SPONTANEOUSLY PRODUCED METACOGNITIVE LANGUAGE AND ACHIEVEMENT IN TWO STEM COLLEGE COURSES: AN EXPLORATORY ANALYSIS

BY

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THESIS

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ABSTRACT

Metacognition is a valuable tool for learning, due to its role in self-regulated learning (SRL). However, the online setting brings a new challenge of examining metacognition on a large scale and yet metacognition may be especially crucial for learning online. Moreover, SRL strategies may be particularly beneficial for students underrepresented in STEM because, by using these strategies, students may ameliorate or offset some of the difficulties these students typically face in more traditional academic settings. This study investigates whether a relationship exists between spontaneously produced metacognitive phrases and success in two online STEM college courses as well as whether this varies across students from different demographic backgrounds. This study then also looks at course engagement as accounting for some variance in course outcome. To do this, a tool for automatic detection of metacognitive phrases in forum posts from two online STEM courses was used. First the relation between students' spontaneously produced metacognitive phrases and their academic performance was analyzed and then differences across demographic groups were examined. Second, students' posts to the forums were analyzed as a potential indicator of engagement. No significant differences between UR-STEM students and non-UR STEM students were found, suggesting that the online space has the potential to equalize the STEM playing field. The nature of metacognitive language varied between the two courses, but the number of forum posts was related to course outcome for both courses. Implications of the results for teaching and learning STEM content in the online space are discussed.

Keywords: Metacognition, STEM college course, underrepresented STEM students, automatic detection, replication

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This project, along with all of my successes, is dedicated to my huge-hearted mom, Andrea.

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CHAPTER 1:

LITERATURE REVIEW

Overview

In the current study, the issue of underrepresentation in science, technology, engineering, and mathematics (STEM) is addressed. To do so, the study focuses on college students in their online STEM courses. The purpose of this study is to identify students' behaviors that are related to their success in their college courses and explore whether differences exist between underrepresented (UR) students and their (non-UR) peers in behaviors. The issue of whether findings from one online STEM course replicate in a second online STEM course is also taken analyzed. Ultimately, the goal is to understand these relations to inform online teaching and learning to support all students—and especially UR-STEM students—to succeed in STEM.

Although a large range of students' online behaviors (see e.g., Greene et al., 2019) could have been examined, evidence of students' self-regulated learning (SRL) behaviors were chosen to be examined both because these behaviors represent important skills needed to survive in online learning contexts and because these skills are malleable, can be taught, and do not rely on intellectual ability (Veenman & Spaans, 2005). Within SRL, which constitutes a large array of behaviors, this study focuses on students' expressions of metacognition. To understand and explain the underpinnings of this crucial skill, this study will follow Winne and Hadwin's (1998) information processing model of SRL, which includes an essential role for metacognition.

Because others have noted problems with offline and intrusive measures of metacognition (e.g., Bråten & Samuelstuen, 2007; Perry & Winne, 2006), examining students' spontaneously produced metacognitive comments in their online forum posts are considered, also being mindful of the scale and analytic issues with thousands of student forum posts. Finally, this study considers the issue of a potential confound and correlate of spontaneously produced metacognitive comments—course engagement—as measured by the number of student posts to the online discussion forum.

Underrepresentation in STEM

The United States has experienced a lag behind other industrialized nations in subjects like mathematics and science, at least since Sputnik in 1957, when the United States was suddenly seen as having fallen behind in terms of education compared to other nations (e.g., Wissehr, Concannon, & Barrow, 2011). To compound matters, the alarming underrepresentation of U.S. ethnic and racial minorities in STEM majors and STEM careers is garnering serious attention (e.g., Dika & D'Amico, 2016; Su & Rounds, 2015), and has also sounded the alarm to the absence of women and first-generation college students in many STEM fields (Engle, Tinto, & Pell Institute for the Study of Opportunity in Higher Education, 2008; Hernandez, Schultz, Estrada, Woodcock, Chance, 2013). Although the concern for UR-STEM students exists throughout the educational trajectory, this study focuses on investigating the disturbing phenomenon of UR-STEM students who make it to college and who decide to major in STEM. This is disturbing because UR-STEM students have made it this far, but then drop their major or switch to a non-STEM major (Latz, 2015).

