

# Automatic Detection of Metacognitive Language and Student Achievement in an Online STEM College Course

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## Abstract

Metacognition is a valuable tool due to its role in self-regulated learning. However, online learning settings bring new challenges for engaging in metacognition given the unique opportunities and challenges presented by the online space, especially for diverse populations and students underrepresented in STEM (UR-STEM). Thus, we investigated whether a relationship existed between college STEM students' metacognition—measured by their spontaneously produced metacognitive phrases in online course discussions forums—and their success in an online STEM college course—measured by their final course grade. Using Bayesian generalized linear models, we examined whether this relationship differed for UR-STEM compared to non-UR-STEM students and whether related course behaviors (i.e., engagement and verbosity) and prior knowledge predicted variance in course grade. Metacognition plausibly predicted course grade and no plausible differences between UR- and non-UR-STEM students were found, suggesting that the online space could afford students from diverse groups the capacity to engage equally in a critical aspect of self-regulated learning: metacognition. Implications of the results for teaching and learning STEM content in the online space are discussed.

*Keywords:* metacognition, online, college, STEM, underrepresentation

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## Overview

In this paper, we explore how college students, in an online, asynchronous science, technology, engineering, and mathematics (STEM) college course, spontaneously express metacognition—i.e., awareness of their own thinking—without experimental manipulation or prompting. Metacognition is useful to college students' learning and can be necessary for academic success (Baumeister & Vohs, 2007; Garrison, 2022). We specifically focus on metacognitive language that is produced spontaneously because doing so can eliminate some biases that occur in experimental conditions (e.g., observer-expectancy effect; Nichols & Maner, 2008) and because automated assessments of online learning can be of practical usage to instructors by relieving the burden of constant monitoring. In doing so, instructors can have a more accurate understanding of who needs extra assistance than if they were to assess students' learning without automated assistance. We also address whether students who are underrepresented in STEM (UR-STEM) demonstrate differential production of metacognitive language compared to non-UR-STEM peers because of the limited work on metacognition in diverse populations (Anyichie & Butler, 2017), possibly resulting in understandings of metacognition that are not generalizable across populations. Finally, we measure constructs adjacent to metacognition to understand the moderating role of prior knowledge and how engagement and verbosity might mediate the relationship between students' metacognitive language and their course grades. We examine these issues in the context of an online course, given the importance of metacognition in the online context where students typically must take large responsibility for monitoring their own learning (Chen & Bogachenko, 2022; Rovai & Downey, 2010).

### ***Background: Why Metacognition?***

Metacognition has a strong relationship to students' learning outcomes (Azevedo & Cromley, 2004; Cardelle-Elawar, 1995; Dent & Koenka, 2016; Hadie et al., 2018; Nietfeld et al., 2005; Schuster et al., 2023). Weinstein et al. (2011) described metacognition as an element of self-regulated learning (SRL) that is “both the glue and the engine that helps students manage their strategic learning” (p. 47). Hart (1965) suggested that “metacognition mediates between reflection and action” (p. 186), making it a necessary step in students' process of becoming critical thinkers and effective learners (Snyder & Dringus, 2014). Thus, metacognition is a crucial component of learning.

Having SRL skills means that students take active control of their learning, viewing learning not as something that happens external *to* them, but *by* them; thus, these students exhibit motivation to set goals, reflect on progress, and use metacognitive strategies to ensure comprehension and understanding (Parkes et al., 2015). We care about metacognition skills in particular because these skills directly translate to college achievement; for example, university students who use metacognitive strategies effectively, as an aspect of self-regulated learning, are less likely to drop out than students who use metacognitive strategies less effectively (Park et al., 2019). Students who use metacognitive skills have knowledge about their own information processing skills, the nature of cognitive tasks, strategies for coping with such cognitive tasks, and executive skills related to monitoring and self-regulating their own learning process (Schiender & Lockl, 2002).

The evidence that metacognition supports student learning is overwhelming: even slight prompting of metacognitive behaviors is highly related to comprehension of and performance on academic material (Stanton et al., 2015; Tsai et al., 2018; Zimmerman et al., 2011). These results suggest that metacognition can be a signal of impending learning (e.g., Perry & Lewis, 1999) and thus makes it an important target of investigation. Additionally, students who engage in metacognition strategies tend to be more inclined to try novel approaches when they are faced with academic struggle; whereas students who do not regulate their own learning tend to be defensive in their reactions to their performance and may avoid productively challenging situations to preserve their self-image as a learner (Andrzejewski et al., 2016). Thus, detecting the presence of metacognition unveils information regarding students' learning process. For example, a student engaging in metacognition might monitor their learning by asking themselves whether they understood what the instructor explained and if they did not understand, they would know which resources to draw from to ensure they attain their learning goal. In these ways, metacognition can play an important role in supporting student learning.

