and use, that may signal development and writing skill and knowledge transfer (Baird & Dilger, 2017; Driscoll, 2011; Driscoll & Powell, 2016; Driscoll & Wells, 2012).

This study also aims to contribute to STEM-specific writing-complemented learning. As a recent special issue linking WAC and writing in the disciplines (WID) to high-impact educational practices (HIPs) in the journal *Across the Disciplines* reaffirms (Boquet & Lerner, 2016), since its start in the 1970s, WAC/WID has always been about helping students navigate and become members of disciplinary communities that have their own specialized literacy practices (Russell, 2002). In STEM fields, specialized literacy practices have been described as involving informative-genre writing, for instance through lab reports on science experiments. Described elsewhere

as a HIP (Kuh, 2008), a uniquely effective way to engage STEM students in STEM-community academic practices has been course-based research experiences (Hanauer & Bauerle, 2012; Hanauer, Graham, & Hatfull, 2016; Hanauer, Hatfull, & Jacobs-Sera, 2009; Hanauer et al., 2006). Undergraduate research experiences generally have been linked to STEM-student persistence (Gardner & Willey, 2016; Goonewardene, Offutt, Whitling, & Woodhouse, 2016; Jones, Barlow, & Villarejo, 2010; Schultz et al., 2011) and intent to become research scientists (Hanauer et al., 2016). Mainly, the educational experiences described above may be said to fall on the learning-to-write (LTW) or WID end of McLeod's (1992/2000) WAC-approach continuum. This WID focus may reflect what Reynolds, Thaiss, Katkin, and Thompson (2012) referred to as a relative neglect of WTL in STEM programs. Yet, linking a signature pedagogical feature of WAC/WID, namely WTL activities, to how students evaluate and use activities in their own, self-directed learning (Zimmerman, 1989, 2002) could provide a powerful additional argument for the value of WAC/WID in higher education. After all, students' perceptions of what they are doing in their courses and programs matter. In his evidence-based theory of college student persistence, for instance, Tinto (2015) has noted that students' perceptions that their curriculum provides relevant and meaningful learning experiences impact students' motivations to stay in college.

In my emphasis on WTL, I should note here that I do not wish to advance a theoretical distinction between WTL and LTW. WAC/WID practitioners and researchers have long advocated integrated perspectives that consider the implications of composition research broadly speaking without focusing through the lens of exclusively WTL or LTW (Melzer, 2014; Thaiss, 2001). In my reference to McLeod's (1992/2000) traditional WAC-approach continuum, I wish to highlight the interconnected nature of writing in college in general, and my focus in this study on WTL is meant to narrow the scope of my analysis to specific in-class writing activities meant to assist STEM students in engaging with course content. While LTW places emphasis on learning as well as on socialization into disciplinary communities (Carter, Ferzli, & Wiebe, 2007), my aim here is to shed light on activities that may take place in class, reserving, then, genres such as lab reports and persuasive/informative genres for future research.

To guide inquiry, I posed the following research questions:

1. To what writing-to-learn activities do STEM majors report being exposed?
2. What writing-to-learn activities do STEM majors report using?
3. How do STEM majors' exposure to and evaluations of writing-to-learn activities in their STEM majors relate to use of those activities?

Method

Study Design and Hypotheses

The purpose of this study was to measure the relationships among STEM students' exposure to, evaluations of, and use of WTL activities. A quantitative design using inferential difference and association tests was used. To explore whether evaluation of WTL activities differed depending on degree of exposure and use, participants were categorized into two groups for Mann-Whitney U testing of difference: those who reported being exposed to and using three or more WTL activities, and those who reported being exposed to and using fewer than three. To further explore whether greater exposure and evaluation were associated with greater use of WTL activities in STEM classes, Spearman's rho tests were used.

Hypotheses for this study can be stated as follows:

- *Hypothesis:* Students with greater exposure to and higher evaluations of WTL activities will use more WTL activities than students with less exposure and lower evaluations.
- *Null Hypothesis:* There will be no difference in evaluative judgments of WTL activities among students based on degree of exposure and use of WTL activities.

