# Work in Progress: Predictive analysis of conceptual understanding based on self-reported student engagement with resources in a blended engineering class

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***Abstract**: In an attempt to increase student retention and improve academic performance within science, technology, engineering, and mathematics disciplines, educators have begun to foster the use of active, blended, and collaborative pedagogical approaches within traditional classroom settings. Developed for a core mechanical engineering course, Freeform was among the first of these classroom environments to incorporate all three unique strategies and has consistently shown trends of increased student performance. This work in progress further investigates the Freeform environment to more specifically determine how it benefits student learning. It is among the first efforts to examine the extent to which engagement with online and collaborative resources predicts students' conceptual understanding of the course content. The results suggest that engagement with Freeform's online resources may not contribute to the students' overall conceptual understanding or gains in their conceptual understanding of dynamics. However, the results also suggest that peer collaboration may foster more engagement with online resources.*

## Introduction

Higher-education institutions worldwide are working to address the continued high rates of student attrition in science, technology, engineering, and mathematics (STEM) majors. An estimated 60% of all students pursuing a STEM-related major decide to switch to a non-STEM field or end up not graduating altogether, making STEM courses a high priority for pedagogical adjustment (Christensen, Knezek, & Tyler-Wood, 2014). To improve the retention of students in STEM, many instructors are turning to active (Freeman et al., 2014), blended (Bernard, Borokhovski, Schmid, Tamim, & Abrami, 2014; Francis & Shannon, 2013; Means, Toyama, Murphy, & Baki, 2013), and collaborative (Johnson, Johnson, & Smith, 1991; Smith, Johnson, & Johnson, 1981) learning environments which have been shown to increase the students' engagement and performance. In addition, in the field of engineering, prominent works have called for an increased emphasis on students' conceptual understanding to better prepare them for the ill-defined problems they will face in professional practice (Litzinger, Lattuca, Hadgraft, & Newstetter, 2011; Sheppard, Macatangay, Colby, & Sullivan, 2009, Chapters 4-5). This work in progress study is positioned at the intersection of introducing novel pedagogical strategies into a traditional, lecture-based classroom environment and the emphasis on conceptual understanding. Specifically, this paper studies the extent to which students' engagement with online and collaborative resources predicts their conceptual understanding of material taught in an active, blended, and collaborative learning environment. We anticipate that the results of this research will add to the growing body of evidence documenting the benefits of implementing non-traditional educational strategies into a university-level STEM course.

### ***Freeform*: An Active, Blended, and Collaborative Learning Environment**

In 2008, three professors at Purdue University developed an active, blended, and collaborative classroom environment, which they called *Freeform*, with the goals of accommodating the diverse learning styles of engineering students, improving student academic achievement, and increasing student retention within the course (Rhoads, Nauman, Holloway, & Krousgrill, 2014). *Freeform* was developed for two core, introductory-level mechanical engineering courses (Statics and Dynamics) at Purdue University, but has since expanded to five different institutions worldwide. Dynamics is the most mature instantiation of *Freeform* and will be the focus in this paper.

Five fundamental elements form the *Freeform* core: student-centered in-class instruction, a custom-written textbook (known as a "lecturebook", which the developers describe as a hybrid between a workbook and a textbook), an interactive online course discussion forum (referred to as the course blog), extensive multimedia content (such as online example and homework-solution videos), and refined student assessment tools, including an abbreviated Dynamics Concept Inventory (Rhoads et al., 2014; Stites et al., 2016). As a part of *Freeform*, instructors are encouraged to facilitate student collaboration in class (e.g., through group quizzes) and online (e.g., the course blog). Most *Freeform* instructors choose to solve several example problems from the lecturebook during class, whereas video solutions for these problems can be found on the course website. In addition, the homework problems, interactive simulations, and videos that demonstrate various concepts covered during class are also available on the course website for the students to view at their own convenience.

One of the defining characteristics of the *Freeform* environment is its emphasis on the students' conceptual understanding of the material. Every chapter of the lecturebook has a series of short-answer or multiple choice questions that the students may use to assess their own conceptual understanding. Quizzes often consist of multiple-choice conceptual questions, and typically one third of the content on each of the four exams (three midterm exams and the final exam) is devoted to assessing conceptual knowledge. Overall, *Freeform* is a flexible learning environment with extensive resources to scaffold and enhance the students' conceptual understanding and problem-solving abilities, with the overarching goal of improving student success and persistence in engineering.