Targeting Successful Behaviors: Metacognition as a Key Self-regulated Learning Behavior, Especially in Online Contexts

To contribute to ameliorating this problem, this study reckoned that it was wise to investigate students' behaviors that have been documented in past research to support positive outcomes. Thus, this study pursues students' self-regulated learning (SRL) behavior because this has been shown to lead to success in college students' learning (Fielding, Winters, Greene, & Costich, 2008; Park et. al., 2019) and ought to be even more valuable in the online context, where students are typically provided more freedoms than in traditional face-to-face STEM courses. With the increased freedoms and reduced structures (e.g., typically all learning is asynchronous, leaving students to choose when and sometimes even how to access course information), to be a successful student in an online setting, SRL is of the utmost importance (Xu & Jaggars, 2011; Xu & Jaggars, 2014).

More specifically, metacognition is targeted—which can be defined as a person's ability to think about their own thinking (Flavell, 1979)—because this is often cited as a crucial component of SRL (Winne & Perry, 2000). As Winne and Perry (2000) put it, metacognitive monitoring is "…the gateway to self-regulating one's learning" (p. 540). It noted that metacognition includes knowledge about one's own information processing skills, the nature of cognitive tasks, strategies for coping with such tasks, and executive skills related to monitoring and self-regulation of one's own cognitive activities (Schneider & Lockl, 2002). Even the mere presence of metacognitive monitoring has been shown to be highly related to comprehension and performance of academic material (Stanton, Neider, Gallegos, & Clark, 2015; Tsai, Lin, Hong, & Tai, 2018; Zimmerman, Moylan, Hudesman, White, & Flugman, 2011). Additionally, the production of metacognitive comments has been found to be a harbinger of acquiring new knowledge (e.g., Perry & Lewis, 1999).

Metacognitive monitoring is of utmost importance to support academic achievement. For example, several reviews (National Reading Panel, 2000; Trabasso & Bouchard, 2002) have concluded that certain metacognitive strategies–such as organization, elaboration, and *monitoring*–are particularly important for successful academic performance. Not only can metacognitive monitoring tell researchers about the current state of a student's thinking, but it is also indicative of a student's likelihood to deploy appropriate learning strategies to achieve an academic goal. Bråten and Samuelstuen (2007) proposed the idea that increased metacognitive monitoring in some instances may increase the use of an appropriate strategy in the future.

Given the role that metacognitive monitoring plays in SRL, it is not a surprise that increasing students' metacognitive monitoring has been shown to improve their learning outcomes (Azevedo & Cromely, 2004; Cardelle-Elawar, 1995; Hadie, Mohd, Hassan, Ismail, Talip, & Rahim, 2018; Nietfeld, Osborne, & Cao, 2005), and has been shown to be the differing variable between high-achieving students and low-achieving students (i.e., Horowitz, Rabin, & Bodale, 2013; Vanderstoep, Pintrich, & Fagerlin, 1996).

Theoretical Support: Winne and Hadwin's SRL Framework

Although many models of self-regulated learning exist, few specifically emphasize metacognition (and, even more precisely, metacognition free from emphasis on emotion and motivation, which is put aside for the purposes of this investigation). One theoretical framework that recognizes self-regulated students as active in managing their own learning was put forth by Winne and Hadwin (1998). It has been a widely used model, especially in research focusing on online learning (Panadero et al., 2015). According to Winne and Hadwin's SRL model (Panadero, 2018; Winne, 2011), when engaging in SRL, students go through four stages to reach an end goal of learning to evaluate and self-assess their progress in learning. These include (1) task definition, where students attempt to understand the task or the question at hand; (2) goal setting and planning, where students create goals and a plan to achieve their objectives; (3) students implement their plan and enact study strategies; and (4) metacognitively adapting studying, which occurs once the main processes are completed and the student decides to make changes in their strategies for the future. Each of these stages of SRL is important and special attention is payed to capture these behaviors. However, it is noted that the fourth stage is especially crucial because this is when students engage in metacognition, the focus of our investigation.

Measuring Metacognition

Much-used, but Problematic Methods

Although researchers agree on the importance of metacognition as an index of self-regulation in online courses, its measurement remains problematic (Veenman, Van Hout-Wolters & Afflerbach 2006; Winne, Hadwin, & Gress, 2010). Traditionally, metacognition has been studied through self-report surveys of offline strategies (Harrison & Vallin, 2017). For example, Schraw and Dennison (1994) created the widely used MAI (Metacognitive Awareness Inventory) to assess adults' metacognition under two categories: knowledge of cognition and regulation of cognition (alternatively referred to as metacognitive knowledge and metacognitive control). However, metacognition is dynamic, complex, subtle, and maybe even subconscious (e.g., Rovers et al., 2019), making self-reports among the least valid, and most controversial measures (Harrison & Vallin, 2017) for studying metacognition. It is important to consider that self-regulated strategies are context- and motivation-dependent (Bråten & Samuelstuen, 2007). Therefore, measurement methods that do not treat metacognition as context-dependent may not pick up on the sensitive and subtle nature of metacognition.

