Linguistic Features of Discourse within an Algebra Online Discussion Board

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ABSTRACT
This study leverages natural language processing to assess dimensions of language and discourse in students' discussion board posts and comments within an online learning platform, Math Nation. This study focusses on 1,035 students whose aggregated posts included more than 100 words. Students' wall post discourse was assessed using two linguistic tools, Coh-Metrix and SEANCE, which report linguistic indices related to language sophistication, cohesion, and sentiment. A linear model including prior math scores (i.e., Mathematics Florida Standards Assessments), grade level, semantic overlap (i.e., LSA givenness), incidence of pronouns, and noun hypernymy accounted for 64.48% of the variance for the Algebra I end of course scores (RMSE=13.73). Students with stronger course outcomes used more sophisticated language, across a wider range of topics, and with less personalized language. Overall, this study confirms the contributions of language and communication skills over and above prior math abilities to performance in mathematics courses such as Algebra.

Keywords
Student performance, performance prediction, discussion posts, linguistic features

1. INTRODUCTION
Discussion boards have emerged to be among the most beneficial features of online learning platforms. Some of the positive outcomes obtained include greater student involvement and improved academic performance [1-5]. Discussion boards have been implemented to achieve a number of educational goals, namely, to supplement course resources, evoke creativity and motivation, facilitate interaction between teachers and learners, and for class management or administrative purposes [6-9]. Student engagement and collaboration within discussion boards are critical towards their success. Indeed, students' language used within these discussion boards has been linked to positive learning outcomes [10-12]. This creates a pressing need to further understand the language used by students when collaborating with each other or engaging with their teachers within informal online academic settings.

1.1 Language and Math Success
While empirical evidence shows mixed results in the correlations between language proficiency and academic success (i.e., some found significant correlations and some none), proponents have articulated that language proficiency, and more importantly - communicative competence significantly influence success in math [13]. The dimensions of language that have been found to specifically influence math achievement include linguistic complexity, language control, and vocabulary usage [14].

A number of studies have demonstrated links between language and performance in math [10, 11, 15]. There are strong links between language skills and the ability to engage with math concepts and problems. For instance, success in math is partially based on the development of language that affords children the ability to participate in math instruction in the classroom as well as "engage quantitatively with the world outside the classroom" [16]. Similarly, strong math skills are presumed to interact with language ability to understand numbers and symbols [17]. Linguistic skills may be one of the key factors that relate to math ability. For instance, Cummins identified language difficulties in second language speakers as a key obstacle in solving math problems [18]. Articulating and representing cognitive processes in math domains is especially challenging for students with lower literacy skills. Successfully solving verbal analogies and mathematical word problems, in particular, demand certain levels of linguistic fluency and reading comprehension skills, which can be barriers to success.

More specific to discourse in online discussion boards, substantial work has been done to characterize the language used within online discussion forums [19-24]. This research indicates that linguistic features distinguish subject matter experts from nonexperts and are predictive of student learning outcomes. In social questioning and answering sites (e.g., Quora), linguistic features such as word usage, average number of words, subjectivity of words, and word complexity have been found to be markers of expertise [19]. Discourse analyses conducted on online discussion boards show that linguistic characteristics are predictive of student learning performance [20]. To name a few, the complexity of syntactic structures, cohesion, emotion words, modal verbs, and words that provide additional information or make claims when elaborating are significant predictors of students' performance [20-24].

1.2 Current Study

This study examines students' discussion wall posts for an entire academic year within an online Algebra tutoring platform, Math Nation, developed by the University of Florida Lastinger Center for Learning [25-29]. Math Nation is an interactive and comprehensive math teaching and learning platform that provides video tutorials and online resources aligned to the Mathematics Florida Standards (MAFS). Most relevant to the current study, Math Nation also features an online discussion forum called Algebra Wall where students can collaborate with other students, teachers, and study experts. Wall posts (see Figure 1 for a sample discussion thread) from 3,277 students, Math Nation study experts, and Algebra teachers were collected for the period August 1, 2018 to July 31, 2019, including comments within more than 14,000 threads.