Since the inception of *Freeform*, student performance in Dynamics has markedly increased. Prior to *Freeform*, the rate of students who earned a D, F, or withdrew from Dynamics (on an A-B-C-D-F grading scale), also known as the "DFW" rate, was above 20% (Rhoads et al., 2014). Most students who withdrew from the course or earned an F had to retake the class because Dynamics is a required class for the majority of those enrolled. Students who earned a D in the class likely lacked sufficient understanding of the material on which future courses build. Since implementing *Freeform*, the DFW rate has steadily decreased to approximately 10% (DeBoer et al., 2016; Stites et al., 2016). Previous research investigating this trend suggested that a student's incoming grade point average (GPA, which is measured on a 4.0-scale), international status, grade in Statics (which is a pre-requisite for Dynamics), year since *Freeform* inception (a proxy measure for the quantity and quality of *Freeform* resources), and instructor experience in the *Freeform* environment were significant predictors of overall student performance (DeBoer et al., 2016; Stites et al., 2017). Among these studies, none have begun to analyze the impact of the students' engagement with specific components of *Freeform*—namely the blended and collaborative resources—on student learning or performance in the class. Furthermore, no studies have used the students' conceptual understanding as the outcome variable; only the students' overall grade in Dynamics has been used as the outcome. Therefore, this work contributes to the body of knowledge for active, blended, and collaborative learning environments by examining the relationship between the students' usage of resources and their conceptual understanding of dynamics.

### Conceptual Framework

*Freeform* is founded on a combination of findings from the literature and multiple theoretical frameworks supporting the benefits of implementing active, blended, and collaborative pedagogies. Research has highlighted the advantages of active and collaborative learning for decades now (e.g., Smith et al., 1981). More recently, Freeman et al. (2014) conducted a meta-analysis of the literature on active learning (including a substantial number of articles about collaborative learning) and concluded that students enrolled in an active classroom were 1.5 times more likely to pass when compared to students enrolled in a passive classroom. These results corroborated earlier claims that collaborative learning enhances knowledge construction (Jeong and Chi, 2007).

A blended course, as defined by Allen and Seaman (2013), is when a "substantial portion of the content is delivered online" (p. 7). A meta-analysis of blended learning in K-12 and higher education (including graduate and professional programs) found that students in blended courses significantly outperform those in face-to-face (only) courses (Means et al., 2013). A similar meta-analysis, focused solely on higher education, also concluded that students in blended classes have significantly higher achievement outcomes than those in classes without online components (Bernard et al., 2014). In the field of engineering specifically, Francis and Shannon (2013) found that the performance of architectural engineering students was higher for those who engaged with online resources. These prior findings illustrate the advantages of blended instruction and directly inform our hypothesis that the students' engagement with *Freeform* resources positively impacts their conceptual understanding of dynamics.

### Research Question

This work in progress study is the first to examine how student engagement with online videos and a course blog relates to conceptual learning outcomes in a second-year, undergraduate engineering course. Specifically, our research question is: to what extent does engagement with online videos and a collaborative peer-to-peer discussion forum within the *Freeform* environment predict students' conceptual understanding of dynamics? We hypothesize that student engagement with these online resources is a significant positive predictor for attained conceptual understanding, which would provide further support for implementing blended and collaborative learning strategies in core engineering classes.

## Methods

### Participants

The data for this study were collected from students enrolled in Dynamics at Purdue University during the semesters of Fall 2015, Spring 2016, and Fall 2016. Of the 602 students enrolled in Dynamics during the three semesters, only the data from students who had completed an optional post-course survey were included in the final analyses of this study. The final sample consisted of 163 students (77% male and 23% female) of which 74% were domestic students (~60% white, ~7% Asian, and ~8% underrepresented minorities/other) and 26% were international students (any student with non-US citizenship).

## Measures

During the final weeks of the semester, the students enrolled in Dynamics were asked to complete an online survey, which included questions about their study behaviors (e.g., group collaboration), their engagement with the course blog and online solution videos, as well as their attitudes towards and perceptions of the course. Four of the original fifty survey questioned were analyzed in this preliminary study. Due to the extensive length of the survey, only students completing 50% of the analyzed questions were included in the final sample. The four survey questions of interest included one study behavior question and three resource engagement questions. To measure in-person, collaborative interactions, students were asked to report the average number of hours they spent studying with at least one other student each week. This study-behavior metric was used as a control variable because students have told us during post-course interviews that their study group would utilize the online resources when working on homework assignments. In this study, we wanted to focus on the individualized usage of online resources rather than the resource usage that occurs during group collaboration.