Self-reported measures can be problematic for various reasons. One issue is that much of metacognition occurs subconsciously, making it difficult to detect in general, let alone for students to report accurately (Perry & Winne, 2006). For example, Winne and Jamieson-Noel (2002) found significant discrepancies between students' self-report survey answers and trace data of student online learning behaviors. Thus, just because students do not report metacognitive activity does not necessarily mean that they are not engaging in metacognitive activity. The inverse is also a problem: when students are conscious of their use of metacognitive strategies, they report these more accurately (Bråten & Samuelstuen, 2007). This may be a chicken-and-egg problem: we do not know if self-reports are more accurate when students have consciousness of their use of the strategies or whether more use of the strategies leads to increased consciousness of use. A related issue with relying on self-reports of metacognition is that, even when these processes are conscious, memory can still be fallible or biased (Winne Jamieson-Noel, & Muis, 2002). In any case, students' awareness and accurate memory of their use of metacognitive strategies must be a prerequisite for any self-report measure, and thus we prefer to consider other means for detecting and measuring students' metacognition.

An Alternative Method

Due to the shortfalls of self-report measures, we propose a method that takes advantage of students' behaviors that reveal metacognition in the moment. Huang, Valdiviejas, and Bosch (2019) developed a tool to detect metacognitive language automatically from online forum posts. High agreement was found between human and machine coding of metacognition in online forum posts from a natural science course.

An advantage of Huang et al.'s (2019) automatic detection tool is that it permits large-scale analysis of metacognition in online learning contexts, and avoids the problems of time-intensive methods where either the researcher conducts post-activity inquiries to analyze metacognition (Cardinale & Johnson, 2017; McCarthy, Likens, Johnson, Guerrero, & McNamara, 2018) or participants are required to self-report their metacognitive awareness (e.g., Vrugt & Oort, 2008). Previous research may have been limited by the amount of data collected, having focused on manual annotation and reporting methods. Given that Huang et al.'s (2019) tool avoids the problem with self-reports and can be used on large-corpus text data, their tool is used in the current study a different natural science course.

Potential Confounds and Correlates

Although this study will avoid after-the-fact, self-reporting of metacognition, and the problems that accompany bringing attention to one's use of metacognitive strategies by analyzing all students' forum posts from online courses, this study now considers how the motivational context of two different online STEM courses might impact students' metacognition and their performance in these online STEM courses. The two motivational contexts that will be looked at in this paper are students' engagement in their course and the percentage weight the instructor assigns to discussion forum posts.

Metacognition as motivation-dependent. Many researchers cite the importance of including students' motivation in the self-regulation and metacognition framework (e.g., Eflklides, 2011; Wolters, 2003; Zimmerman, 2000). A student who is in a course (i.e., context) is likely to have external motivation, which in turn might impact the student's use of metacognition. For example, if posting to a forum is a moderate to large component of a students' course grades, students may be more motivated and this, in turn, might promote metacognition. If the forum posts are worth very little of the students' grade, they might only be motivated to do the bare minimum, or only the required amount of posts, diminishing the likelihood that students will engage in metacognitive thinking. Because the structure of the course grading might impact students' behaviors in the course, student behaviors in two different online STEM courses (reported in Study 1 and Study 2) will be examined.

Engagement's effect on metacognition. Engagement is highly related to motivation and we can expect that, for example, when students are motivated to participate they are likely to be engaged. This is important because, as Zheng and Warschauer (2015) found, well-designed online discussions (i.e., courses that provide motivation to participate) result in increased participation and interaction, leading to positive learning outcomes. Relatedly, Greene et. al. (2018) found that students who were more active in the course had better course outcomes. We expect that both external forum motivation (i.e., the weight that posting in the forum counts towards final grade) and student forum engagement (i.e., the number of posts produced in the online discussion forums) should be taken into consideration when examining students' spontaneous production of metacognitive comments.

CHAPTER 2:

RESEARCH QUESTIONS

The goals of the current study are to identify spontaneously produced metacognition in two online STEM courses and seek answers to three research questions. The data come from two different natural science STEM college courses, which will allow us to see if results replicate over different courses.