Participants

Participants were invited to participate in two ways: a web-based survey (via Qualtrics) that was emailed to STEM majors with the help of professors in students' departments and hard-copy versions of the survey distributed and collected in the opening minutes of first-year mathematics sections for STEM majors. Students were invited to pass the survey on to a STEM-major peer. Participation in this study was voluntary and anonymous, and it was carried out under supervision of the research site's institutional review board.

Table 1 details characteristics of participants who took the survey ($N = 134$).

Table 1

Participants' Characteristics

Category	Characteristic	Number
STEM Major	Anthropology	1
	Biochemistry	8
	Biology (Molecular)	27
	Chemistry	7
	Chemical Engineering	1
	Computer Science	28
	Engineering	1
	Geography	2
	Geoscience	11
	Health Science	1
	Mathematics	29
	Natural Science	9
	Physics	6
	Psychology	1
	Wildlife Science	1
Location	Midwestern/Great Plains	6
	Southern	12
	Western	9
	Eastern	107
Level of Education	Graduate	24
	Undergraduate	110
Self-Identified Gender	Female	59
	Male	72
	Preferred Not to Answer	3
Age	18-25	115
	26-35	18
	36-45	1

Instruments

The survey (Appendix A) followed items from Schmidt's (2004) writing-to-learn attitude survey (WTLAS). WTL activities included in items in the WTLAS are (a) in-class impromptu focused writing; (b) brainstorming, freewriting, or listing ideas

before writing; (c) brief summaries or microthemes about points in reading assignments; (d) peer-critiquing of a classmate's writing; (e) personal-experience writing to see connections between content and a student's life; and (f) journaling (Schmidt, 2004, p. 462).

Data Analysis

After checking of core assumptions of the survey data, a Shapiro-Wilk test ($p < .05$) indicated data was not normally distributed. Nonparametric Spearman's rho association and nonparametric Mann-Whitney U difference tests were then chosen as most appropriate. In addition, the result of Cronbach's Alpha to test internal reliability of the *evaluation of writing to learn activities in STEM majors scale* ($\alpha = .80$) was within an acceptable range (Nunnally, 1967) to create a composite variable also used in the analysis.

Results

To What Writing-to-Learn Activities Do STEM Majors Report Being Exposed?

The median for WTL exposure was 3, with a minimum of 0 and maximum of 7. While more than half of all participants reported being exposed to three or more of these WTL activities (69/134, [51.5%]), fewer than half reported being exposed to fewer than three (65/134, [48.5%]). Only two participants reported never being exposed to a WTL activity. Of those who did report exposure, a majority reported being exposed to pre-writing (88/134, [66%]) and summarizing (85/134, [63%]). Fewer than half reported being exposed to peer-critiquing (60/134, [45%]) and in-class impromptu writing (53/134, [40%]). Some reported being exposed to reflective writing (39/134, [29%]), personal writing (36/134, [27%]), and journaling (34/134, [25%]).

What Writing-to-Learn Activities Do STEM Majors Report Using?

The median for WTL use was 3, with a minimum of 0 and maximum of 7. While more than half of all participants reported using three or more WTL activities (68/134, [50.7%]), fewer than half reported using fewer than three (66/134, [49.3%]). Only one participant reported not using at least one WTL activity. A majority reported using pre-writing (102/134, [76%]). More than half reported using summarizing (77/134, [58%]). Some reported using reflective writing (43/134, [32%]); peer-critiquing (40/134, [30%]); personal writing (37/134, [28%]); in-class impromptu writing (36/134, [27%]); and journaling (30/134, [22%]). Aside from these, one student indicated using creative writing, one indicated using poetry, and one indicated using proof writing as alternative WTL activities.

How Do STEM Majors' Exposure to and Evaluations of Writing-to-Learn Activities in Their STEM Majors Relate to Use of Those Activities?

In evaluating the usefulness of WTL activities in STEM courses, participants reported a composite mean of 3.85 on a 5-point Likert scale, indicating they mainly understood WTL activities as supporting their learning in STEM classes. See Table 2.