### Metacognition in the Online Context

Metacognition is important in many learning contexts, but may be especially crucial in online learning environments (Akyol & Garrison, 2011; Garrison, 2022; Zhang et al., 2023). For example, Andrade (2012) found that students who are most successful in online courses exhibit high levels of self-regulation skills like metacognition (also see Bernacki et al., 2011; Fielding et al., 2008). More generally, with the increased freedoms and reduced structures in online settings (e.g., many online courses are offered asynchronously, leaving students to choose when—and sometimes even how—to access course information), metacognition is likely to be integral to success (Azevedo et al., 2019; Xu & Jaggars, 2011; Xu & Jaggars, 2014). Throughout the twenty-first century, online learning for college students has been—and will likely continue to be—commonplace (Allen et al., 2016). One reason that the online space became so pervasive as a medium for learning, even prior to the COVID-19 pandemic, is that it provides college students with increased opportunity for access, allowing students to take courses independently of their physical location and time of day (e.g., Means et al., 2009). In general, online learning environments allow students more control and flexibility in accessing instruction and instructional resources than in traditional in-person courses (Greene et al., 2019), making student activation of metacognition essential in many online academic contexts.

In this investigation, we assess metacognition expressed in online discussion forum posts, where metacognition is socially situated but unprompted. Metacognition that is used in a social setting for critical thinking has been studied through a Community of Inquiry (CoI) framework (Sadaf et al., 2022). The CoI framework captures the shared and collaborative meaning-making of students' learning experience in the online environment (Sadaf et al., 2022). In this sense, metacognition can be seen as a medium between one's internal knowledge and collaborative activities (Garrison, 2022; Sadaf et al., 2022). In their study, Sadaf and colleagues (2022) used online discussion forums to explore students' metacognition (self-regulation and co-regulation) in relationship to their perceived social presence (i.e., online presence). Their results suggested that students with higher perceived social presence tended to possess higher metacognition (Sadaf et al., 2022). Because metacognition has ties to the CoI framework (Garrison, 2022), this is a useful theoretical framework for situating our investigation. However,

we also interrogate whether these issues play out similarly or differently for students who are UR-STEM compared to their non-UR-STEM peers.

### A Focus on UR-STEM Students

Success in online STEM courses is of particular concern for students underrepresented in STEM (UR-STEM), such as Black, Latine, Indigenous, women, and first-generation students (Means & Neisler, 2023; National Center for Science and Engineering Statistics, 2023). UR-STEM students have identified various concerns—including lack of social context in the online environment, lack of collaboration, and feeling isolated from other students as barriers to success (Gardner & Leary, 2023). Prior to COVID-19, Wladis et al. (2015) reported that Black and Hispanic students, who are underrepresented in STEM, were significantly less likely to enroll in online STEM courses compared to white students and that online STEM courses presented challenges to UR-STEM students not faced by majority students. Clearly, there is a need to understand UR-STEM college students' learning in online courses, given the concerning findings regarding online learning's differential impacts on UR- and non-UR-STEM students.

Of particular concern to this investigation is the learning behaviors of students in the “S” portion of STEM, science, as the course under investigation was a natural science course. Students with science identities participate in “normative scientific practices,” which Carlone and colleagues (2011) defined as practices that a student engages in when striving to be considered competent in a scientific setting. Normative science practices consist of asking and answering scientific questions, sharing scientific tools and ideas, communicating scientifically, making scientific inferences, and conducting scientific observations (Nealy & Orgill, 2019). Hence, scientific discourse in a group setting, like the discourse from discussion forums, is a powerful tool for developing a UR-STEM student's science identity as it is a main way that a science identity is communicated and recognized by others (Carlone & Johnson, 2007). It is during a scientific discursive exchange in a group setting that a UR-STEM student may gain valuable information about how others view their scientific identity, which in turn, impacts how they view their own scientific identity (Nealy & Orgill, 2019), promoting successful academic behaviors and learning strategies.

Based on the understanding that metacognitive skills are imperative to success in STEM (e.g., Al-Gaseem et al., 2020; Park et al., 2019) and on research describing UR-STEM students' lack of engagement in successful learning behaviors like metacognition (Bernacki et al., 2020; Nacu et al., 2015), findings in this area could be used to understand and support UR-STEM students' use of metacognition. However, to analyze metacognitive regulation in an online environment with UR-STEM students, traditional methods of measuring metacognition may not be effective for capturing metacognition as it naturally occurs, especially in the online setting.

