How Syllabi Relate to Outcomes in Higher Education: A Study of Syllabi Learner-Centeredness and Grade Inequities in STEM

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Abstract

Background: Fostering equity in undergraduate science, technology, engineering, and mathematics (STEM) major programs can be accomplished by incorporating learner-centered pedagogies, resulting in the closing of opportunity gaps, defined in this research as the difference in grades earned by minoritized (including Black, Latinx, Pacific Islander and American Indian students) and non-minoritized students. We examined STEM courses that exhibit small and large opportunity gaps at a large enrollment, minority-serving, research intensive university, and the degree to which their syllabi are learner-centered, as defined by a modified version of a previously validated rubric. We specifically chose syllabi as they are often the first interaction a student has with a course and can serve to establish expectations for course policies and practices.

Results: Through this analysis, we found that STEM courses with a more learner-centered syllabus according to the rubric scoring also had smaller opportunity gaps between minoritized and non-minoritized students. The syllabus rubric factor that most correlated with smaller opportunity gaps was *Power and Control*, which consists of items reflecting Student's Role, Outside Resources, and Syllabus Focus.

Conclusion: This work highlights the importance of course syllabi as a tool as instructors consider how to create more inclusive classroom environments, and the need for instructors to be supported by their respective institutions of higher education to dedicate adequate time and resources to ensure that courses are designed and carried out in a learner-centered fashion.

Keywords: syllabus analysis, STEM education, grade gaps,, active learning, learner-centered pedagogy, higher education

1 Introduction

Higher education is one of the most promising paths to social mobility and moving up the socioeconomic ladder (Bathmaker et al., 2016; Haveman & Smeeding, 2006). University graduates have more opportunities in life, can find jobs faster and with less difficulty, are more likely to be employed, and on average have higher salaries (Ma et al., 2019; NCES, 2020). Representation of minoritized populations (which we define as individuals from Black, Latinx, Pacific Islander, and American Indian populations) in higher education is one of the most effective ways to close the wealth gap (Haveman & Smeeding, 2006; Oliver & Shapiro, 2013). In addition to decreasing income inequality, equitable participation and success in post-secondary education can increase workplace diversity which results in a greater range of talent with diverse worldviews, creativity, productivity, and innovation (Cletus et al., 2018; Foma, 2014; Hong & Page, 2004; Tamunomiebi & John-Eke, 2020). Although the college enrollment gap between minoritized and non-minoritized students (which we define as students from White and Asian populations) has decreased, as of 2018, students who are Black, Latinx, Pacific Islander, and American Indians still enroll at a rate that is 5%, 5%, 7%, and 19% less, respectively, relative to students who are White (NCES, 2020).

Despite this shrinking gap in enrollment rates between students from minoritized and non-minoritized populations, academic success rates once in college still show stark disparities. In particular, science, technology, engineering, and mathematics (STEM) programs in higher education fail to foster and promote equitable and inclusive learning environments, resulting in lower retention and graduation rates for women, minoritized populations and low-income students (Holden & Lander, 2012). There are several reasons for this underrepresentation in college STEM classes.

Of primary significance is the well-documented “chilly climate” of STEM professional fields and learning spaces, which refers to the student perception of faculty, researchers, and other professionals being unapproachable, intimidating, cold, and indifferent (Daempfle, 2003; Doolen & Long, 2007). In higher education, this chilly climate in STEM majors decreases interactions between students and faculty (Flynn, 2016) and increases attrition especially among minoritized students (Flynn, 2016; Swail et al., 2003). Research shows that minoritized students consistently are awarded lower grades than Asian and White students in STEM courses (a phenomenon which we will refer to as an opportunity gap), which strongly contributes to whether they choose to persist in attaining their degrees, switch to another or drop out of college altogether (Whitcomb et al., 2021; Whitcomb & Singh, 2021). By creating a more equitable learning environment, it may be possible to narrow this opportunity gap, aiding in the retention of minoritized students.

One way to combat the chilly climate in STEM programs and minimize opportunity gaps is by changing the culture of teaching and learning in STEM education through modifications to institutional and classroom policies and practices. This change of culture also likely involves redirecting the focus from teaching to learning by embracing a more learner-centered approach when designing curricula or training instructors (Armbruster et al., 2009; Freeman et al., 2014; Rainey et al., 2019; Theobald et al., 2020). One of the main means to increase the learner-centeredness at the classroom level is through the implementation of active learning pedagogies (Bell & Kozlowsky, 2006; KeenGwe et al., 2009; Smart & Csapo, 2007). In general, research shows that active learning strategies in STEM courses are more effective than traditional lectures in increasing student performance and retention (Armbruster et al., 2009; Freeman et al., 2014), particularly those from minoritized populations (Eddy & Hogan, 2014; Theobald et al., 2020). Strategies such as using portfolios, leveraging pre-course material, and incorporating collaborative problem-solving activities (boosting the socio-emotional aspect of the course as discussed above) not only increase students' grades and performance, but also promote student engagement, and strengthen a sense of community (DeMara et al., 2016; Gupta, 2004; Marlowe, 2012). It has been demonstrated that active learning practices in STEM courses differentially benefit minoritized students by closing opportunity gaps, increasing self-efficacy, and promoting a sense of belonging (Ballen et al., 2017; Rainey et al., 2019; Theobald et al., 2020). This is also related to the increased structure commonly associated with an active learning course that provides a roadmap for students who may not be as familiar with the tricks for academic success in the competitive STEM environment (Eddy & Hogan, 2014; Freeman et al., 2011).