Table 2

Means and Standard Deviations for Exposure, Evaluation, and Use of WTL Activities

Item	M	Mdn	SD
WTL Exposure	2.99	3.00	1.90
WTL Evaluation	3.85	3.86	0.67
WTL Use	2.80	3.00	1.55

In measuring the relationship among these variables, Spearman's rank correlation coefficient (Spearman's rho) test of association indicated that there was a statistically significant positive relationship between exposure to WTL activities and use of WTL activities, $r_s = .26, p = .003$, as well as between evaluation of WTL activities and use of WTL activities, $r_s = .40, p < .001$. These relationships can be described respectively as weak and moderate (Cohen, 1988). Finally, there was no statistically significant relationship between exposure and evaluation. Ultimately, the greater students' reported exposure to and evaluation of WTL activities, the greater their likelihood was of using them.

After the checking of core assumptions, nonparametric Mann-Whitney U tests were run to check for differences between participants who reported being exposed to three or more WTL activities ($n = 69$) and those who reported being exposed to fewer than three ($n = 65$).

Table 3

Means and Standard Deviations for Evaluations of Usefulness of WTL Activities by Exposure

Item	M		SD	
	≥ 3	< 3	≥ 3	< 3
Summarizing	4.23	3.94	.75	.93
Pre-writing*	4.16	3.85	.90	.91
Peer-reviewing*	4.16	3.72	.92	1.13
Personal-experience writing*	3.84	3.42	.99	1.13
Impromptu in-class writing	3.81	3.68	.91	.90
Journaling	3.52	3.29	1.13	1.14
Composite ($\alpha = .80$)*	3.99	3.70	.59	.71

Note. * $p < .05$. ** $p < .01$. *** $p < .001$. Differences significant at the $p < .05$ level. A five-point Likert scale was used: 1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, 5 = strongly agree.

As reflected in Table 3, results showed that positive evaluation of WTL activities overall was significantly greater for students exposed to three or more WTL activities ($Mdn = 4$) than for students exposed to fewer than three ($Mdn = 3.86$), $U = 1674.50$, $p = .011$. In addition, when students were exposed to three or more WTL activities, they also reported significantly more positive evaluations of the following: pre-writing ($Mdn = 4$, $Mdn = 4$, $U = 2009.50$, $p = .021$); peer-reviewing ($Mdn = 4$, $Mdn = 4$, $U = 1723.50$, $p = .014$); and personal-experience writing ($Mdn = 4$, $Mdn = 4$, $U = 1764$, $p = .024$).

Table 4 below presents evaluations of WTL activities based on reported use. After the checking of core assumptions, nonparametric Mann-Whitney U tests were run to check for differences in how participants evaluated WTL activities in STEM classes between participants who reported using three or more WTL activities ($n = 68$) and those who reported using fewer than three ($n = 66$).

Table 4

Means and Standard Deviations for Evaluations of Usefulness of WTL Activities by Use

Item	M		SD	
	≥ 3	< 3	≥ 3	< 3
Summarizing**	4.31	3.86	.74	.91
Pre-writing**	4.28	3.73	.69	1.03
Peer-reviewing*	4.16	3.73	.94	1.10
Impromptu in-class writing*	3.93	3.56	.76	1.01
Personal-experience**	3.93	3.33	.97	1.11
Journaling***	3.75	3.06	1.08	1.09
Composite ($\alpha = .80$)***	4.09	3.59	.49	.73

Note. * $p < .05$. ** $p < .01$. *** $p < .001$. Differences significant at the $p < .05$ level. A five-point Likert scale was used: 1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, 5 = strongly agree.

Results showed that positive evaluation of WTL activities overall was greater for students using three or more WTL activities ($Mdn = 4.14$) than for students using fewer than three ($Mdn = 3.86$), $U = 1312.50$, $p < .001$. In addition, when students used three or more WTL activities, they also reported significantly more positive evaluations of the following: impromptu in-class writing ($Mdn = 4$, $Mdn = 4$, $U = 1805$, $p = .035$);

pre-writing ($Mdn = 4, Mdn = 4, U = 1561.50, p = .001$); summarizing ($Mdn = 4, Mdn = 4, U = 1627, p = .003$); peer-reviewing ($Mdn = 4, Mdn = 4, U = 1715, p = .012$); personal writing ($Mdn = 4, Mdn = 4, U = 1562.50, p = .001$); and, journaling ($Mdn = 4, Mdn = 3, U = 1485.50, p < .001$).