Replicating findings from research on metacognition in the context of this investigation. Before looking at the nuanced relations among student behaviors and outcomes, I first must ask:

(1) Are students' production of metacognitive comments related to their success in their online college course?

Exploring the Impact of UR status. If it is the case that students' production of metacognitive comments is related to their course outcome, a logical second research question is

(2) Are students' production of metacognitive comments and their success in their online college course related to their status as being a UR- versus a non-UR-STEM student?

Engagement's effect on metacognition. Engagement is highly related to course outcome. Greene et. al. (2019) found that students who were more active in the course had better course outcomes. Based on this, it is expected that an outward expression of internal motivation (operationalized here as the number of posts produced) should be taken into consideration when examining students' spontaneous production of metacognitive comments. Therefore, I ask the question:

(3) Are students' engagement with the course (i.e., number of posts) related to their outcome in the course (i.e., final exam score or letter grade in the course)?

These three research questions apply to two different natural science courses. In Study 1, results are reported for Science Course A, and in Study 2, results are reported for Science Course B, which serves as a replication of the study conducted for Science Course A. The differences between the results from the two courses are discussed.

In summary, the current study has three major advantages (or contributions) over previous studies. First, by looking at spontaneously produced language, I avoid the problems with self-report measures. By conducting this investigation in two online STEM courses, in two different natural science disciplines, I can answer questions of generalizability of results as well as begin to understand the context-dependent aspect of metacognition. Finally, because few studies have looked at metacognitive monitoring specifically among UR-STEM students, I embarked on an exploratory analysis of students' spontaneous production of metacognitive comments in two online STEM courses' discussion forums because it is important to understand how all students, but especially those at risk for not succeeding in STEM, make use of this crucial SRL strategy to support their learning in the online context.

CHAPTER 3:

STUDY 1

Method

Participants and Data Sources

Data were obtained from all 205 students enrolled in one semester of one online natural science course after the course was completed in 2016. The UR-STEM students in this sample included students from three UR-STEM groups: non-males (i.e., any student who selected “female” or “non-binary” on their college application), U.S. UR-ethnic-and-racial minorities (i.e., African Americans, Hispanics/Latinx, and Native Americans), and first-generation college students (i.e., students whose parents did not complete college). The sample included 26% non-males, 16% U.S. UR-ethnic-and-racial minorities (URMs), and 17% first-generation (1^{st}-Gen) college students, and 62% non-UR (i.e., White, non-first-generation male) students from a large Midwestern public university in the United States. Note that the total number of students across the subsamples is greater than the total number of all students because some students belonged to more than one UR group. The intersection group-level findings of students who fit multiple UR categories are not reported in order to comply with FERPA regulations that protect students’ identities.

Data for analysis come from two main sources: (1) all of the students’ discussion forum posts (n = 7,007) and (2) their final exam scores[1], which were provided by university data curators. All prompts for students to post to the forums were open-ended, leaving students with a

[1] There was little variability in course grades (i.e., 84% of the students received As); therefore, the final exam scores were used the outcome variable. The exam scores better reflected the students’ learning, showed more variability, and were approximately normally distributed.

great deal of flexibility for what they posted. Posting to the forum constituted 25% of the students' course grade.

Identifying Metacognition

To detect metacognition in the forum posts, this study relied on Huang et al.'s (2019) automatic metacognitive language detection tool. An example of what a post might look like can be seen in the text below:

> On worksheet 23 Question IIIc, it asks to determine the moles of HN02 and of N02-, I understand how to get these values, but I just want to make it clear: the total column of the solution (when 250 mL of Na0H is added) isn't factored in when doing this particular calculation, am I right on that? In other words, I wouldn't need to multiple the concentrations of each molecule by the total column, correct?

For this particular post, the automatic detection tool would flag the metacognitive phrase "I understand" because it shows evidence that the student is assessing what they know and what they do not know, therefore, engaging in metacognitive thought. This tool exhibits excellent reliability with a human coder on more than 600 online forum posts coded by expert-level humans (linear-weighted Cohen's $\kappa = .82$).

Data Analysis

All of the statistical analyses for this study were done using R: A language and environment for statistical computing version 3.6.2 (R Core Team, 2019).

To address RQ1 (are students' production of metacognitive comments related to their success in the course?), a linear regression was used, where the final exam score was the outcome variable and total number of metacognitive comments was the explanatory variable.