Our objective in this study was to further examine the extent to which the linguistic features of these posts were predictive of End of-Course (EOC) Algebra performance, over and above their scores Math scores from the previous year. Providing information concerning students' potential EOC performance is important because it has the potential to augment stealth assessment of students' abilities such that the instructor or the tutoring system can intervene and provide scaffolding when necessary.

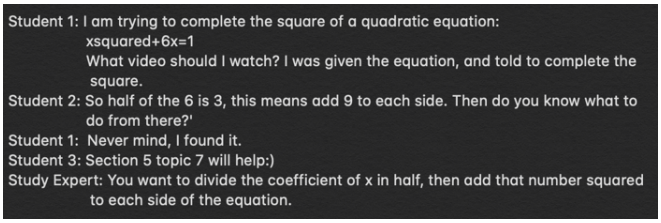

Figure 1. Sample Discussion Thread

2. METHODS

2.1 Participants

The participants included 3,277 Algebra students from the different Florida school districts in grade levels 7, 8. and 9 who participated in the Math Nation discussion board for the academic year August 1, 2018 to July 31, 2019. The majority of these students were white (n = 2,464, 75%). This study focusses on 1,035 students in this larger sample whose aggregated posts that included more than 100 words because NLP indices are not reliable with small language samples, and many of our indices (e.g., lexical diversity) require a minimum of 100 words [32]. Those who included more words in their posts had significantly higher FSA scores, $t(3275) = 5.79$, $p<.001$ ($M_{\leq 100\ words}$,= 354.08, SD = 16.83; $M_{>100\ words}$,= 357.75, SD = 16.89); and EoC scores, $t(3275) = 8.12$, $p<.001$ ($M_{\leq 100\ words}$,= 522.66, SD = 22.99; $M_{>100\ words}$,= 529.67, SD = 22.93). As such, number of words in posts are strong indicators of future and current math performance; the purpose of this study is to examine language beyond number of words.

*2.1.1 **Prior Math and Algebra I EoC Scores***

Students' mathematics performance was measured using Algebra I End-of-Course (EoC) assessment (M=524.88; SD=23.20; Range = 425-575), which is a high-stakes exam required by the Florida Department of Education [30] for high school graduation. Mathematics Florida Standards Assessments (FSA) scores (M=355.24; SD=16.93; Range = 269-393), from the previous year were included as proxy baseline scores indicative of Math preparedness [31]. The FSA math scores are often used as a baseline measure of Algebra skills or preparedness because they are strongly related to the students' Algebra I EoC scores. Indeed, the relation between these two tests was strong in the current study ($r=0.76$, $p<0.01$). Controlling for gender, grade level and district did not result in significant variations in the correlation between the Math FSA score and the Algebra I score (i.e., r = .73 - .76). Table 1 shows the mean scores for both the FSA Math and Algebra I exams as a function of grade level and gender.

Table 1. Algebra performance

	Math (FSA) Score from Previous Year (Mean / SD)	**Algebra I Score (Mean / SD)**
Grade 7 (n =440)	362.89 (15.74)	539.31 (19.02)
Grade 8 (n = 520)	355.39 (16.04)	525.58 (20.75)
Grade 9 (n = 75)	343.92 (17.95)	501.49 (26.49)
Male (n = 429)	359.92 (16.79)	531.55 (23.25)
Female (n = 606)	356.21 (16.80)	528.33 (22.62)

2.2 Natural Language Processing Tools

We assessed students' Math Nation Wall discourse using two linguistic tools, namely Coh-Metrix [32] and SEANCE [33], which report linguistic indices related to language sophistication, cohesion, and sentiment. Use of these two tools was motivated by prior work relating academic performance in mathematics to these features of language in online forums and discussion boards [20-24].