Results, then, establish that greater exposure to and evaluation of WTL activities were systematically associated with greater use of WTL activities in this sample of STEM students. It was also the case that no meaningful differences were found as a result of subgroup analysis that compared participants by major, location, level of education, gender, or age.

Discussion

This study explored the degree to which STEM students' exposure to and evaluations of WTL activity use in their STEM majors were associated with reported use of those activities. Because WTL theory and prior research have established that WTL generally if modestly supports learning, I hypothesized that students with greater exposure to and more positive evaluations of WTL activities would report using more of those activities. Data analysis led to rejection of the null hypothesis, which stated that no statistically significant difference or association would be found, and to three main findings: (a) STEM majors in this sample reported being exposed to and using a range of WTL activities, with more than half reporting using three or more activities to learn STEM-course content, and, as reported exposure went up, so too did reported use, suggesting that greater exposure is associated with greater use; (b) STEM majors here positively evaluated WTL activities; and (c) STEM majors who were exposed to a greater number of WTL activities and who more positively evaluated those activities also reported using more of them.

In her recent book on the literacy narratives of scientists, Emerson (2016) noted that scientists she interviewed reported having undergraduate experiences mainly "devoid of authentic opportunities to engage as writers of science" (p. 202). Emerson suggests that we question whether WAC programs are adequately reaching undergraduate programs "and whether they are designed to meet the needs of our science students" (p. 202). The findings here, however, hint that WAC's reach may have the capacity to extend into the way students manage their own learning through WTL activities, even if further work may be required to explore whether undergraduate programs provide authentic WID experiences.

The findings reported here also potentially reflect a problematic issue regarding trends in higher education to assign informative genres or modes of writing while neglecting personal, expressive, or poetic writing experiences (Melzer, 2014). Participants in this study reported being exposed to and using mainly pre-writing and

summarizing while only about 30% reported being exposed to and using reflective writing, personal-experience writing, and journaling. The story may be more complicated when looking at STEM majors, of course, because signature genres such as the chemistry lab report, while essentially informative genres, may be designed to communicate with specific scholarly communities and mimic genre moves reinforced in published reports, suggesting something different from more teacher-student, transactional writing to inform. Still, the results here showing STEM students' relative lack of reported exposure to and use of more reflective, expressive WTL activities should motivate WAC practitioners to continue our work of emphasizing the value of such writing for writers.

Additionally, that STEM majors in this sample positively evaluated WTL activities further supports research on students' perceptions that writing has face validity when presented or used as a way of learning (Elder & Champine, 2016; Schurle, 1991; Steffens, 1991). Summarizing and pre-writing were reportedly especially valued WTL activities. Though the survey instrument used here was not sensitive enough to shed light on how summarizing or pre-writing were specifically used, it may be that these activities encouraged the kinds of elaboration and reorganization of course material that WTL researchers have long identified as especially impactful for content recall and learning achievement (Arnold et al., 2017; Bangert-Drowns et al., 2004; Newell, 1984). Not only does WTL enhance coverage of class content, an important issue for STEM professors who may have varying definitions of what coverage means for them (Scheurer, 2015), but also students believe in WTL. And perceptions matter. In his evidence-based theory of college student persistence, Tinto (2015) has noted that students' perceptions that their curriculum provides relevant and meaningful learning experiences impact students' motivations to stay in college.

The systematic differences measured here between those participants who used many and those who used few WTL activities are also striking. If this result reflects that students use more WTL activities because they find that those activities help them succeed in their specific departmental and disciplinary communities, this finding may reflect and add to knowledge derived from Bangert-Drowns et al. (2004), who concluded that longer-lasting WTL interventions had more significant effects on learning achievement than shorter ones. Along with longer sequences of WTL experiences, wider exposure to a variety of activities seems to be useful as well.