Pending results from RQ1 (i.e., if it is found that a significant relation between metacognitive phrases and final exam score), this study will investigate RQ2 (is the relation between production of metacognitive comments and their success in their online college course related to their status as being a UR- versus a non-UR-STEM student?) using a logistic regression. A logistic regression model was chosen because the outcome variable was UR status and total metacognitive phrases was the explanatory variable.

For RQ3 (are any of these relations related to students' engagement with the course, as measured by number of posts?), a linear regression model was used with final exam score as the outcome variable and course engagement, measured by total post count by student, as the explanatory variable, to examine if a relationship existed between final exam grade and engagement.

Results

Descriptive Statistics

The 205 students in Course A produced a total of 11,417 metacognitive comments across their total of 7,007 posts. Each student, on average produced 56 metacognitive phrases (SD = 24) during the 8-week term. On average, each student posted to the forum 34 times (ranging from 1 to 346 posts, SD = 23). The distribution of metacognitive comments had a slightly positive skew, with the median number of metacognitive comments being 51. The distribution of posts also had a slightly positive skew, with the median number of posts being 33.

The minimum score on the final exam was 69.26 and the maximum (perfect) score on the final exam was 180. The average exam score was a 135.42 (SD = 19.80). The exam scores appeared to be approximately unimodally distributed.

In Study 1, RQs 1 and 3 dealt with linear regressions using the "lmtest" package version 0.9-37 (Zeileis & Hothorn, 2002). RQ2 dealt with a logistic regression using the "MASS" package version 7.3-51.4 (Venables, 2002).

RQ1. Are students' production of metacognitive comments related to their success in their online college course?

A linear regression was used with final exam scores as a function of spontaneously produced metacognitive comments indicated a significant relationship. Students who used more metacognitive comments earned higher final exam scores ($\hat{\beta}$ = 0.17, SE = 0.06, $p < .01$, R^2 = .04). Although the R^2 and $\hat{\beta}$ are small, an increase of one SD (24) of a metacognitive comment leads to expected value increase of 4 points in the final exam. Thinking about the results in these terms takes into account the scale of the current sample.

RQ2. Are students' productions of metacognitive comments and their success in their online college course related to their status as being a UR- versus a non-UR-STEM student?

A logistic regression analysis was performed where UR status was the outcome variable and total metacognitive phrases was the explanatory variable. This analysis was performed to examine whether UR status and production of metacognition differed for each group of students. A relationship between a student's UR status and their production of total metacognitive comments was not uncovered.

RQ3. Is students' engagement with the course related to their outcome in the course?

A linear regression was used with final exam score as a function of course engagement, measured by total post count by student, indicated a significant relationship. Students who posted more often earned higher final exam scores ($\hat{\beta}$ = 0.64, SE = 0.16, $p < .01$, R^2 = .07). Although the R^2 and $\hat{\beta}$ are small, an increase of one SD (23) of a post leads to an expected value increase of 14 points on the final exam. As previously mentioned, taking into account the scale of the variable (i.e., total post count) helps to convey the effect size.

CHAPTER 4:

STUDY 2

Method

Participants and Data Sources

Data were obtained from all 77 students enrolled in one semester of one online natural science course after the course was completed in 2016. The sample included 47% non-males, 19% U.S. URMs, 22% 1st-Gens, and 12% non-UR students from a large Midwestern public university in the United States. Note that the total number of students across the subsamples is greater than the total number of all students because some students belonged to more than one UR group. As in Study 1, I do not report intersectional group-level findings of students who fit multiple UR categories, to comply with FERPA regulations, which are in place to protect students' identities.

Data for analysis included two main sources: (1) all of the students' discussion forum posts (n = 6,086) and (2) course grades[3], which were provided to me by university data curators. It is noted that all prompts for students to post to the forums were open-ended, leaving students with a great deal of flexibility for what they posted. Posting to the forum constituted 5% of students' grades.

Identifying Metacognition

To detect metacognition, this study relied on the same tool that I used for Course A (Huang et al., 2019).

[3] Due to the final exam being administered via paper and pencil; it was not available to the researchers.

Data Analysis

In Study 2, a different analytical approach was taken because the only outcome variable available was course grade (A, B, C, and D). In particular, because the outcome variable was an ordered categorical variable for Course B (unlike Course A), a proportional odds model was used to address RQ1 to examine the relation between metacognition (the total number of metacognitive comments) and students' course outcomes (letter grades in the course). Course grades were unimodally distributed.

If it is confirmed that a significant relation between metacognition and course success, RQ2 can be asked (if not, RQ2 cannot be addressed), where it is asked whether the relation between production of metacognitive comments and their success in their online college course is also related to their status as being a UR- versus a non-UR-STEM student. If a significant relation between metacognition and course success exists, the plan is to use a proportional odds model to examine this question.