2.2.1 Coh-Metrix

Coh-Metrix provides multiple levels of linguistic analysis that include indices at word level and sentence level, indices related to connections between the sentences, and discourse relationships between the texts and their mental representations. Coh-Metrix has been used to analyze different forms of text in the English language that are written to communicate messages to readers, including those within tutoring sessions, chat rooms, email exchanges and other forms of informal conversation [34, 35]. In the current study the Coh-Metrix indices that estimate psycholinguistic measures, word information, syntactic patterns, syntactic complexity, situation model, lexical diversity and other descriptive indices were used to specifically investigate the linguistic profiles of discourse in the Math Nation Wall posts.

2.2.2 SEANCE

The Sentiment Analysis and Cognition Engine (SEANCE) calculates sentiment indices for a text using pre-developed word vectors that measure sentiment and pre-existing sentiment, social positioning and cognition dictionaries. One particular advantage of SEANCE is that accounts for the presence of negations in the texts (e.g., *not sad*, would not be assessed as negative). Yoo and Kim found positive emotions reported by SEANCE to be strong predictors of success [35]. SEANCE has also been previously used to model math identity and math success [12]. In another study, Crossley et al. demonstrated using SEANCE that math performance was related to the use of fewer words related to respect [11]. Similarly, we used SEANCE in the current study to assess the extent to which sentiment expressed within the discussion posts was related to math performance.

2.3 Data Preprocessing and Feature Selection

The dataset was checked for multicollinearity as it reduces the precision of the estimate coefficients and makes it difficult to assess the relative importance of the independent variables in explaining the variation caused by the dependent variable. Highly correlated features (r >= 0.90) were removed from the analysis. In case two or more attributes were found to be highly correlated, the attributes with the greater number of pairwise correlations were removed. The dataset was further filtered such that features with more than 20% values were missing and those with zero and nearly zero variance were also removed.

The analysis initially included 124 variables (92 Coh-Metrix features, 20 SEANCE Component Scores, and 12 variables related to student factors). After preprocessing and feature selection, 12 linguistic indices, and 4 student variables were included in subsequent analyses. The 12 features represent cohesion and sentiment measures, whereas the 4 non-linguistic indices represent demographics and performance data.

3. RESULTS

The purpose of this study was to assess the degree to which linguistic features of students' language within the Math Nation Wall posts predicted EOC performance compared to other more traditional measures such as demographics and prior math performance. To this end, three linear models were examined using different combinations of candidate predictors of math performance (i.e., non-linguistic features, linguistic features, and the combination of both the non-linguistic and the linguistic features). The necessary assumptions for testing the regression models were met by examining model residuals for all three models. Figure 2 provides the sample diagnostic plots for the residual analysis of the full model. The residuals versus fitted graph reveal no pattern, show a constant variation, and depict linearity. The normal Q-Q plot also shows normal distribution of the residuals. The remaining 2 plots do not depict any non-linear behavior nor any influence of homoscedasticity. These models were also validated using 10-fold cross-validation which rendered the best fit models in terms of RMSE performance.

3.1 Non-linguistic Predictive Model

The non-linguistic features included in this regression model were the students' gender, grade level, and FSA math scores of the previous year (see Table 2). Using only the FSA math scores as a candidate predictor the resulting model accounted for 58.64% of the variance. Using the FSA math score, gender, and grade level, grade level also emerged as a significant predictor but gender did not. The model with the FSA and grade level as predictors accounted for 63.12% of the variance of the EoC scores. No significant interactions between grade and gender emerged.

These results suggest that the Math FSA score depicting prior performance in mathematics and the grade level significantly contributes to Algebra EoC performance, providing adequate proxies for students' baseline performance prior to the course.

3.2 Linguistic Predictive Model

The primary purpose of this study is to examine the degree to which features of the language used by students in the wall posts are predictive of students' Algebra EoC scores over and above baseline proxies provided by FSA performance and demographic variables.