### Measuring Metacognition

Although researchers have agreed on the importance of metacognition as an index of self-regulation in online courses, its measurement is often difficult (Veenman et al., 2006; Winne et al., 2010). Traditionally, metacognition is studied through self-report surveys that rely on students' recollection of strategies they had previously used (i.e., their recollection of their metacognitive control; see Harrison & Vallin, 2018). However, Winne and Jamieson-Noel

(2002) found significant discrepancies between students' self-reports and trace data of student online SRL behaviors like metacognition. Thus, just because students do not report metacognitive activity does not necessarily mean that they are not engaging in metacognitive activity. Although its adaptive role is most useful when it is conscious, metacognitive monitoring may occur at a non-conscious level (Reder, 1996). Metacognition is dynamic, multifaceted, perhaps subtle, and may not be entirely obvious to the learner when it is in progress (Rovers et al., 2019). 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. For example, a student may report using a particular metacognitive strategy because they use it often, even though that strategy was not used during the time of investigation (Winne et al., 2002). These are some of the well-known problems with measuring metacognition.

Issues with measuring metacognition become even more complex when considering the context of learning in an asynchronous online course. To deal with some of the aforementioned problems with measuring metacognition, we reason that it is possible to assess metacognitive behaviors in the online context, as they naturally occur. Online assessments have promising potential in supporting and improving online learning outcomes (Heil & Ifenthaler, 2023). Online assessment is defined as "a systematic method of gathering information about a learner and learning processes to draw inferences about the learner's dispositions" (Heil & Ifenthaler, 2023; p. 188). Thus, as a solution to avoiding self-report measures, several investigations have ascertained metacognition from students' written and spoken language. For example, Akyol and Garrison (2011) captured metacognitive knowledge, monitoring, and regulation (i.e., control) in online discussions. After hand-coding the text from three weeks of discussion posts of 16 graduate students, albeit in a non-STEM course, the researchers found that metacognition in online discussion forums could be categorized similarly to metacognition in face-to-face contexts (e.g., Nelson & Narens, 1994). Following this work, Snyder and Dringus (2014) developed a priori codes derived from Akyol and Garrison's (2011) metacognition construct and Garrison and Akyol's (2013) metacognitive questionnaire and then developed additional categories that were generated by the data. They found that metacognitive knowledge, monitoring, and regulation (i.e., control) could be detected from text. Given the demands of the online space and the issues with intrusive methods of measuring metacognition, we also chose to identify metacognition as it naturally occurs in text written by students taking online courses. Online discussion forums hold much information about students' learning processes (Ahif & McNeil, 2023). Therefore, online discussion forums are ripe for measuring and assessing metacognition students express when working toward a conclusion or learning goal. Measuring metacognition from these forums alleviates potential biases that arise from experimental procedures that influence learning experiences, and which may confound interpretations of findings and therefore understandings of metacognition. As in these studies cited here, we define spontaneous production of metacognitive comments as metacognition that appears in students' posts to the course discussion forum, where the post is required, but the metacognition is produced without being prompted (also see Lehmann et al., 2014).

Although prior investigations have examined spontaneously produced metacognition, we recognize that the contexts under which those studies occurred (i.e., small, graduate-level courses in non-STEM fields, with only subsamples of all available online posts) may limit the generalizability of this prior work. To avert some of these issues, we chose to rely on Huang et al.'s (2019) metacognitive language detection tool, which automatically identifies metacognitive language from online forum posts based on a metacognitive phrase dictionary (i.e., phrases and parts of phrases that indicate metacognition).

An advantage of Huang et al.'s (2019) 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 conducted post-activity inquiries to analyze metacognition (Cardinale & Johnson, 2017; McCarthy et al., 2018) or participants are required to self-report their metacognitive awareness (e.g., Vrugt & Oort, 2008). By employing a tool that allows automatic detection, we can now examine large-corpus datasets, which was previously impractical given the burden of manual coding. Given that Huang et al.'s (2019) tool avoids the problem with self-reports and can be used on large-corpus text data, we employ this tool in the current study.

### Measuring Constructs that Might Impact the Relationship Between Metacognition and Success in an Online Course

To contextualize students' metacognitive language, we included important constructs that might be related to metacognition. To account for some of these related behaviors and characteristics, we chose to consider how students' engagement, verbosity, and prior knowledge might relate to their metacognition to impact their performance in an online STEM course.

*Engagement* is important to academic success because students who are more active in a course tend to have better course outcomes than students who are less active (Greene et al., 2019; Rioch & Tharp, 2022). In general, those who participate more in online course forums are more likely to achieve success than those who participate less. This finding is consistent with the results from other investigations, especially in Massive Open Online Courses (MOOCs; e.g., Crues et al., 2018; Castaño-Garrido et al., 2017; Nieuwoudt, 2020; Sharma et al., 2020). Moreover, Waters and Gasson (2015) theorized that engagement in a community can yield a "community-oriented form of metacognition" (p. 93), in which the metacognition is shared among and promoted by the community members. Because of this likely connection of engagement and metacognition, and the likely connection of each of these with outcome in the course, we included a measure of engagement—number of forum posts—in this investigation.