One means by which an instructor can demonstrate the learner-centered nature of their course is through the course syllabus, which education research views as a representation or portrayal of the course content and structure (Cullen & Harris, 2009; Goodwin et al., 2018; Palmer et al., 2014; Stanny et al., 2015).

Palmer et al. (2016) define the syllabus as “a physical artifact outlining key structural elements of a course” (p. 37). Eberly et al. (2001) argue that the course syllabus is a contract that discusses classroom pedagogy and norms, has a significant influence on course development, and is an explicit description of the course. In short, a syllabus is a good indicator of classroom practices, the teachers’ views towards teaching and learning, and a program’s culture; therefore, examining a syllabus can provide a snapshot of the course environment and serves as a proxy for the course characteristics (Cullen & Harris, 2009; Goodwin et al., 2018; Palmer et al., 2014; Richmond et al., 2019; Stanny et al., 2015). For students, syllabi provide information on the course content and its requirements, while helping to shape students’ expectations of the class and its instructor (Habanek, 2005). In fact, the tone and language of the syllabus can affect students’ perceptions of the course, potentially impacting their engagement with the course, the instructor, and their peers (DiClementi & Handelsman, 2005; Harnish & Bridges, 2011). It has been established that low engagement disproportionately affects minoritized students by creating grade inequities, consequently resulting in low persistence in completing their program of study (Kuh et al., 2007).

While researchers have examined the learner-centeredness of course syllabi, there has not been an attempt to link syllabus learner-centeredness to student outcomes, particularly for minoritized populations, in the same vein as research connecting learner-centered teaching practices and opportunity gaps (Theobald et al., 2020). If learner-centered instructional practices correlate with smaller opportunity gaps, it is possible that a similar relationship exists between learner-centered syllabi and opportunity gaps. As such, the current research is an attempt to examine this relationship and determine whether specific syllabus characteristics can aid in creating more equitable STEM environments. This work may identify a means, the course syllabus, by which instructors can intentionally create more inclusive classroom spaces, and accordingly inform institutions to provide resources to ensure that instructors have the training to meaningfully leverage this vital course tool.

Specifically, our research questions are as follows:

1. To what extent is syllabi learner-centeredness related to opportunity gaps in STEM courses?

2. To what extent are specific syllabi characteristics related to these opportunity gaps?

2 Methods

2.1 Study Population

Syllabi from lower division STEM courses taught between Fall 2015-Winter 2020 at a research-intensive university on the west coast were examined for this study. We identified course sections with at least 10 minoritized and 10 non-minoritized students and had minoritized student representation between 12-48% (this represents the middle 50% of minoritized representation within a course section in our sampling frame). We included syllabi from instructors who taught the same course at least three times between Fall 2015-Winter 2020 to determine the variability of opportunity gaps for a particular course-instructor pairing. Syllabi were separated into cases and controls based on the size of the opportunity gap between minoritized and non-minoritized students for the respective course-instructor pairing. The difference in the grade points (on a 4.0 scale) received by minoritized and non-minoritized students is denoted as ΔGP_{ij}, where i represents the course section ($i = 1, \ldots, n_i$) and j represents the syllabus for each course-instructor pair. The opportunity gap for minoritized and non-minoritized students is defined by the average grade point difference for the jth syllabus and is given by:

$$\underline{\Delta GP_j} = \sum_{i=1}^{n_i} \Delta GP_{ij}$$

Syllabi in the large opportunity gap group (25th percentile of $\underline{\Delta GP_j}$) were designated as cases and syllabi in the small opportunity gap group (75th percentile of $\underline{\Delta GP_j}$) were identified as the controls. The distribution of the opportunity gaps can be seen in Figure 1. In our sample, the average opportunity gap was -0.36 with a standard deviation of 0.23 (see Table 1). Exclusion criteria were: (1) upper division courses, (2) non-STEM courses, (3) syllabi where the course-instructor pairs had two or fewer course section occurrences, (4) syllabi where the course-instructor pairs had opportunity gaps that fell within the middle 50% of $\underline{\Delta GP_j}$.