We conducted a multiple linear regression analysis predicting Algebra I scores using the 12 linguistic indices discussed in Section 2.3.

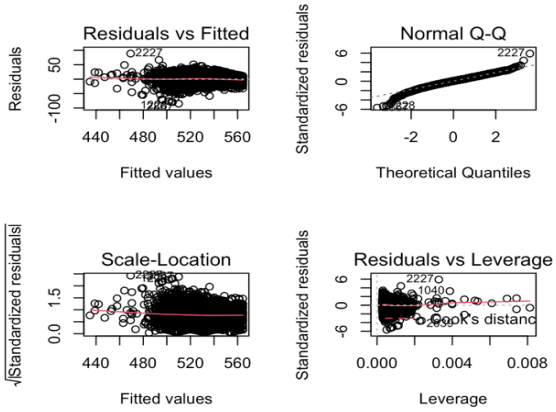

Figure 2 - Diagnostic Plots for linear regressions

Table 2. Linear model including Non-linguistic Features

	Estimate	S.E.	*t*
Using Math FSA only as candidate predictor			
Math FSA Score	1.040	0.027	38.30
Intercept	157.778	9.721	16.23
Using Math FSA, grade and gender as candidate predictors			
Math FSA Score	0.949	0.027	35.052
Grade	-8.395	0.745	-11.262
Gender *	1.000	0.884	1.131
Intercept	253.855	12.691	20.003

Notes: Gender is not significant (p = 0.258); All other p< 0.001. Random-effects were estimated with school district (level 1) in a nested mixed-effects model, resulting in a negligible amount of variance account by the school district (3.67%). Hence, the final models were constructed without district.

Table 3. Linear model including Linguistic Features

	Estimate	S.E.	*t*
Semantic overlap (givenness) of each sentence	-75.698	15.150	-4.997
Incidence of Pronouns	-0.159	0.024	-6.732
Hypernymy for nouns	5.617	0.976	5.758
Intercept	527.486	7.343	71.838

Note: p-value at < 0.001

After the 10-fold cross validation, the best-tuned model accounted for 10.64% of the EOC variance with an RMSE = 21.73. Table 3 reports the coefficients of the significant linguistic. Students whose posts include higher noun specificity (hypernymy) also tended to have higher Algebra I EoC performance. Moreover, lower degrees of sentence givenness and pronoun incidence also emerged as indicators of Algebra I EoC performance. These results imply that the posts by better performing students were structured in such a way that they used more specific terms for concepts or topics (higher noun hypernymy), less personal (lower pronoun incidence), and included queries or responses with greater amount of elaboration on topics that varied across posts (lower sentence givenness/newness).

3.3 Combined Model

The combined model included the significantly predictive features from both the non-linguistic and linguistic models (i.e., FSA score, grade level, LSA givenness, incidence of pronouns, and hypernymy of nouns). This model accounted for 64.48% of the variance for the Algebra I EoC scores with an RMSE of 13.73. The results are summarized in Table 4.

The findings revealed that the full model with the combined linguistic and non-linguistic features performed only slightly better than the baseline model in predicting Algebra I scores (i.e., 63.1% vs. 64.5% of the variance). An ANOVA was conducted to compare the fitness of both regression models, comparing the non-linguistic model to the model with the linguistic predictors. The results indicated that the more complex model with the additional linguistic predictors better captured the variance of the Algebra I EoC scores than the baseline model, $F = 20.879$, $p < 0.001$. We also used Akaike information criterion (AIC) model selection to select the best fit model between the non-linguistic model and the model with the linguistic predictors. The model with the linguistic predictors emerged as the best-fit model carrying 100% of the model weight (AICc weight = 1) and having lower AICc (AICc full model = 8,357.60; AICc baseline model = 8394.72) in predicting Algebra I EOC performance.