A construct that is closely related to engagement and often presents itself as engagement, is *verbosity*. According to Akyol and Garrison (2011), "metacognition is inherent to communicating, explaining, and justifying one's thinking" (p. 189). Online discussion forums are organized to be socially situated and therefore involve community (Vally Essa et al., 2023); this in turn can encourage the expression of metacognition and facilitate discourse (Akyol & Garrison, 2011). For this reason, we might anticipate that those students who are more likely to be metacognitive may be more communicative and thus may produce posts to the class

discussion forum that contain more words. It is also possible that producing metacognitive comments in forum posts may be an epiphenomenon of being highly verbal: it may be that those students who have more to say also produce proportionately more metacognitive comments than students with less to say. To explore this possibility, we included a measure of students' verbosity—students' average word count per online forum post—and examined its relationship to students' production of metacognitive comments and examined its relationship to course success

Finally, students may engage more with classmates and do so more verbosely because they have more *prior knowledge* in that domain. Having prior knowledge about course content may also relate to the likelihood of engaging in metacognitive regulation. The positive relationship between prior knowledge and metacognitive monitoring accuracy may be explained by the idea that students with more prior knowledge have a more developed and vast knowledge base to use as a reference point for monitoring their cognition compared to students with less prior knowledge about a subject, which leaves low-prior-knowledge students with limited reference points to monitor their learning and understanding (Nietfeld & Schraw, 2002). It may be that students who are generally better prepared academically are also generally more metacognitive, and thus students who perform well on college entrance exams (e.g., SAT or ACT, as an index of background knowledge) are more reflective about their own learning (e.g., Ross et al., 2006). Thus, we included ACT scores as an index of prior knowledge and as a potential moderating factor on students' course success.

### Current Investigation and Research Questions

We anticipated that there would be a plausible relationship between students' posts to the discussion forum that contained unprompted metacognitive comments and their course grades, beyond possible effects of engagement, verbosity, prior knowledge, and UR-STEM status. We also anticipated that the relationship between this spontaneous production of metacognition in their posts to the course discussion forum and their course grades would be moderated by their UR-STEM status and prior knowledge. Furthermore, we anticipated that the relationship between students' posts that contained unprompted production of metacognitive comments and their course grades would be mediated by their engagement in the course discussion forum and by the verbosity of their posts. In summary, the current study was designed to identify spontaneously produced (i.e., unprompted) metacognition in posts to an online STEM course and to address two research questions. Specifically, we asked:

RQ1: What is the relationship between students' spontaneous production of metacognitive comments in their course discussion forum posts and their course grades?

RQ2: Is the relationship between students' spontaneous production of metacognitive comments in their course discussion forum posts and their course grades moderated by their UR-STEM status or prior knowledge, and is this mediated by their engagement in the course discussion forum or the verbosity of their posts?

## Method

### Participants and Data Sources

Data were obtained from all 217 students enrolled in one semester of an online advanced natural science college course at a large Midwestern public university in the United States after the course was completed. Of the students in the sample, 41% came from UR-STEM groups (15% African American/Hispanic/Indigenous, 17% first generation, 24% non-male) and 59% were non-UR-STEM groups (i.e., white or Asian, non-first generation, male). We note that although Asian students are a minority in the United States, they are not underrepresented in STEM—and are actually overrepresented in STEM (Fry et al., 2021)—and thus were not included in our sample of UR-STEM students. Note that the total percentage of UR-STEM subgroups is greater than 41% because some students belonged to more than one UR-STEM group. We do not report the intersectional group-level findings of students who fit multiple minoritized STEM categories to comply with the Family Educational Rights and Privacy Act (FERPA) regulations that protect students' identities. More specific information about the course itself is not included to further protect student privacy.

Data for analysis come from three main sources: (1) all of the students' discussion forum posts ( $n = 7,340$ ); (2) background data (i.e., race and ethnicity; parental college completion information; gender identification; and ACT scores or SAT equivalents if no ACT was available); and (3) course grades, provided by university data curators as letter grades. Although all the prompts for students to post to the forums were open-ended, the prompts had a common theme dealing with the estimation of a mathematical formula that was central to the course. Every week the students were to respond to the same prompt, and it was assumed that with each week of the course, students would have more—and more insightful—estimations based on the knowledge they were attaining from the course. Posting to the forum constituted 25% of the students' course grades. The remainder of students' grades were determined by their project (25%), exams (17%), homework assignments (16%), and other small assignments, each worth less than 5% of students' total grades.