2.2 Data collection

Course syllabi were requested from the instructors by the study team. Instructors were contacted via email (as well as two follow-up emails for non-respondents). In total, 110 course-instructor pairs were identified (52 with large opportunity gaps and 58 with small opportunity gaps) and the respective instructors were contacted by email. We received responses from 50 instructors (a 45% participation rate; 44% participation for the course-instructor pairs with large opportunity gaps and 46% for the course-instructor pairs with small opportunity gaps). The instructors that responded were representative of the sample as a whole in terms of the distribution of the opportunity gaps. All instructors were provided with the study information sheet, gave electronic consent for participation, and sent their course syllabi to a member of the research team. The syllabi were de-identified prior to analysis by eliminating any identifying names (of instructors, teaching assistants, and readers), emails, and course numbers to decrease bias during the coding process. Descriptive data of the large and small opportunity gap groups can be seen in Table 1.

Table 1 Descriptive statistics for the large and small opportunity gap group designations. The number and percent are presented for categorical variables and the mean and standard deviation are presented for quantitative variables.

	Group		
	Large Opportunity Gap	Small Opportunity Gap	Total
Opportunity Gap			
Size	-0.59 (0.06)	-0.17 (0.12)	-0.36 (0.23)
Instructor Type			
Tenure-track teaching faculty	2 (9%)	3 (11%)	5 (10%)
Non-tenure track teaching faculty	11 (48%)	3 (11%)	14 (28%)
Tenure-track research faculty	10 (43%)	21 (78%)	31 (62%)
Discipline			
Biological Sciences	2 (9%)	2 (7%)	4 (8%)
Engineering	3 (13%)	11 (41%)	14 (28%)
Information and Computer Science	4 (17%)	5 (19%)	9 (18%)
Physical Sciences	14 (61%)	9 (33%)	23 (46%)
Number of students			
Black, Latino/a/x, Pacific Islanders or people indigenous to the US and its territories	59 (35)	42 (26)	50 (32)
White or Asian	121 (71)	93 (61)	106 (67)
Total	180 (105)	135 (85)	155 (96)
Minoritized student representation (%)	33 (5)	32 (7)	32 (6)
Number of times the course was taught by instructor	6 (3)	4 (2)	5 (3)
Total	23	27	50

2.3 Measures (Rubric for Evaluation)

We used a modified version of Cullen and Harris's (2009) rubric to code the collected syllabi. There are 13 items included in the rubric: (1) Accessibility of Teacher, (2) Learning Rationale, (3) Collaboration, (4) Teacher's Role, (5) Student's Role, (6) Outside Resources, (7) Syllabus Tone, (8) Syllabus Focus, (9) Grades, (10) Feedback Mechanism, (11) Evaluation, (12) Learning Outcomes, and (13) Revision/Redoing. The 13 items are categorized under three factors: (1) *Community*, (2) *Power and Control*, and (3) *Evaluation/Assessment*. The descriptions of the 3 factors and the 13 items are provided in Table 2. *Community* is the average of rubric items 1-3, *Power and Control* is the average of rubric items 4-8, and *Evaluation/Assessment* is the average of rubric items 9-13. The supplementary materials include the correlation matrix for the rubric items (Table A1) and for the rubric factors (Table A2). Cronbach's alpha for the 13 rubric items was 0.750 with a bootstrap 95% bootstrap confidence interval based on 1000 samples of (0.544, 0.849). For the 3 rubric factors, Cronbach's alpha was 0.775 with a bootstrap 95% confidence interval based on 1000 samples (0.587, 0.877).

Table 2 Our rubric for syllabus evaluation. The description for the 3 factors and 13 items is provided along with the explanation for scoring each rubric item.

2.3.1 Rubric Modifications

The item, Syllabus Tone, was added to the rubric following Richmond et al. (2019). We also revised some of the language on the rubric that we deemed not applicable to our study courses or added clarifying information wherever the descriptions were vague or were not sufficient to produce consistent scoring among the research team. Our modified rubric is on a 5-point scale (0 to 4) with 0 representing the least learner-centered and 4 representing the most (versus the original 4-point scale, 1-4). We added a category for missing information in a syllabus and assigned a score of zero for that item. For example, if there was no information in a syllabus regarding student collaboration in and out of the classroom, a score of zero was assigned to that syllabus for collaboration. However, if collaboration was explicitly not allowed according to the syllabus, a score of one was given. Cullen and Harris's rubric is designed to measure learner-centeredness; therefore, an absence of a learner-centered rubric item indicates the instructor places no value on it in the context of the syllabus. Finally, in alignment with Richmond et al. (2019), we included

Syllabus Length in our study to reflect the overall amount of information provided. We coded syllabus length as the total number of pages in the syllabus.