For RQ3, this study seeks to address whether students' engagement with the course, as measured by their number of posts to the class discussion forums has a relation to the course outcome. To address this question, a proportional odds model with post count as the predictor variable and course grade as the ordered-categorical-outcome variable was used.

Results

Generalizability of the automatic detection tool

The human coder recalculated interrater reliability for the posts from Course B. This was important to do because the tool was originally developed on posts from Course A. This tool exhibited excellent reliability with a human coder (linear-weighted Cohen's $\kappa = .75$) based on

300 online forum posts coded by expert-level humans from Course B. This provides evidence that the tool's capabilities can be transferred to a different environment.

Descriptive Statistics

The 77 students in Course B produced a total of 1,401 metacognitive comments across their 5,061 posts. Students, on average produced 3 metacognitive comments (SD = 5) during the 16-week term however, the distribution of metacognitive comments was positively skewed, with the median being 1 metacognitive comment. On average, each student posted to the forum 12 times (ranging from 1 to 285 posts, SD = 13.30) and posting is also positively skewed, with the median being 7 posts.

The lowest course grade was a D and the highest course grade was an A.16% of students got As, 35% of students got Bs, 40% of students got Cs, and 9% of students got Ds. Course grades appear to be unimodally distributed.

All of the statistical analyses ran for Study 2 were proportional odds models using the VGAM package (version 1.0-6) to analyze the data (Yee, 2010).

RQ1. Are students' productions of metacognitive comments related to their success in their online college course?

Because grades are ordered categorical variables and the proportional odds assumption held (G2 = 2.33, df = 2,230, p = 0.31), a proportional odds model was used with grades being the outcome variable and the total metacognitive comments per student was the explanatory variable. It was found that the odds of obtaining a high final course grade were not significantly higher for students who used more metacognitive language.

RQ2. Are students' productions of metacognitive comments and their success in their online college course related to their status as being a UR- versus a non-UR-STEM student?

The analysis for RQ2 was unwarranted because there was no association between course outcome and metacognition.

RQ3. Are students' engagements with the course related to their outcome in the course?

Because grades are ordered categorical variables and the proportional odds assumption held (G2 = 4.595, df = 2,230, $p = 0.10$), a proportional-odds model was used with grades as the outcome variable and, where the number posts submitted to the discussion forum by each student was the explanatory variables. A significant relationship between course grade and post count was found ($z = 2.00$, $p = .05$). For each additional post, students had 1.013 times the odds of a higher grade. For example, with 10 additional posts the odds of a higher grade were $1.013^{10} = 1.138$ times the odds with no additional posts.

CHAPTER 5:

DISCUSSION

In this section, the results are summarized and discussed, as well as discussing the implications from a comparison of the results from in Studies 1 and 2. After a careful consideration of the results, I consider why features of the courses might have led to the different results obtained in Study 1 and Study 2. Later, both implications for teaching and learning and for theoretical and methodological issues in studying metacognition are discussed. Finally, the limitations of this investigation and suggestions for future research are discussed.

Summary and Implications of the Results

Students' metacognitive phrases were positively and significantly related to their scores on their final exams for Course A, suggesting that students who produced more metacognitive comments in their forum posts were more likely to have achieved a better course outcome. This finding is in line with previous research that has documented a positive relation between metacognition and academic success (e.g., Mata, Ferreira, & Sherman, 2013). However, this was not the case for Course B, which suggests that metacognition may be context dependent.

It was found that that UR-STEM students did not produce metacognitive comments at different rates than non-UR-STEM students (but this was only examined for Course A). This echoes results from Park et al.'s (2019) study, who found minimal differences in self-regulated learning behaviors between URM and non-URM students. Not finding evidence of a relation between UR-STEM status and metacognition suggests that students, independent of their marginalization as STEM students, can engage (or not) in metacognition in their online STEM courses. It is also possible that the online context is, at least in part, ameliorating the negative effects that come with being underrepresented in STEM (also see, e.g., Henricks. Perry, & Bhat, 2020, for a comparable result and interpretation).

Finally, engagement appeared to be related to course success. This suggests that those who participate more in online course forums are more likely to achieve success than those who participate less. This finding replicates the results from other investigations, especially in MOOCs (e.g., Crues et al., 2018; Phan, McNeill, & Robin, 2016).