Limitations and Directions for Future Research

The findings above must be considered in light of the study's limitations. This study sampled from STEM students from different majors. STEM majors' writing experiences would be expected to differ by department and discipline; as Melzer (2014) has argued, each class that students encounter, even within a department or discipline,

may be said to constitute a unique discourse community (Swales, 1990, 2017) students are charged with understanding and navigating. More work is needed to determine the experiences of students in particular departments and similar STEM majors. Another limitation concerns the sensitivity of a survey instrument, which necessarily limits participants' chances to elaborate or add nuance. It is important to note, too, that participants in this study self-reported strategy exposure and use, making it possible that students who remembered their strategy exposure and use most explicitly were the ones who were able to recall the potential efficacy or appearance of efficacy of those strategies. Of importance here, then, is an understanding of the value of explicit instruction and discussion of WTL usage in STEM settings. The goal may be to nurture the kind of students Driscoll (2011) referred to as those "explicitly connected students" who can explain how previous writing instruction transfers to future disciplinary writing situations (Student Attitudes About Future Writing section, para. 10). Finally, an argument can be made for other ways of defining WTL activities and experiences, and therefore of measuring variables in relation to WTL exposure and use. My use of items from a previously validated survey captured general activities and experiences but not specific genres written in class, such as those that have long been discussed in WTL and WAC literature in general (Fulwiler & Young, 1982; Young, 1984/2011).

Future research might explore individual voices of students through qualitative designs, such as case-study or phenomenology research, to nuance big-picture patterns established here. A fuller understanding of WTL activities would be helpful. Preliminary results of my academic life narrative research into STEM majors indicate that reflective, autobiographical writing has potential to nurture STEM students' performances of disciplinary identities and work in service of institutional priorities, specifically student engagement and retention (Nicholes, 2018). Additional research might explore how WTL activities support deep engagement with course material as well as in-class identity work that may support students' reflections of themselves as members of disciplinary communities. Further research seems to be called for to illuminate the practices of departments and programs of different STEM majors to see what may be prized, supported, and reinforced regarding in-class and disciplinary literacy experiences. Exciting work on understanding how departments understand threshold concepts that define their disciplinary, more WID-related writing has been reported by Wardle, Updike, and Glotfelter (2018). Regarding directions for WTL-related writing research, I have found it fitting (Nicholes, in press) to draw on the work of science educators and theorists such as Hadzigeorgiou (2016), who has emphasized the central role of imagination in science education. The wonder especially younger students feel for science, for instance, has been described as a mediating variable or even prerequisite for conceptual understanding (Hadzigeorgiou & Fotinos, 2007).

WTL activities that prompt this kind of imaginative writing related to science, such as science fiction prototyping (Atherton, 2016; De Lepe, Olmstead, Russell, Cazarez, & Austin, 2015; Draudt et al., 2015), could complement more LTW, disciplinary writing that has been credited with prompting socialization into disciplinary communities (Carter et al., 2007).

Overall, though more sensitive qualitative designs are needed to understand participants' reasons for using WTL, such as case-study or phenomenological designs that look to understand how students define and understand the experience of WTL, the present study establishes patterns between WTL exposure, evaluation, and use in one sample of STEM students, offering direction for future research and WAC practice.

References

- 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-dimensionality study. *Research in the Teaching of English*, 50(2), 199–235.
- Anderson, P., Anson, C. M., Gonyea, R. M., & Paine, C. (2016). How to create high-impact writing assignments that enhance learning and development and reinvigorate WAC/WID programs: What almost 72,000 undergraduates taught us. *Across the Disciplines: A Journal of Language, Learning, and Academic Writing*, 13. Retrieved from <http://wac.colostate.edu/atd/hip/andersonetal2016.cfm>
- Arnold, K. M., Umanath, S., Thio, K., Reilly, W. B., McDaniel, M. A., & Marsh, E. J. (2017). Understanding the cognitive processes involved in writing to learn. *Journal of Experimental Psychology: Applied*, 23(2), 115–27. doi:10.1037/xap0000119
- Arum, R., & Roksa, J. (2011). *Academically adrift: Limited learning on college campuses*. Chicago, IL: University of Chicago Press.
- Astin, A. W. (1992). What really matters in general education: Provocative findings from a national survey of student outcomes. *Perspectives*, 22, 23–46.
- Atherton, E. (2016). Science fiction prototyping at work. *Computer*, 49(8), 109–111. doi:10.1109/MC.2016.229
- Baird, N., & Dilger, B. (2017). How students perceive transitions: Dispositions and transfer in internships. *College Composition and Communication*, 68(4), 684–712.
- 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(1), 29–58.
- Boquet, B., & Lerner, N. (2016). Introduction to the ATD special issue on WAC and high-impact practices. *Across the Disciplines: A Journal of Language, Learning, and Academic Writing*, 13. Retrieved from <http://wac.colostate.edu/atd/hip/intro.cfm>