### Identifying Metacognition

We relied on Huang et al.'s (2019) tool for identifying metacognitive language. This tool applies a simple pattern-matching algorithm (i.e., an expert system for natural language processing) to find phrases that exemplify metacognitive regulation beginning with a first-person pronoun (i.e., I, we) and ending with a word or phrase indicating metacognitive knowledge, monitoring, or control. The tool searches for words that appear between a pronoun and metacognitive indicator and accounts for negations within phrases. Here, we present an example of a forum post with the metacognitive terms italicized:

I didn't include binary systems as well because *I think* there are way more binary systems that don't include life as well. *I do think* metallicity is important though. We need metals in order for it to be a life liking planet. But as the book stated *we are not sure* how much we need. *I think* this is the most important factor that you failed to include. I got a way lower answer than you.



For this particular post, the automatic detection tool flagged the metacognitive phrases “I think” and “I do think” because these phrases provide evidence that the student acknowledged their own thinking and their arrival at a conclusion (i.e., metacognitive knowledge), both defined as types of metacognition. “We are not sure” was also identified as metacognitive language because it indicates that the student provided information about the task demand and their feeling of knowing, or lack thereof, sometimes defined as a metacognitive experience (Efklides et al., 2018). Details of metacognitive words identified by the tool can be found in Huang et al. (2019).

### Data Analysis

All statistical analyses for this study were done using R version 3.6.2 (R Core Team, 2019). To address RQ1 and RQ2, we applied Bayesian regression, investigating the relationship between students’ final course grades as a function of average number of metacognitive comments (RQ1), ACT scores, post counts, and word counts (RQ2). Independent variables were centered and scaled to unit standard deviation. We labeled variables that related to students’ activities in the course (i.e., engagement and verbosity) as mediation variables and labeled non-malleable variables that preceded the existence of the course (i.e., prior knowledge) as moderating variables.

We used Bayesian estimation and fit the models using the *brms* package (Bürkner, 2017) in R. We chose a Bayesian approach to estimate the indirect effects because of the complexity added due to the discrete nature of the moderators and our measure of academic performance. We used 4 chains, 2,000 warmups, 2,000 iterations, and non-informative priors for the regression. Parameters were estimated using the cumulative function, which specifies a logit link function and a lognormal distribution (see also: Bürkner & Vuorre, 2019). For reproducibility of the results, we specified a random seed. To assess model convergence, we examined the potential scale reductions (“R-hat” or shrink factors), Geweke statistics, trace plots, density plots, and autocorrelations. All metrics indicated that the reported models converged. We also performed posterior predictive checks to ensure that the models fit the data.

## **Results**

Before addressing the two research questions for this study, we provide descriptive statistics.

### Descriptive Statistics

Descriptive statistics and correlations among variables can be found in Table 1. The 217 students produced a total of 11,637 metacognitive comments across their total of 7,340 posts during the 8-week term. On average, each student posted to the forum 34 times, ranging from 1 to 346 posts,  $SD = 23.5$ . The distribution of posts had little-to-no positive skew, with a median of 32 posts. On average, each student produced 54 metacognitive phrases ( $SD = 25.8$ ). The distribution of metacognitive comments had a slightly positive skew, with a median of 50 metacognitive comments. The highest grade in the course was an A and the lowest grade in the

course was a D. Eighty-one percent of students earned As, 10% earned Bs, 4% earned Cs, and 6% earned Ds. The students' mean ACT score was 30 ( $SD = 4.19$ ).

RQ1: What is the relationship between students' spontaneous production of metacognitive comments in their course discussion forum posts and their course grades?

We used a Bayesian regression model to fit a proportional odds model where course grade (i.e., ordered categorical) is predicted by the total metacognitive comments produced by students. We also included students' UR-STEM status, the number of posts, average number of words in these posts, and their ACT scores to control for confounding effects these variables might have had. We found that metacognitive comments ( $\beta = 2.82$ ; 95% CI<sup>1</sup>: 2.04 to 3.69) were predictive of course grade<sup>2</sup>. In terms on confounding effects, we found that prior knowledge (i.e., ACT score) ( $\beta = .43$ ; 95% CI: .02 to .85) was predictive of course grade, but UR-STEM status ( $\beta = -.30$ ; 95% CI: -1.12 to .50), number of posts ( $\beta = -.23$ ; CI: -.51 to .13), and the average number of words in these posts ( $\beta = .27$ ; CI: -.24 to .81) were not.

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<sup>1</sup> The 95% CIs reported are Bayesian credible intervals that can be interpreted as a 95% probability that the true value is in the interval. This is different from frequentist CIs with +/- 1.96 standard errors.

<sup>2</sup> Because the CI lower bound for ACT was so close to 0, ranging from -.02 to .02, we also conducted a simulation with a range of 100 different seeds. As a full disclosure to the reader, 47% of the time ACT was plausible.