Metacognition as context-dependent. One possibility for the differences between the two courses in the association between metacognition and course success could be that the nature of the course topic prompted either more critical thinking or more surface-level thinking. For example, the nature of Course A had a greater focus on estimation, whereas Course B had a greater focus on exact answers. This difference in focus could have contributed to the differences in metacognitive language being used by the students in the discussion forums. This possibility speaks to the context-dependent nature of metacognition. Metacognition will likely vary, depending on the nature of the task and the learner's relation to that task (see, e.g., Bråten & Samuelstuen, 2004; Hadwin et al., 2001). Clearly, the context in which students engage in any particular task will influence their reliance on metacognitive strategies.

Metacognition as motivation-dependent. The differing results could also have to do with the weight given to posting in the online forum, speaking to the motivation-dependency of metacognition. For Course A, posting was 25% of the students' grades compared to only 5% of the students' grades for Course B. The differences in how students' posts were weighted contributes to our understanding of how metacognition is dependent on a person's motivation (Efklides, 2011). In other words, the students in the studies reported here may have been influenced by extrinsic motivation (i.e., percentage of grades) to engage in the online discussion forums. Others (e.g., Eflklides, 2011; Wolters, 2003; Zimmerman, 2000) have cited the importance of including motivation in the self-regulation and metacognition framework and this investigation supports that conclusion.

It could also be that these two courses attracted two different types of students, one more metacognitively inclined than the other. Perhaps courses like Course A attract more self-paced students who prefer or are better at learning through discussion with their peers on discussion forums and courses like Course B attract students who prefer clear-cut direction and do not feel comfortable expressing metacognition in the course discussion. This is clearly speculative and deserves further investigation in future research.

Implications for Teaching and Learning

Few studies have looked at metacognition and its role in the online space at the university level for UR-STEM students. Significant findings in this area could contribute to understanding subtle self-regulated learning strategies in online learning. Based on the differences in the use of metacognitive language across courses—and the fact that no differences were found between UR-STEM students and non-UR-STEM students—this study could give insight into what is and what is not contributing to the achievement gap, specifically in STEM at the university level. In other words, the current study reminds us that metacognitive language produced in online forums are likely to be context and motivation dependent.

On a broader scale, findings could inform curriculum designers to create enhanced learning environments that level the playing field through learning technologies to enhance students' engagement, as findings in this study were robust for engagement, compared to modest for metacognition. For example, researchers could work closely with instructors to implement consistent prompts throughout the curriculum that require students to post to online discussion forums more often than the average course, which may promote successful academic achievement in the course.

Methodological and Theoretical Issues

A methodological innovation to metacognition research of the present study is that metacognitive monitoring is measured by examining forum posts, rather than through surveys or experimental interventions. These findings, that metacognitive monitoring is related to academic success (at least for one course), were consistent with others who used different approaches to examine metacognition, which lends support to the validity of the automatic detection tool. Expansion on the usages of the automatic detection tool could be very useful to equip instructors with the ability to detect promotions of successful learning experiences besides metacognitive language, like self-efficacy, which not only has the capability to promote students' creation of internal knowledge and enhance their personalized motivation, but it can also provide guidance and/or the framework for the integration and application of educational technology (Xie, Li, Qiu, Huang, & Lai, 2019). For the tool to perform an operation of this nature, the same steps that were gone through in creating the tool used for metacognition need to be accomplished, but instead targeting self-efficacious language.

This work provides compelling evidence about the role of metacognition in students' learning in spontaneously generated text. Understanding how metacognition functions to support student learning in the online space merits further investigation for at least one main reason: the novelty of the automatic detection tool. Work on spontaneously produced metacognitive language is scarce, especially with large text corpora. Thus, the current study can serve as a preliminary step to understanding metacognition's role in complex and authentic educational contexts, without the obvious presence of a researcher.

Limitations and Future Research

These results and interpretations are constrained by several limitations in the current study. First, the sample was not representative in terms of academic achievement (students attended a large, relatively selective, land-grant university); moreover, they were relatively high achieving, as measured by their average ACT score (28-32), which is considerably above the national average (21 in 2016; ACT.org). It could be that the results would have been different if the sample was representative of a wider range of students. Future work should explore whether the findings from this investigation generalize to other universities, more academically diverse students, and other STEM courses.

Second, although comparable to the percentages of UR students enrolled at the university where the course was offered, this sample contained a comparably low number of students from all three of the underrepresented demographic groups included in this investigation. Because of the relatively small sample size, the analyses may have been underpowered. With a larger sample, perhaps differences in the associations explored in this investigation would have been stronger.