Engagement with the course blog and the online solution videos was determined by self-reported frequency of use, with the responses ranging from “never” to “at least once per day.” The students reporting engagement with the resources 1-2 times per week or more were categorized as “frequent” users, whereas the students reporting usage of less than 1-2 times per week were categorized as “infrequent” users.

To measure conceptual understanding, an abbreviated, 12-question version of the Dynamics Concept Inventory was administered to all consenting students at the beginning and end of the semester (Gray et al., 2005; Stites et al., 2016). The abbreviated Dynamics Concept Inventory (aDCI) is made up of multiple-choice questions that require minimal calculations (if any) and targets the assessment of the students’ conceptual understanding of 12 subtopics of dynamics (one question per subtopic). The students’ scores on the aDCI post-test ($M$ = 64%, $SD$ = 19%) and their normalized gain ($M$ = 0.41, $SD$ = 0.27) were used as measures of conceptual understanding in this study. The aDCI was scored out of 100%, while the normalized gain ($G$) for each student ranged from zero to one and was calculated by the following established metric (Coletta, Phillips, & Steinert, 2007):

$$G = \frac{(postscore\ \%) - (prescore\ \%)}{100 - (prescore\ \%)},$$

which is an individualized version of the normalized gain popularized by Hake (1998). The post-test score measures the students’ conceptual understanding at the end of the course, and the normalized gain accounts for the fact that some students may enter the course with significant prior knowledge of dynamics. Therefore, the normalized gain attempts to measure how much conceptual knowledge the students gain specifically from Dynamics.

A Kolmogorov-Smirnov test for the post-test scores ($p$ = 0.999) and the normalized gains ($p$ = 0.835) suggested that the students who completed the survey and those who did not take the survey were likely to be derived from the same population. Additionally, the proportion of students in each of the ethnicity and gender categories were compared for the students who did and did not complete the survey, and no difference in proportions exceeded 6%. Therefore, the performance and demographic comparisons suggested that the sample of students who completed the survey were representative of the population of students who enrolled in Dynamics at Purdue University, which minimizes the bias in our results.

## Statistical Analysis

A sequential linear regression analysis was conducted to determine if engagement with the course blog or online solution videos significantly predicted conceptual understanding of dynamics. The correlations between the continuous variables were used to check for collinearity. The predictor variables included in base models for the aDCI post-test scores (Model 1) and the normalized gains (Model 3) were demographic data (gender and ethnicity), prior academic performance (aDCI pre-test scores, Statics grade, and cumulative GPA at the start of the academic period in which they enrolled in Dynamics), and study behaviors (the number of hours studying in a group). The full models (Models 2 and 4) for each outcome variable added the self-reported number of videos watched and the frequencies of using the course blog and online solution videos. All variables except gender, ethnicity, and self-reported frequencies were considered continuous, and all numeric predictors were centered on their mean for the regression analysis. Multiple imputation (m = 5) using chained equations (Rubin, 1987) was used to estimate any missing values.

## Results

The results of the correlations, as shown in Table 1, suggest that there is a positive correlation between aDCI post-scores and both Statics grade and incoming GPA. This may suggest that students who have a better academic history are more likely to score higher on the aDCI post-test. The post-test scores were also significantly correlated with both the pre-test scores and normalized gain (which is not surprising given that the post-test scores are part of the normalized gain equation). However, the correlation results suggest the lack of a significant relationship between aDCI pre-test scores and normalized gain. This may indicate that regardless of the level of conceptual understanding at the beginning of the semester, all students are equally likely to improve their conceptual understanding of the material throughout the semester. Additionally, both incoming GPA and Statics grade have only a slightly positive correlation with the pre-test scores. This relationship was expected due to the fact that majority of the aDCI assesses topics that are unfamiliar to students who have never taken Dynamics previously.