Table 1

*Correlation Table (n = 217 students), including means, standard deviations, and confidence intervals*

|                            |          |           | Variable            |                     |                     |                     |                        |
|----------------------------|----------|-----------|---------------------|---------------------|---------------------|---------------------|------------------------|
| Variable                   | <i>M</i> | <i>SD</i> | 1                   | 2                   | 3                   | 4                   | 5                      |
| 1. Course Grade            | 3.65     | 0.81      |                     |                     |                     |                     |                        |
| 2. Meta-cognitive Comments | 53.63    | 25.84     | .52**<br>[.42, .61] |                     |                     |                     |                        |
| 3. Forum Posts             | 33.82    | 23.50     | .07<br>[-.06, .20]  | .18**<br>[.05, .31] |                     |                     |                        |
| 4. Average Word Count      | 108.06   | 31.26     | .29**<br>[.17, .41] | .48**<br>[.37, .58] | -.00<br>[-.14, .13] |                     |                        |
| 5. ACT Scores              | 30.00    | 4.19      | .13<br>[-.01, .26]  | .05<br>[-.08, .19]  | -.05<br>[-.19, .08] | .08<br>[-.05, .22]  |                        |
| 6. UR-STEM Status          | .41      | 0.49      | -.10<br>[-.23, .04] | -.05<br>[-.19, .08] | -.06<br>[-.20, .07] | -.01<br>[-.15, .12] | -.18**<br>[-.31, -.04] |

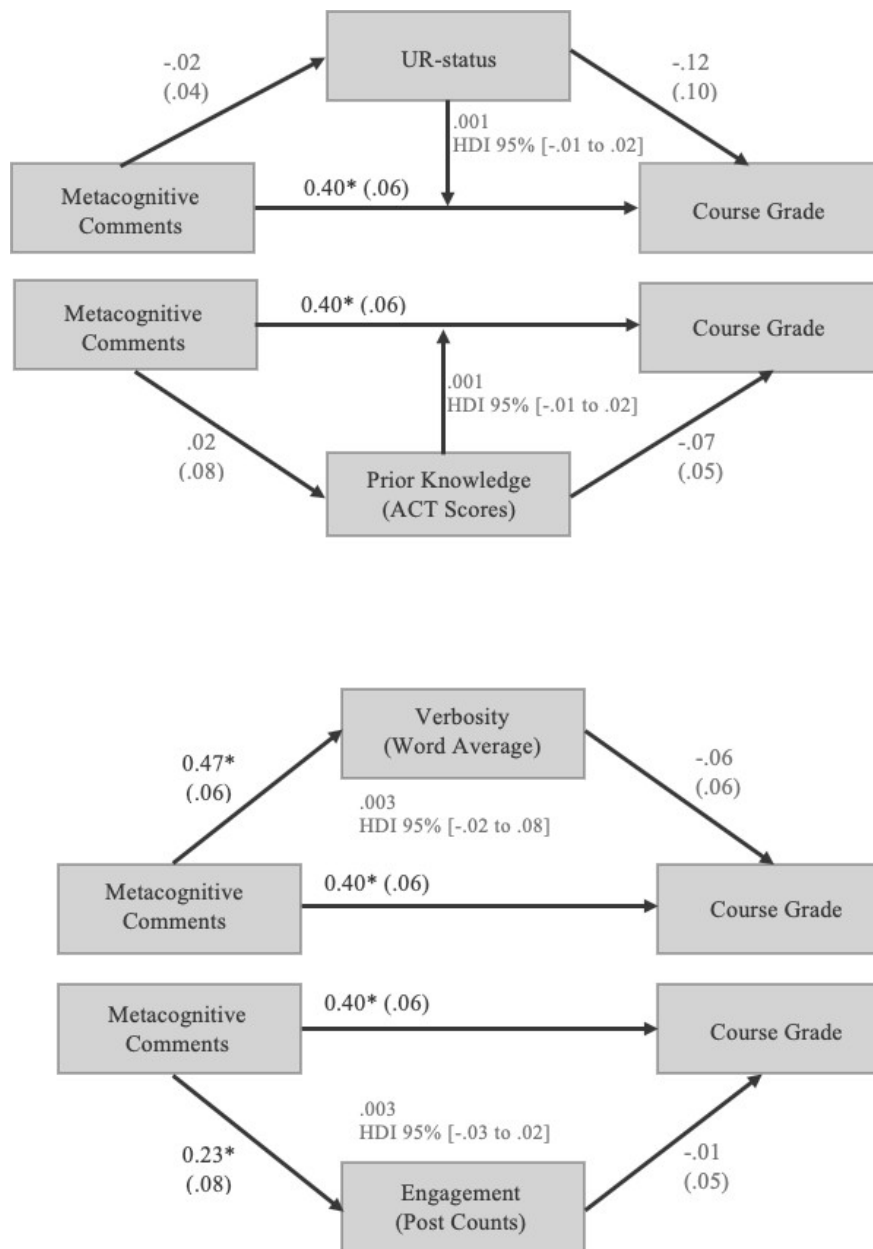
*Note.* \*\* $p < .01$ 

RQ2: Is the relationship between students' spontaneous production of metacognitive comments in their course discussion forum posts and their course grades moderated by their UR-STEM status or prior knowledge, and is this mediated by their engagement in the course discussion forum or the verbosity of their posts?