- Carter, M., Ferzli, M., & Wiebe, E. N. (2007). Writing to learn by learning to write in the disciplines. *Journal of Business and Technical Communication*, 21(3), 278–302.
- Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum.
- De Lepe, M., Olmstead, W., Russell, C., Cazarez, L., & Austin, L. (2015). Using science fiction prototyping to decrease the decline of interest in STEM topics at the high school level. In D. Preuveneers (Ed.), *Workshop proceedings of the 11th International Conference on Intelligent Environments*, 1–11. Amsterdam, Netherlands: IOS Press.
- Doe, S., Pilgrim, M. E., & Gehrtz, J. (2016). Stories and explanations in the introductory calculus classroom: A study of WTL as a teaching and learning intervention. *The WAC Journal*, 27, 94–118.
- Draudt, A., Hadley, J., Hogan, R., Murray, L., Stock, G., & West, J. R. (2015). Six insights about science fiction prototyping. *Computer*, 48(5), 69–71.
- Driscoll, D. L. (2011). Connected, disconnected, or uncertain: Student attitudes about future writing contexts and perceptions of transfer from first year writing to the disciplines. *Across the Disciplines: A Journal of Language, Learning, and Academic Writing*, 8(2). Retrieved from <http://wac.colostate.edu/atd/articles/driscoll2011/index.cfm>
- Driscoll, D. L., & Powell, R. (2016). States, traits, and dispositions: The impact of emotion on writing development and writing transfer across college courses and beyond. *Composition Forum*, 34. Retrieved from <http://compositionforum.com/issue/34/>.
- Driscoll, D. L., & Wells, J. (2012). Beyond knowledge and skills: Writing transfer and the role of student dispositions. *Composition Forum*, 26. Retrieved from <http://compositionforum.com/issue/26/beyond-knowledge-skills.php>
- Elder, C. L., & Champine, K. (2016). Designing high-impact “writing-to-learn” math assignments for killer courses. *Across the Disciplines: A Journal of Language, Learning, and Academic Writing*, 13. Retrieved from http://wac.colostate.edu/atd/hip/elder_champine2016.cfm
- Emerson, L. (2016). *The forgotten tribe: Scientists as writers*. Fort Collins, CO: The WAC Clearinghouse.
- Emig, J. (1977). Writing as a mode of learning. *College Composition and Communication*, 28(2), 122–28.
- Estrem, H. (2015). Writing is a knowledge-making activity. In L. Adler-Kassner & E. Wardle (Eds.), *Naming what we know: Threshold concepts in writing studies* (pp. 19). Logan: Utah State University Press.
- Fulwiler, T. (1982). The personal connection: Journal writing across the curriculum. In T. Fulwiler & A. Young (Eds.), *Language connections: Writing and reading across the curriculum* (pp. 15–32). Urbana, IL: National Council of Teachers of English.
- Fulwiler, T., & Young, A. (Eds.). (1982). *Language connections: Writing and reading across the curriculum*. Urbana, IL: National Council of Teachers of English.