**Table 1. Correlation Coefficients (Bottom Left) and Their Associated *p*-Values (Upper Right) for Numeric Variables in the Regression Analysis**

| | Post-test Score (%) | Pre-test Score (%) | Normal-ized Gain (*G*) | Incoming GPA | Statics Grade | Study Group Hours | Number of Videos Watched |
|---|---|---|---|---|---|---|---|
| Post-test Score (%) | - | <0.001 | 0.000 | <0.001 | <0.001 | 0.29 | 0.26 |
| Pre-test Score (%) | **0.52** | - | 0.13 | 0.01 | 0.009 | 0.23 | 0.40 |
| Normalized Gain (*G*) | **0.83** | 0.12 | - | <0.001 | <0.001 | 0.34 | 0.11 |
| Incoming GPA | **0.47** | **0.21** | **0.47** | - | 0.000 | 0.80 | 0.50 |
| Statics Grade | **0.44** | **0.21** | **0.46** | **0.75** | - | 0.12 | 0.19 |
| Study Group Hours | -0.09 | -0.10 | -0.08 | -0.02 | -0.129 | - | <0.001 |
| Number of Videos Watched | -0.09 | -0.07 | -0.13 | -0.05 | -0.11 | **0.53** | - |

*Note*: Incoming GPA and Statics Grade were measured on a scale of 0.0 – 4.0.

A positive relationship exists between the average weekly hours spent studying with a group and the number of videos watched. This may suggest that students choose to utilize the online resources when studying with other students. Although these variables are significantly correlated to one another, both group study hours and the number of online videos watched are not significantly related to post-test score or normalized gain.

Finally, the students' incoming GPAs and their Statics grades are highly correlated. This is partially due to the part-whole relationship between the two variables (the Statics grade contributes to the overall GPA). To reduce variance inflation due to multicollinearity, we only included incoming GPA in our regression model.

**Table 2. Summary of Sequential Linear Regression Results Predicting aDCI Post-test Score and Normalized Gain**

| | Post-test Scores (%) | | Normalized Gain (*G*) | |
|---|---|---|---|---|
| | Model 1 | Model 2 | Model 3 | Model 4 |
| | B (SE) | B (SE) | B (SE) | B (SE) |
| Gender: Female | **-7.35**** (2.58) | **-6.95**** (2.59) | **-0.12**** (0.05) | **-0.11*** (0.05) |
| Ethnicity: | | | | |
| Domestic: Asian | -7.47 (4.36) | -7.76 (4.37) | -0.07 (0.08) | -0.08 (0.08) |
| Domestic: URM/Other | -4.93 (4.05) | -5.31 (4.13) | -0.06 (0.07) | -0.07 (0.07) |
| International | 0.69 (2.56) | 0.89 (2.66) | 0.02 (0.05) | 0.02 (0.05) |
| Pre-test Scores (%) | **0.61***** (0.07) | **0.62***** (0.08) | 0.00 (0.00) | 0.00 (0.00) |
| Incoming GPA | **15.01***** (2.78) | **14.16***** (2.84) | **0.25***** (0.05) | **0.24***** (0.05) |
| Study Group Hours | -0.06 (0.19) | 0.06 (0.24) | 0.00 (0.00) | 0.00 (0.00) |
| Number of Videos Watched | | -0.07 (0.07) | | 0.00 (0.00) |
| Frequency of Video Usage | | -0.03 (3.27) | | -0.01 (0.06) |
| Frequency of Blog Usage | | 4.10 (2.73) | | 0.08 (0.05) |
| Constant | 42.02*** (3.18) | 40.56*** (3.24) | 0.44*** (0.06) | 0.41*** (0.06) |
| Observations | 163 | 163 | 163 | 163 |
| adj. $R^2$ | 0.49 | 0.50 | 0.18 | 0.19 |
| $\Delta R^2$ | - | 0.01 ($p$ = 0.356) | - | 0.01 ($p$ = 0.368) |

*$p < 0.05$. **$p < 0.01$. ***$p < 0.001$

*Note*: The comparison group for gender is males, and the comparison group for ethnicity is domestic, white students.

The results of the sequential linear regression analysis for both the post-test scores and normalized gains can be seen in Table 2. In Model 1, where the post-test score was the dependent variable, the initial set of variables accounted for 49% of the total variance in the post-test scores. In this model, gender, pre-test scores, and incoming GPA were significant predictors of aDCI post-test scores. Regarding the significance of the pre-test scores, it is reasonable to expect that students who come into the class with a higher conceptual understanding of dynamics also leave with a higher understanding. In Model 2, the group of engagement predictor variables (the total number of videos watched, frequency of online video usage, and frequency of blog usage) were not significant predictors of aDCI post-test scores, collectively or individually. Model 2 had a nonsignificant change in $R^2$, and none of the individual coefficients for the additional variables had p-values less than 0.05.