We tested the moderators and mediators under the specified Bayesian generalized linear model framework. Each moderating or mediating variable was tested separately to ensure full variance to be modeled between metacognitive comments and students' course grades. By testing these variables as moderators and mediators, rather than simply direct relationships, the coefficients describe whether the variables mediate or moderate the relationship between metacognition and grades. In other words, the analysis for RQ2 describes the indirect effects of the relationships tested, not a direct effect as in RQ1. As theoretically predicted, our results revealed a plausible relationship between metacognitive comments with the number of posts ( $\beta = .23$ ; 95% CI: .08 to .39) and the average number of words in these posts ( $\beta = .47$ ; 95% CI: .35 to .59). However, neither UR-STEM status, number of posts, mean number of words, nor ACT scores helped to explain the relationship between metacognitive comments and students' course grades (see Figure 1).

Figure 1

*Regression Coefficients from the Moderation and Mediation Models Examining the Relationships between Metacognitive Comments and Students' Course Grades*



*Note.* Values in parentheses denote standard errors. Asterisks based on 95% Credible Intervals (CI). Each moderating or mediating variable was tested separately to ensure full variance to be modeled between metacognitive comments and students' course grades.

## Discussion

We begin by summarizing and discussing the results and the implications. We then consider how this study adds to the body of knowledge about metacognition in online contexts, and then focus more specifically on UR- and non-UR-STEM students in online STEM courses.

Finally, we consider some of the limitations of this investigation and entertain suggestions for future research before sharing concluding remarks.

### Summary of Results

For the first research question, students' spontaneously produced metacognitive phrases plausibly predicted their course grades, suggesting that students who produced more metacognitive comments in their forum posts were more likely to achieve a better course outcome than students who produced fewer metacognitive comments, above and beyond the contribution of prior knowledge. This finding aligns with previous research that documented a positive relationship between metacognition and academic success (e.g., Mata et al., 2013). We also found that prior knowledge, as measured by ACT scores, plausibly predicted final course grade, based on our Bayesian regression model measuring direct effects. This suggests that although prior knowledge and metacognition are, indeed, related, their relationship to learning might be different. Unexpectedly, we found that engagement, as measured by the number of each student's discussion forum posts, was not plausibly related to course grade. Recall that students' forum posts constituted a substantial percentage of students' grades, which may have possibly put engagement, which we measured by posting, at a ceiling.

For the second research question, we found that the production of metacognitive comments had a plausible relationship with both engagement and verbosity. This suggests that those who were more engaged in the online forum and were more verbose were also more likely to produce metacognitive comments than those who were less engaged and less verbose. This finding replicates results from other investigations, especially in MOOCs (e.g., Crues et al., 2018; Phan et al., 2016).

We found that a student's status as a UR-STEM or a non-UR-STEM student did not moderate their metacognitive comment production and did not predict course grades. Because metacognition is closely related to SRL, these findings echo results from Park et al.'s (2019) study, which found minimal differences in SRL behaviors between UR- versus non-UR-STEM students.

### Metacognition Research in Online Learning

Although metacognition has been a popular topic at least since the 1980s, now that online learning is so pervasive, it is imperative that educational researchers effectively adapt metacognition research to the online space. By analyzing metacognitive language relating to metacognitive monitoring in an online STEM course as it occurs spontaneously, we attempted to uncover information about metacognition's role in online learning. Exploring how metacognition is expressed spontaneously reveals important information about signals of impending learning and thus makes it an important target of investigation.

Although already noted, we want to emphasize that the findings from this study align with previous work highlighting the strong and positive relationship between metacognition and learning (e.g., Azevedo & Cromley, 2004). However, this relationship has rarely been studied in

the online context (e.g., Akyol & Garrison, 2011; Guo, 2022), making our investigation an important contribution to the conversation about metacognition in the online context.

Furthermore, the automatic metacognitive language detection tool represents a methodological innovation to metacognition research. By looking at spontaneously produced metacognition in students' online forum posts, we avoided the problems with commonly used self-report measures, such as students reporting using a metacognitive strategy, when they indeed have used that strategy at some point but did not actually use that strategy for the specific window under investigation (Winne et al., 2002).

We add to the body of research examining students' expressions of their metacognition in a way that may be practical for instructors to use during their courses. Recall that Akyol and Garrison (2011) found that metacognition in online discussion forums could be categorized similarly to metacognition in face-to-face contexts. From this premise, and with the facility of using the automated metacognitive detection tool, identifying students who are struggling using metrics other than grades, when perhaps it is too late to intervene, could be valuable in online settings where instructors are not afforded traditional indicators of struggle like body language. Thus, the current study can serve as a preliminary step in understanding metacognition's role in complex and authentic educational contexts, without the obvious presence of a researcher.