- Gardner, A., & Willey, K. (2016). Academic identity reconstruction: The transition of engineering academics to engineering education researchers. *Studies in Higher Education*, 43(2), 234–50. doi:10.1080/03075079.2016.1162779
- Gingerich, K. J., Bugg, J. M., Doe, S. R., Rowland, C. A., Richards, T. L., Tompkins, S. A., & McDaniel, M. A. (2014). Active processing via write-to-learn assignment: Learning and retention benefits in introductory psychology. *Teaching of Psychology*, 41(4), 303–08. doi:10.1177/0098628314549701
- Goonewardene, A. U., Offutt, C. A., Whitling, J., & Woodhouse, D. (2016). An interdisciplinary approach to success for underrepresented students in STEM. *Journal of College Science Teaching*, 45(4), 59–67.
- Hadzigeorgiou, Y. (2016). *Imaginative science education: The central role of imagination in science education*. Cham, Switzerland: Springer.
- Hadzigeorgiou, Y., & Fotinos, N. (2007). Imaginative thinking and the learning of science. *The Science Education Review*, 6(1), 15–23.
- Hanauer, D. I., & Bauerle, C. (2012). Facilitating innovation in science education through assessment reform. *Liberal Education*, 98(3), 34–41.
- Hanauer, D. I., Graham, M. J., & Hatfull, G. F. (2016). A measure of college student persistence in the sciences (PITS). *CBE-Life Sciences Education*, 15(4), 1–10.
- Hanauer, D. I., Hatfull, G. F., & Jacobs-Sera, D. (2009). *Active assessment: Assessing scientific inquiry*. New York, NY: Springer.
- Hanauer, D. I., Jacobs-Sera, D., Pedulla, M. L., Cresawn, S. G., Hendrix, R. W., & Hatfull, G. F. (2006). Teaching scientific inquiry. *Science*, 314, 1880–1881.
- Jones, M. T., Barlow, A. L., & Villarejo, M. (2010). Importance of undergraduate research for minority persistence and achievement in Biology. *Journal of Higher Education*, 81(1), 82–115.
- Kuh, G. D. (2008). *High-impact educational practices: What they are, who has access to them, and why they matter*. Washington, DC: Association of American Colleges and Universities.
- Light, R. J. (2001). *Making the most of college: Students speak their minds*. Cambridge, MA: Harvard University Press.
- McLeod, S. H. (1992/2000). Writing across the curriculum: An introduction. In S. H. McLeod & M. Soven (Eds.), *Writing across the curriculum: A guide to developing programs* (pp. 1–8). Fort Collins, CO: The WAC Clearinghouse.
- Melzer, D. (2014). *Assignments across the curriculum: A national study of college writing*. Logan: Utah State University.
- Nevid, J. S., Ambrose, M. A., & Pyun, Y. S. (2017). Effects of higher and lower level writing-to-learn assignments on higher and lower level examination questions. *Teaching of Psychology*, 1–6. doi:10.1177/0098628317727645
- Newell, G. E. (1984). Learning from writing in two content areas: A case study/protocol analysis. *Research in the Teaching of English*, 18(3), 265.

- Nicholes, J. (in press). Developing STEM interest and genre knowledge through science fiction prototyping. *The STEAM Journal*.
- Nicholes, J. (2018). *Exploring how chemistry and English majors understand and construct disciplinary identities in relation to life, departmental, and writing experiences: Implications for WAC and retention*. (Doctoral dissertation). Retrieved from ProQuest.
- Nunnally, J. C. (1967). *Psychometric theory*. New York, NY: McGraw-Hill.
- Ochsner, R., & Fowler, J. (2004). Playing devil's advocate: Evaluating the literature of the WAC/WID movement. *Review of Educational Research*, 74(2), 117–40. doi:10.3102/00346543074002117
- Reynolds, J. A., Thaiss, C., Katkin, W., & Thompson, J., Robert J. (2012). Writing-to-learn in undergraduate science education: A community-based, conceptually driven approach. *CBE-Life Sciences Education*, 11(1), 17–25. doi:10.1187/cbe.11-08-0064
- Russell, D. R. (2002). *Writing in the academic disciplines: A curricular history* (2nd ed.). Carbondale: Southern Illinois University Press.
- Scheurer, E. (2015). What do WAC directors need to know about “coverage”? *The WAC Journal*, 26, 7–21.
- Schmidt, L. A. (2004). Psychometric evaluation of the Writing-To-Learn Attitude Survey. *Journal of Nursing Education*, 43(10), 458–65.
- Schultz, P. W., Hernandez, P. R., Woodcock, A., Estrada, M., Chance, R. C., Aguilar, M., & Serpe, R. T. (2011). Patching the pipeline: Reducing educational disparities in the sciences through minority training programs. *Educational Evaluation and Policy Analysis*, 33(1), 95–114. doi:10.3102/0162373710392371
- Schurle, A. W. (1991). Does writing help students learn about differential equations? *PRIMUS: Problems, Resources, and Issues in Mathematics Undergraduate Studies*, 1(2), 129–36.
- Steffens, H. (1991). Using informal writing in large history classes: Helping students to find interest and meaning in history. *Social Studies*, 82(3), 55–58.
- Swales, J. M. (1990). *Genre analysis: English in academic and research settings*. Cambridge, MA: Cambridge University Press.
- Swales, J. M. (2017). The concept of discourse community: Some recent personal history. *Composition Forum*, 37. Retrieved from <http://www.compositionforum.com/issue/37/swales-retrospective.php>
- Thaiss, C. (2001). Theory in WAC: Where have we been, and where are we going? In S. H. McLeod, E. Miraglia, M. Soven, & C. Thaiss (Eds.), *WAC for the new millenium: Strategies for continuing writing-across-the-curriculum programs* (pp. 299–325). National Council of Teachers of English: Urbana, IL.
- Tinto, V. (2015). Through the eyes of students. *Journal of College Student Retention: Research, Theory, and Practice*, 19(3), 254–69. doi:10.1177/1521025115621917