2.4 Syllabus coding

Training sessions: 20% of our course syllabi were selected for review by the entire research team during the initial calibration of the syllabus rubric. The syllabi chosen for this purpose were from different departments and courses for which an instructor had submitted more than one syllabus. This selection created a sample that reflected the wide range of variation in syllabus content that evaluators would encounter across academic disciplines during the analysis. Training took approximately 3 hours until 100% consensus was achieved.

Scoring sessions: Two members of our research group evaluated the remaining syllabi after the conclusion of the training sessions. The raters scored the syllabi in sets of 10, after which they met to calculate the interrater reliability for each set, go over scoring to reach consensus (wherever there was a discrepancy in scoring), and discuss the items in the rubric that brought about high levels of disagreement to refine the rubric guidelines and improve accuracy in scoring. There were only three cases (out of the 50 syllabi) in which the two raters were not able to reach consensus on an item in the rubric. A third rater was asked to evaluate that particular item to resolve the disagreement and reach consensus. Initially, Cohen's weighted kappa for interrater reliability (IRR) ranged between 0.49 and 0.88 for each rubric item with an average IRR of 0.71. However, after reaching consensus the weighted kappa for interrater reliability increased to between 0.76 and 0.99 for the individual rubric items with an average IRR of 0.90 (see supplemental Table A3)--achieving substantial agreement (Landis & Koch, 1977).

2.5 Statistical Analyses

We conducted a case-control study to assess the association between syllabus components and the risk of having large opportunity gaps compared to small opportunity gaps for 50 unique syllabi spanning 50 instructors, 43 lower-division courses, and 14 STEM departments. To test if there was a difference between the overall rubric scores and the size of the opportunity gaps, we compared the median rubric score for the two groups using a 2-sample test of medians.

To present evidence of syllabus items (Accessibility of Teacher, Learning Rationale, Collaboration, Teacher's Role, Students' Role, Outside Resources, Syllabus Tone, Syllabus Focus, Grades, Feedback Mechanisms, Evaluation, Learning Outcomes, and Revision/Redoing), syllabus factors (*Community, Power and Control,* and *Evaluation/Assessment*), and the length of the syllabus that correlate with small opportunity gaps, logistic regression was used. We modeled the odds of a syllabus being in the small opportunity gap group (compared to a large opportunity gap group) to address our specific research questions. More specifically, we wanted to know if there is an increase in the odds of a syllabus being in the small opportunity gap group based on certain syllabus characteristics compared to being in the large opportunity gap group. We fit a logistic regression model using the stats (R Core Team, 2021) and MASS package in R (Venables & Ripley, 2002). The assumption of the logistic regression model is that there is a linear relationship between the predictor variables and the log-odds of the event that the syllabus is part of the small opportunity gap group. Assuming we have a sample of n independent observations, $(x_i,\ y_i)$, we obtain estimates for $\beta^t = (\beta_0, \ldots, \beta_k)$. Let Y be whether or not the syllabus was part of the small opportunity gap group and the probability that the syllabus was part of the small opportunity gap group be $p = P(Y = 1)$ and let $x^t = (x_1, \ldots, x_k)$ be the k predictors in the model, which is given by:

$$log\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k.$$

The model with the lowest Akaike Information Criteria (AIC) indicates a balance of model fit with generalizability (Chakrabarti & Ghosh, 2011; Sakamoto et al., 1986). The AIC is given by:

$$AIC = -2ln(L) + 2k,$$

where L is the likelihood and k is the number of parameters of the model. The AIC is based on the log-likelihood (a measure of how likely the observed data is given a model) and is penalized as the parameter complexity increases. The reason for the penalty is that adding parameters into a model can lead to overfitting of the data. Therefore, AIC strikes a balance between the best model fit and the model complexity.

In order to understand the relationship between syllabus items, syllabus factors, and length of the syllabus we follow the procedure as outlined. First, we built a model where we include syllabus items and the length of the syllabus as the covariates. Next, we built a model where we include syllabus factors and the length of the syllabus as the covariates. Third, we performed best subsets logistic regression using the *bestglm* package in R (McLeod & Xu, 2018) where we minimized the AIC to choose the best fitting model. In step 1, we fit a model for all possible subsets of covariates (syllabus items and length of syllabus) and then we calculated the corresponding AIC for each model. In step 2, we carried out best subsets logistic regression using the syllabus items from the first step and the syllabus factors to obtain the final model. We compare our third model to the results of a stepwise logistic regression for the syllabus items, syllabus factors, and length of the syllabus.