#### UR- and Non-UR-STEM Students in Online STEM Courses

Given that we found no differences between UR-STEM and non-UR-STEM students, this study suggests what is likely *not* contributing to inequities in STEM, specifically at the post-secondary level. We embarked on an exploratory analysis of students' spontaneous production of metacognitive comments as an indication of successful learning strategies, in one online STEM courses' discussion forums. We paid special attention to students' demographic backgrounds due to a lack of research directed at how metacognition manifests in populations other than white students. It is important to understand how all students, but especially those from groups underrepresented in STEM disciplines, make use of this crucial SRL strategy to support their learning in the online context. The current study suggests that UR-STEM students and their non-UR-STEM peers may be equally likely to engage in metacognition in college STEM courses and not likely to differ from each other in terms of their grades in these courses.

However, this work challenges previous studies that have pointed to differences in metacognition use between types of students (e.g., Siegel & Castel, 2019; Stanton et al., 2021). Although little work to date has been done analyzing the use of metacognition among UR-STEM students, our findings echo results from Park et al.'s (2019) study, which found minimal differences in self-regulated learning behaviors, metacognition included, between racially minoritized and majority students.

Researchers have paid little attention to metacognition and its role in the online space at the university level for UR-STEM students. Given that we did not find a significant relationship between UR-STEM status and metacognitive language suggests that students, independent of their underrepresentation in STEM, can express metacognition in their online STEM courses. It is also possible that the online context contributes to ameliorating the negative effects that come

with being underrepresented in STEM. Along these lines, research (e.g., Henricks et al., 2021) shows, for example, that women and men did not differ in their language use along traditionally gendered lines when posting to an online course forum. These findings suggest that there must be other differences, other than differences in metacognition as a facet of effective learning behaviors, that explain differential outcomes (Wladis et al., 2015; Xu & Jaggars, 2014).

### Limitations and Future Research

This study relied on Huang et al.'s (2019) tool to detect metacognitive phrases automatically from online forum posts. We acknowledge the possibility of this tool's inherent limitations, some of which may lead to potential errors in assigning metacognition. For example, phrases that this tool considered as metacognitive knowledge or metacognitive experiences, such as "I think," may have indicated some figure of speech or rhetorical modes (e.g., irony, litotes, accismus) other than metacognition (Callaway et al., 2009). Perhaps phrases like "I think" (Chen & Zhang, 2017) were considered metacognitive but, in reality, could have indicated that the students were simply being polite. It could also be the case that metacognitive language might be subtler and more difficult to tag than what was possible by relying on the dictionary of metacognitive words used by Huang et al.'s (2019) metacognitive detection tool.

Future research can focus on attempting to model additional predictors to verify the true explanatory power of the role that metacognition plays on grades. We make this suggestion because issues of restriction of range might exist within the study reported here. For example, the metacognition tool only detected the metacognition that students expressed in their forum posts, thus restricting the forms of metacognition that were analyzed. There may have also been a restriction of range in the outcome measure, course grades, given that most students received an "A" in this course. It is also possible that the data from online forums contain an inherent amount of variability because students' comments are unpredictable in nature, making detection a difficult task. Assignments that are structured (e.g., guided reflections) might increase the consistency with which students engage in and describe their metacognitive processes and serve as a comparison to metacognition detection in unstructured settings. However, the current method of analyzing spontaneously produced metacognition (i.e., in text from activities not exclusively intended for self-assessment) may be advantageous in terms of measuring metacognitive regulation during typical learning activities where students are not necessarily prompted to engage in metacognition.

In future research, it will be important to assess the extent to which our findings replicate in other online STEM courses. Replication will be important to determine whether the robustness and generalizability of the current results are characteristic of the types of STEM courses studied here and perhaps whether these results are characteristic of a wider range of STEM courses.

### **Conclusions**

We examined spontaneously produced metacognitive comments in one online STEM course. This work contributes to understanding the relationship between metacognition and students' success in the online context. We also analyzed constructs that are adjacent to metacognition, further informing which aspects are related to the expression of metacognition by



college students online. We found a plausible relationship between the production of metacognitive comments and course grade.

The current study further suggests that longstanding differences in STEM success are not attributable to measurable (meta)cognitive differences between UR-STEM and non-UR-STEM students, which is an important finding regarding our understanding of SRL. This work not only used a scalable method to identify and measure metacognition without researcher presence, but also helps to describe SRL as it naturally occurs through written language, potentially informing various theoretical models of metacognition. Thus, this work contributes to understanding how metacognition plays a role in STEM learning online.

### **Declarations**

The authors declare that there is no conflict of interest in this study.

The authors received approval from the Institutional Review Board of the University of Illinois Urbana–Champaign to conduct this study.

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