- Wardle, E., Updike, A., & Glotfelter, A. (2018). Using Threshold Concepts and Disciplinary Teams as the Backbone of WAC Seminars, IWAC 2018, Auburn University, Auburn, AL.
- Young, R. E. (1984/2011). *Toward a taxonomy of "small" genres and writing techniques for use in writing across the curriculum*. Fort Collins, CO: The WAC Clearinghouse.
- Zimmerman, B. J. (1989). A social cognitive view of self-regulated academic learning. *Journal of Educational Psychology*, 81(3), 329–39. doi:10.1037/0022-0663.81.3.329
- Zimmerman, B. J. (2002). Becoming a self-regulated learner: An overview. *Theory Into Practice*, 41(2), 64–70. doi:10.1207/s15430421tip4102_2

Appendix A: Writing-to-Learn Evaluation Survey

1. In what department or program are you studying?

- Biochemistry
- Biology
- Chemistry
- Computer Science
- Geoscience
- Mathematics
- Physics
- Another _____

2. At what level are you studying?

- PhD
- Master's
- Bachelor's
- Associate's
- Another _____

3. With what gender do you most identify?

- Male
- Female
- Another _____
- Prefer not to answer

4. How old are you?

- 18-25
- 26-35
- 36-45
- 46-55
- 56-above
- Prefer not to answer

5. Please rate the degree to which you agree with the following statements.

	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree
Impromptu focused writing during class in my major can help me solve problems or clarify concepts.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree
Brainstorming, freewriting, or listing ideas before writing about topics related to my major can help me find out what I know and think about topics related to my major.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Writing brief summaries can make me aware of the most important points in classes related to my major.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Critiquing a classmate's writing for conceptual clarity can result in increased understanding of topics related to my major for both of us.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Writing personal experience pieces can make me see connections between what I am learning in classes related to my major and my own life.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Journal writing [journaling] can enhance my understanding of concepts and course materials related to my major.	<input type="checkbox"/>	<input type="checkbox"/>	v	<input type="checkbox"/>	<input type="checkbox"/>

6. Please mark which ways you use writing to help yourself learn.

- impromptu focused writing in class
- brainstorming, freewriting, or listing ideas
- writing brief summaries about readings
- critiquing a classmate's writing for conceptual clarity
- writing about personal experiences
- journal writing [journaling]
- reflective writing
- Another _____

7. Which, if any, of these activities have you been exposed to in classes in or related to your major?

- impromptu focused writing in class
- brainstorming, freewriting, or listing ideas
- writing brief summaries about readings
- critiquing a classmate's writing for conceptual clarity
- writing about personal experiences
- journal writing [journaling]
- reflective writing
- Another _____