3 Results

3.1 Research Question 1: To what extent is syllabi learner-centeredness related to opportunity gaps in STEM courses?

To address our first research question about the potential relationship between syllabi learner-centeredness and opportunity gaps, we examined the rubric scores assigned to syllabi and compared the groups (syllabi from course-instructor pairs with small and large opportunity gaps). Figure 2 shows that the total rubric score is significantly higher for the syllabi from the small opportunity gap group ($\Delta_{medians} = -3.00, p = 0.037$). In other words, the course-instructor pairs with small opportunity gaps tend to have more learner-centered syllabi.

3.2 Research Question 2: To what extent are specific syllabi characteristics related to these opportunity gaps?

The summary statistics of the thirteen individual rubric items, three factors, and length of syllabus for syllabi from course-instructor pairs with large and small opportunity gaps are presented in Table 3.

Table 3 Rubric summary statistics. The mean and median for each one of the rubric items, factors, and length of syllabus is provided for both small and large opportunity gap groups.

			Mean (SD)		Median (IQR)	
Factor	Item	Predictor	Large opportunity gap group	Small opportunity gap group	Large opportunity gap group	Small opportunity gap group
1		*Community*	1.90 (0.69)	1.91 (0.84)	2.00 (0.83)	2.00 (1.33)
	1	Accessibility of Teacher	1.83 (1.34)	1.96 (1.06)	2.00 (3.00)	2.00 (1.50)
	2	Learning Rationale	2.13 (0.69)	1.96 (0.52)	2.00 (1.00)	2.00 (0.00)
	3	Collaboration	1.74 (1.48)	1.81 (1.75)	3.00 (3.00)	3.00 (3.00)
2		*Power and Control*	1.72 (0.43)	2.07 (0.48)	1.60 (0.70)	2.00 (0.50)
	4	Teacher’s Role	1.57 (0.66)	1.52 (0.70)	2.00 (1.00)	2.00 (1.00)
	5	Student’s Role	1.22 (0.52)	1.81 (0.96)	1.00 (0.50)	2.00 (2.00)
	6	Outside Sources	1.70 (0.82)	2.15 (1.13)	1.00 (1.00)	2.00 (2.00)
	7	Syllabus Tone	2.30 (0.76)	2.56 (0.80)	2.00 (1.00)	3.00 (1.00)
	8	Syllabus Focus	1.83 (0.83)	2.30 (0.95)	2.00 (1.00)	2.00 (1.00)
3		*Evaluation/Assessment*	1.97 (0.34)	2.10 (0.56)	1.80 (0.50)	2.20 (0.50)
	9	Grades	2.00 (0.43)	2.04 (0.71)	2.00 (0.00)	2.00 (0.00)
	10	Feedback Mechanisms	2.30 (0.47)	2.30 (1.07)	2.00 (1.00)	3.00 (1.00)
	11	Evaluation	2.70 (0.47)	2.89 (0.93)	3.00 (1.00)	3.00 (1.00)
	12	Learning Outcomes	2.04 (0.98)	2.22 (0.89)	2.00 (2.00)	2.00 (1.50)
	13	Revision/Redoing	0.78 (0.80)	1.07 (0.92)	1.00 (1.00)	1.00 (2.00)
		Overall	1.86 (0.38)	2.05 (0.52)	1.85 (0.54)	2.08 (0.62)
		Length of Syllabus	4.91 (3.67)	4.85 (2.86)	4.00 (2.00)	4.00 (3.00)
		n	23	27	23	27

Table 4 presents the results of Model 1 which predicts the log odds of a syllabus coming from the small opportunity gap group modeled on the 13 syllabus items. When considering all of the individual syllabus items at once, none are significant in predicting which syllabi come from the small opportunity gap group.

Table 4 Model 1. Logistic regression with syllabus items and length of syllabus as covariates. The coefficients represent the increase/decrease in the odds of being in the small opportunity gap group for each of the 13 rubric items and length of syllabus as model 1 variables while holding the other variables constant.

	Exponentiated Coefficients	95% Confidence Interval for the Odds Ratio	Test Statistic	p-value
(Intercept)	0.31	(-0.52, 0.6)	-0.52	0.6008
Accessibility of Teacher	0.95	(-0.13, 0.89)	-0.13	0.8937
Learning Rationale	0.17	(-1.69, 0.09)	-1.69	0.0918
Collaboration	0.80	(-0.75, 0.46)	-0.75	0.4552

Teacher's Role	1.11	(0.14, 0.89)	0.14	0.8885
Student's Role	2.54	(1.59, 0.11)	1.59	0.1126
Outside Resources	2.14	(1.5, 0.13)	1.50	0.133
Syllabus Tone	1.59	(0.73, 0.46)	0.73	0.4641
Syllabus Focus	2.89	(1.45, 0.15)	1.45	0.1476
Grades	0.38	(-0.99, 0.32)	-0.99	0.3217
Feedback Mechanisms	1.06	(0.1, 0.92)	0.10	0.9231
Evaluation	1.46	(0.47, 0.64)	0.47	0.6399
Learning Outcomes	0.79	(-0.46, 0.65)	-0.46	0.6463
Revision/Redoing	1.68	(1.04, 0.3)	1.04	0.2968
Length of Syllabus	1.00	(-0.01, 0.99)	-0.01	0.9914
AIC = 79.71				