The variables included in Model 3 for the normalized gain accounted for 18% of the total variance. Unlike in Model 1 and 2 for the post-test scores, the aDCI pre-test scores did *not* have a significant effect on normalized gain. This might suggest that all of the students enrolled in Dynamics have an equal opportunity to increase their conceptual understanding (proportionally), no matter how they performed on the pre-test. In Model 4, the engagement variables explained an additional 1% of the total variance in the normalized gains, but this change in $R^2$ was not statistically significantly different from that of Model 3. Similar to the models for post-test scores, the variables for online video and course blog engagement, both individually and as a group, were not significant predictors of normalized gain.

## Discussion

The results of the regression analyses for the aDCI post-test scores and normalized gains suggest that engagement with the *Freeform* course blog and online videos does not significantly predict the students' overall conceptual understanding or their proportional increase in conceptual understanding of dynamics. However, the students' self-reported average weekly hours spent studying with a group significantly correlated with the number of videos watched throughout the course. Therefore, the online resources may still be impacting the students' understanding of dynamics via group settings, but our model does not examine this relationship. The possibility of an interaction effect between study behaviors and resource usage deserves further investigation.

The regression coefficients suggest that for every 10% increase in a student's pre-test score, their post-test score increases by approximately 6%. The pre-test scores and incoming GPA, however, do not significantly explain the variance in Model 3 or Model 4 where normalized gain was the dependent variable. The insignificance of the pre-test scores influencing the normalized gains suggest that students with various levels of conceptual understanding at the beginning of the semester increase their conceptual understanding of dynamics proportionally. However, because the students with lower pre-test scores had more conceptual knowledge to gain, their absolute gain is higher than that of students with higher pre-test scores. In other words, the students who entered the class with a higher conceptual understanding of dynamics also exit Dynamics with a higher understanding, but the differences in conceptual understanding across all students have been reduced.

The results of all four models also indicate that, all other factors being equal, female students are predicted to have lower post-course conceptual understanding and lower gains as compared to males. Models 1 and 2 suggest that females score about 7% lower on their post-test aDCI than males, when the values for all other variables are held constant. Models 3 and 4 also estimate that females' normalized gains are approximately 11% lower than the normalized gains for similar males. The significance of gender as a predictor for conceptual understanding contrasts with the insignificance of gender in predicting a student's success in the class, as measured by the student not earning a D, F, or withdrawing from the course (DeBoer et al., 2016; Stites et al., 2017). Similarly, the significance of a student's residency status in this work contradicts results that have been published for predicting a student's overall success in the course. *As such, one of the main conclusions of this study is the need to further investigate the relationship between gender, residency status, resource usage, and study behaviors on conceptual understanding and overall grade in the course.*

## Conclusion

This work in progress study is among the first to investigate how engagement with online and collaborative resources affects student conceptual understanding of material taught in an introductory-level mechanical engineering course. The results of the sequential linear regression analysis suggest that students' self-reported engagement with *Freeform*'s online videos and blog does not significantly predict their overall conceptual understanding of dynamics or their proportional gain of conceptual understanding.

Although the preliminary results of this study indicate that the collective effect of online-resource engagement on conceptual understanding of dynamics is not significant, there are several opportunities beyond those mentioned in the Discussion section to improve and expand on this work. For example, the predictor variables measuring engagement with the course blog and online videos were self-reported averages for the entire semester and may have been inaccurate reports of usage. Additionally, the regression models treated the aDCI post-test and normalized gain as continuous variables, but a similar analysis should treat the outcome variables as ordinal measures to see if the results change.

Future work may also focus on how engagement with these blended and collaborative resources affects the development of problem-solving skills. Although conceptual information makes up a sizable portion of the Dynamics curriculum, instructors in *Freeform* often devote the majority of class time to the development of students' problem-solving skills. Thus, it would be useful to investigate how resource engagement affects problem-solving skills.

In conclusion, this work in progress study indicates that the students' engagement with online and collaborative resources in the *Freeform* environment does not significantly predict their conceptual understanding in a core, undergraduate engineering class. However, the average weekly hours spent studying with a group and the number of videos watched are positively correlated which may indicate an interaction between the blended and collaborative resource utilization. Furthermore, this study identifies interesting paths for future work, including the effect of gender and residency status on the conceptual understanding of dynamics.

## Acknowledgements

We would like to thank David Evenhouse and Craig Zywicki, as well as the many other faculty, staff, and students that make up the *Freeform* team. This project was funded by the National Science Foundation, grant number: DUE-1525671. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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