These results replicate prior studies [10,15] suggesting students' language fluency and use within Math discussion boards provide valuable information regarding students' potential performance at the end of the year. Importantly, these features can be captured dynamically as the course progresses, and in the absence of other information, such as prior course scores and demographics.

Table 4. Linear model for Combined Features

	Estimate	S.E.	t
Math FSA score	0.902	0.027	32.889
Grade	-8.432	0.731	-11.533
Hypernymy for nouns	2.919	0.617	4.730
Semantic overlap (givenness) of each sentence	-27.529	9.594	-2.869
Incidence of Pronouns	-0.044	0.015	-2.929
Intercept	264.302	13.502	19.575

Note: all $p < 0.001$

4. CONCLUSION

In summary, the results reported in this study confirm prior studies that have suggested that the students' math course scores, and in this case Algebra 1 EoC scores, can be significantly predicted by language, in particular hypernymy, pronoun incidence, and lower semantic overlap between sentences. Students with stronger course outcomes used more sophisticated language, across a wider range of topics, and with less personalized language.

Students' math scores from the previous year served as a proxy for baseline math performance, or prior math skills. As expected, prior math skills provided the strongest predictors of the EoC Algebra I scores. Students' grade level also emerged as a significant (negative) predictor of the Algebra I EoC performance. The students self-select as to when they would take the Algebra I course. As such, higher ability students tend to take Algebra I in middle school whereas lower ability students tend to take the exam later in high school, and thus grade was negatively related to scores.

Hypernymy (specificity) of nouns, an indicator of language fluency, contributed to the prediction of EoC performance such that a higher degree of hypernymy or specificity the words used in the discourse was related to higher EoC scores. Further, the discourse of higher performing students can be characterized as less personal as depicted by lower pronoun incidence. In addition, higher performing students' posts had lower overlap between posts, and more new information as depicted by the lower givenness/new LSA index.

We assume that students' engagement in online discussions reveals some aspects of their mental representations or understanding of the academic content. In turn, the linguistic features of their language can serve as proxies for underlying literacy and math skills. The linguistic features that pertain to language fluency suggest that students' posts were reflective of their ability to communicate more effectively and use terms more specific to the academic content.

Notably, linguistic features depicting sentiment did not emerge as significant predictors of Algebra I EoC performance. This could be attributed to the academic nature of the discussion such that students' discourse tends to be more domain-related and less personal in nature. Yet, there is a strong tendency in the NLP literature to focus on sentiment in language. This study indicates that when other features related to language sophistication are considered, sentiment may not emerge as a significant predictor of performance.

There are multiple implications from this work. The first is relatively obvious: literacy and language skills contribute to students' math performance. Language skills aide in student' comprehension of math and their ability to communicate regarding math. In turn, they are more likely to succeed. As such, providing literacy instruction is important: to enhance students' performance in language courses (ELA), but also for performance in content courses (science, history) and mathematics courses. Second, these results suggest that it behooves educators to consider literacy and communication skills, and provide instructions as concretely and coherently as possible [36-38].

Third, within the context of online platforms, these results further confirm the potential of leveraging linguistic and semantic features of students' posts as indicators of potential course performance. It might be assumed that language is not an important indicator of math; and yet, multiple studies have demonstrated that the linguistic features are powerful proxies for students' underlying skills and knowledge across a variety of contexts. Our future studies will consider other features of language (e.g., rhetorical features, lexical features) as well as examining students' language use across various times during the course. Whereas this study solely examined aggregated posts at the end of the course, our future work will examine the number of posts necessary to significantly predict performance. Dynamic, online predictions are necessary in order to intervene, provide appropriate scaffolding to the students, and usable information for the mathematics instructors. Linguistic dimensions of the production of online discourse and their association with academic performance is a promising field of research. As such, linguistic profiles of discourse have strong potential to inform instructional and pedagogical design of collaborative learning environments such as Math Nation.

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