Table 5 presents the results of Model 2, the logistic regression model that predicts the log odds of a syllabus coming from a course-instructor pair in the small opportunity gap group based on syllabus factors and the length of the syllabus. This model shows that *Power and Control* is a significant predictor of a syllabus coming from a course-instructor pair from the small opportunity gap group; increasing the average *Power and Control* to be more learner-centered by 1 point is associated with 19.62 times increase in the odds of being in the small opportunity gap group.

Table 5 Model 2. Logistic regression with syllabus factors and length of syllabus as covariates. The coefficients represent the increase/decrease in the odds of being in the small opportunity gap group for each of the 3 rubric factors and length of syllabus as model 2 variables while holding the other variables constant.

	Exponentiated Coefficients	95% Confidence Interval for the Odds Ratio	Test Statistic	p-value	
(Intercept)	0.04	(0, 1.22)	-1.85	0.0645	.
Community	0.50	(0.16, 1.55)	-1.21	0.2266	
Power and Control	19.62	(2.36, 162.83)	2.76	0.0058	*
Evaluation and Assessment	0.98	(0.15, 6.58)	-0.02	0.9822	
Length of Syllabus	0.85	(0.65, 1.11)	-1.23	0.2198	
AIC = 67.64					

The best subset logistic regression ran every combination of syllabus items and length of syllabus for models with 1-14 predictors (a total of 16,383 possible models). The top 5 models (regressing the log odds of being in the small opportunity gap group on the subset of covariates) can be found in the supplementary materials (Table A4). The model with the lowest AIC has Learning Rationale, Students Role, Outside Resources, and Syllabus Focus included as covariates and is presented in Table 6.

Table 6 Model 3. The logistic regression model with the lowest Akaike Information Criteria (AIC) when considering syllabus items and length of syllabus was the one that included 4 rubric items (Learning Rationale, Student's Role, Outside Resources, and syllabus focus). The coefficients represent the increase/decrease in the odds of being in the small opportunity gap group.

	Exponentiated Coefficients	95% Confidence Interval for the Odds Ratio	Test Statistic	p-value	
(Intercept)	0.30	(0.02, 4.78)	-0.85	0.3935	
Learning Rationale	0.23	(0.06, 0.90)	-2.11	0.0345	*
Student' s Role	2.35	(0.93, 5.99)	1.80	0.0722	.
Outside Resources	2.12	(0.97, 4.63)	1.89	0.0582	.
Syllabus Focus	2.25	(0.91, 5.58)	1.75	0.0793	.
AIC = 61.64					

Out of all the syllabus items, the most significant predictors of the odds of the syllabus being in the small opportunity gap group are Learning Rationale, Student's Role, Outside Resources, and Syllabus Focus. If we consider syllabi from course-instructor pairs with the same rubric scores for Student's Role, Outside Resources, and Syllabus Focus, increasing the Learning Rationale is associated with a decrease in the odds of having a small opportunity gap. While only marginally significant (significant at the $\alpha = 0.10$ level), an increase in each of the rubric scores for Students' Role, Outside Resources, and Syllabus Focus to be more learner-centered is associated with greater odds of having a syllabus being in the small opportunity gap group. Not surprisingly, Students' Role, Outside Resources, and Syllabus Focus are all components of the *Power and Control* syllabus factor which we previously saw from Table 4 to be a significant predictor of the odds of being in the small opportunity gap group. We also note that a stepwise logistic regression yields the same model as the one found in Table 6.

Our final model results are presented in Table 7. The best subset logistic regression ran every combination from the previous step's model (Learning Rationale, Student's Role, Outside Resources, and Syllabus Focus) syllabus factors, and length of syllabus for models with 1-8 predictors (a total of 255 possible models). The top 5 models can be found in the supplementary materials (Table A4). The final model (the model with the lowest AIC) has two covariates (1) Learning Rationale, and (2) *Power and Control*.

Table 7 Model 4. The logistic regression with the lowest Akaike Information Criteria (AIC) when considering the syllabus items from Model 3 (Learning Rationale, Student's Role, Outside Resources, and Syllabus Focus), syllabus factors (*Community*, *Power* and *Control*, and *Evaluation/Assessment*) and length of syllabus. The coefficients represent the increase/decrease in the odds of being in the small opportunity gap group. The final model includes one syllabus item (Learning Rationale) and one syllabus factor (*Power and Control*)

	Exponentiated Coefficients	95% Confidence Interval for the Odds Ratio	Test Statistic	p-value	
(Intercept)	0.17	(0.01, 3.45)	-1.15	0.2492	
Learning Rationale	0.19	(0.05, 0.80)	-2.28	0.0229	*
Power and Control	1.75	(1.20, 2.54)	2.94	0.0033	.
AIC = 59.75					

Increasing Learning Rationale, while holding *Power and Control* constant is associated with a decrease in the odds of being in the small opportunity gap group. If Learning Rationale remains unchanged, but *Power and Control* is increased, there is a 75% increase in the odds of being in the small opportunity gap group. Overall, Learning Rationale and *Power and Control* are predictive of the odds of being in the small opportunity gap group.