Third, because this study relied on Huang et. al's (2019) tool to detect metacognitive phrases automatically from online forum posts, I acknowledge that this tool may have had some inherent limitations, some of which may have led to potential errors in assigning metacognition. For example, phrases that this tool considered to indicate metacognition, such as "I think," may have actually indicated some figure of speech or rhetorical modes (e.g., irony, litotes, accismus, etc.) other than metacognition. It could also be the case that metacognitive language is much subtler and more difficult to tag than what was possible when relying on the dictionary and white list from Huang et al.'s (2019) metacognitive detection tool. Both of these scenarios would affect the statistical and theoretical relationship of metacognition and academic outcome measures.

Future studies can attempt to model additional predictors to verify the true explanatory power of the role that metacognition plays on grades. This is suggested because issues of restriction of range (e.g., only detecting the metacognition that students write in their forum posts) might exist within these studies. It is also possible that the data from online forums contain an inherent amount of variability because students' comments are fairly unpredictable in nature. Assignments that are more structured in terms of metacognitive text generation (e.g., guided reflections) might allow more sensitive detection of metacognition and thus offer more robust statistical models, with a higher R^2.

Future research might also shed additional light on student success in online STEM college courses by including a proxy for prior knowledge (e.g., ACT score or grades in prior courses) in the analysis to examine whether metacognition's role remains consistent or changes when accounting for students' prior knowledge. As previously mentioned, studies (e.g., Zimmerman, 1990) have shown that metacognition oftentimes is the differing variable between high-achieving students and low-achieving students, independent of students' measured aptitudes. Because the number of metacognitive comments predicted course outcome in one course but not the other, we cannot rule out the possibility that this difference was a result of differences in prior knowledge. Perhaps by expanding this research to courses with a greater variation in skill level as well as including a measure of prior knowledge, it could be analyzed if the case remains for all students, low-prior knowledge and high-prior knowledge students.

In future research, it will be important to see if the same results hold true and then eventually replicate to other courses, both STEM and non-STEM courses. This would be important in determining whether the robustness and generalizability of the current results are characteristic of this type of STEM course and then whether these results are characteristic to STEM courses, and other college courses, more generally. Replication studies from the current exploratory analysis are also important to validate the automatic detection tool. The tool was programmed and tested through the online forum posts from only one course. In other words, the tool might do exactly what is it supposed to do in this course because it was tested and modeled after this course. When this study is replicated in different courses, the tool's validity in detecting metacognitive language can be looked at closer. The tool could also be tweaked if potential problems with the algorithm arise that were absent in this current course. In general, the current project has all the capacity to contribute to innovative educational technology as well as instructional design that empowers diverse learners.

Summary and Conclusions

Spontaneously produced metacognitive comments were examined and compared between students underrepresented in STEM and majority STEM students, in two online STEM courses. This work contributes to understanding the relation between metacognition and students' success in this online STEM courses.

A significant difference was found in the production of metacognitive comments for one, but not another, course, raising questions about whether it was something about the courses themselves or the students attracted to the different courses that might have led to the observed differences.

No differences between students traditionally underrepresented in STEM and their non-underrepresented peers were found. This finding suggests that some long-standing differences among students and their success in STEM courses may be ameliorated in the online environment.

It was also found that engagement in the course was related to student outcome. This finding could be beneficial to an instructor, to provide clear direction about encouraging students to participate or perhaps which students need direct help or additional resources, supporting students to achieve positive outcomes in a course.

Although the findings about metacognition were inconclusive when considering both courses, it is still worth considering the promise of metacognition given that it has been shown to have nothing to do with underlying intellectual abilities and that it can be taught (Zimmerman, 1990). Given its prominent role in academic achievement, metacognition could be a very useful tool in equalizing the academic playing field for underrepresented students in STEM. With more research of this nature, it may be possible to teach students to recognize and capitalize on their own cognitive resources, exercising control and autonomy over their educational trajectory.

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APPENDIX A

METACOGNITION DICTIONARY WORDS

Metacognitive Words
confused
unsure
struggling
struggle
clarify
uncertain
worried
worry
skeptical
forgot
forget
misunderstood
stuck
sure
know
knew
figure
think
thinking

thought

understand

understood

understanding

certain

believe

believe

believed

believing

believed

believing

doubt

expect

expected

aware

consider

considered

consideration

realize

realized

assume

assumed

assuming

notice

noticed

decide

decided

feel

felt

curious

wonder

wondering

imagine