4 Discussion

While considerable work is being undertaken to examine how to create more learner-centered classroom spaces in STEM learning spaces that are traditionally known for their "chilly climates", course syllabi have yet to be a significant part of this discussion. Syllabus design is a place where instructors can emphasize aspects of learner-centered pedagogy in STEM classes. This research identifies that the degree of learner-centeredness of a syllabus is related to student outcomes, particularly in the context of opportunity gaps.

Previous studies examined the extent to which a syllabus can be learner-centered to inform curricular and pedagogical change that can benefit student learning (Cullen & Harris, 2009; Richmond et al., 2019) and it has been demonstrated that active learning practices as part of a learner-centered pedagogy benefit minoritized students and correlate with reduced opportunity gaps (Theobald et al., 2020). The current study followed up these efforts by confirming a relationship between the learner-centeredness of a course syllabus and the size of the opportunity gap in that particular course-instructor pair (Figure 2).

Attending to syllabus design is a simple, yet potentially powerful, means by which instructors can make their courses more inclusive.

4.1 Association between Rubric Components and Opportunity Grade Gaps in STEM Courses

In addition to examining the extent to which syllabus learner-centeredness is related to opportunity gaps, we investigated which rubric components have the strongest relationship with course opportunity gaps. The *Power and Control* factor (the average of Teacher's Role, Students' Role, Outside Resources, Syllabus Tone, Syllabus Focus rubric items) showed significant association with course-instructor pairs with small opportunity gaps (Table 4). Further investigation showed that Student's Role, Outside Resources, and Syllabus Focus (three out of five items under the *Power and Control* factor) are mainly responsible for this finding. Higher scores for *Power and Control* represent syllabi that exhibit higher student responsibility when it comes to learning and generating knowledge, more use of outside resources for learning outside the classroom and independent investigation, and less focus on policies and procedures as opposed to course objectives and learning outcomes. Syllabi scores with higher scores for *Power and Control* are more likely to belong to STEM classes with small opportunity gaps.

These findings are in alignment with previous work. Recent research on the effectiveness of outside resources in engineering college classes shows that students find textbooks to be the least effective among the different types of resources provided to them because of textbooks' complexity and formality which makes them less accessible (Maclaren, 2018). However, external resources such as certain educational websites or material generated by the instructor are believed to be the most useful (Maclaren, 2018). The results of our study support these findings about the use of outside resources. Syllabi that mentioned providing resources other than the course textbook showed small associations with course-instructor pairs with small opportunity gaps. Providing additional resources may encourage greater active learning among students, as it may emphasize students' responsibility for investigation and learning and increase students' role in acquiring knowledge. In learner-centered classes, the student is actively involved in the process of learning instead of a one-way transfer of information from the instructor to students (Wright, 2011; Wulf, 2019). Our findings support the importance of increasing students' roles in STEM courses by asking students to take responsibility for bringing additional knowledge to class and valuing student-generated knowledge. Integrating strategies in the course syllabus that require students to play a more significant role in advancing their learning can increase the odds of having small opportunity gaps compared to syllabi in which students are told what they are responsible for learning.

Research also suggests that syllabi that focus on instructor generated rules instead of student learning can be perceived negatively by students, signaling "an adversarial relationship between instructors and students" (DiClementi & Handelsman, 2005, p. 19). Syllabi that sound "authoritative and rule-infested" may indicate a lack of shared power in the classroom and lead students to have an unfavorable perception of the course and instructor (Palmer et al., 2016, p. 37). This negative perception adversely affects the level of student engagement (DiClementi & Handelsman, 2005), which impacts student success in the classroom especially for minoritized students (Kuh et al., 2007). In contrast, syllabi that focus more on learning goals and outcomes instead of policies, and empower students by including them in decision making and giving them more choice, share power in the learning community. Such syllabi may promote a shift towards learner-centeredness to provide a more effective learning environment (DiClementi & Handelsman, 2005; Wright, 2011). The current study supports these inclusive practices, in that Syllabus Focus as an item in the rubric is marginally correlated with the odds of having small opportunity gaps. This means syllabi that focus on learning outcomes instead of policies and procedures might be more inclusive.

Another rubric item that had a significant association with rubric scores was providing a Learning Rationale for assignments, activities, policies and procedures while connecting them to the learning outcomes of the course. This item is negatively related to the size of opportunity gaps, with a higher Learning Rationale being correlated with larger opportunity gaps. This adverse effect might be related to the instructor's perception of students. If the syllabus is written with the assumption that students do not bring any previous knowledge, skills, or individual experiences to class and have no driving motivators, the inclusion of an extensive Learning Rationale in the syllabus may limit the student's agency and choice. According to Deci et al. (1994), "a rationale that is personally meaningful to the target person can aid him or her in understanding why self-regulation of the activity would have personal utility" (p. 124). It seems logical to suggest that providing a rationale for learning without changing the dynamic of power and control in a classroom is missing this key component of a "personally meaningful" connection to the course activities and material. Therefore, instructors cannot rationalize why it is important to learn a particular topic in a vacuum, but must provide opportunities for students to bring in their own experiences as well in order to have a more learner-centered environment.

4.2 Limitations and Future Directions

We acknowledge that the current study has limitations. The collected syllabi were all from a single institution, and one that enrolls nearly 30,000 undergraduates, is classified as an R1-institution by the Carnegie Classification of Institutes of Higher Education and is a federally designated minority-serving institution. It is possible that our findings are limited to course sections and syllabi found at similar institutions. Nevertheless, despite being a highly selective university, this institution is unique in that it also enrolls a significant number (nearly 50%) of first-generation and low income students, which are much more likely to be represented in less-research intensive universities or two-year institutions, thus making our findings more generalizable across a broader range of higher education institutions. Our claims regarding the learner-centeredness of a course are also limited to the course syllabus, which we use as a proxy for characterizing a course. This work did not leverage any other data from the instructor, course, or students for this characterization. That being said, it has been demonstrated that syllabi are significant artifacts that have been shown to drive student decisions in course selection (Kim & Ekachai, 2020). Our work also looks broadly across a variety of STEM courses and does not attempt to identify important syllabi characteristics in the context of specific STEM disciplines. We did this intentionally, as this work is a starting point for future studies, but must acknowledge that considerable research has highlighted that the climate can vary widely between STEM fields in terms of inclusion for females, minoritized students, or first-generation students (Almatrafi, 2017; Cheryan et al., 2017; Eddy & Brownell, 2016; Greene et al., 2010; Seyranian et al., 2018; Whitcomb et al., 2021). As a result, future work with more intentional disciplinary representation will be necessary to determine whether this is the case. From an institutional perspective, discipline or individual specific findings could also help to create more targeted feedback or training to particular departments or instructors.

5 Conclusion

In our study, we coded 50 syllabi from STEM courses using a modified version of the rubric developed by Cullen and Harris (2009) and expanded upon by Richmond et al (2019) and examined whether the rubric score is correlated with the size of the opportunity gap for particular courses. From this work, we found that more learner-centered syllabi, as coded by the rubric, did in fact correlate with course-instructor pairs that exhibited smaller opportunity gaps. In addition, we found that the *Power and Control* rubric factor also correlated with the opportunity gap size. There is a substantial reduction in the risk of having large opportunity gaps in courses whose syllabi have received a high score for the *Power and Control* factor.

The finding that syllabus learner-centeredness correlates with opportunity gaps has important implications for institutions of higher education that are aiming to increase inclusivity in their STEM programs in order to foster the success of all of their students. As opposed to much work aiming to solve this issue which focuses on "fixing" minoritized students (Harper, 2010; McGee, 2016), a syllabus is specific to a course section, as is the course climate that it serves as a proxy for. To help instructors in creating more learner-centered syllabi, it is vital that the appropriate professional development mechanisms are available to support them in this endeavor (Goos et al., 2007). It is also important to note that this type of support is distinct from many professional development practices that focus on particular instructor pedagogies (Ebert-May et al., 2011; Pelletreau et al., 2018), and that altering one's syllabus could serve as a gateway to enable faculty to reflect on their course policies and instructional practices and potentially adjust them to create a more learner-centered space. Institutions also must reward faculty for the time dedicated to participating in these activities. It is well-known that research-intensive institutions value research productivity over teaching-related activities, and that time spent on teaching is often discouraged (Hardre & Cox, 2009; Parker, 2008; Serow, 2000). It has also been acknowledged that the evaluation of teaching in general, and the reliance on student evaluations of teaching, often fails to capture instructor effectiveness to promote learning or create an inclusive climate (Boring & Ottoboni, 2016; Dewsbury & Brame, 2019; Radchenko, 2020). We propose that the steps taken in this work can be replicated for instructor merit and promotion processes, and that if scaffolded with the appropriate professional development activities, can be a means by which an institution encourages and rewards its instructors for better supporting their students.

6 Figures

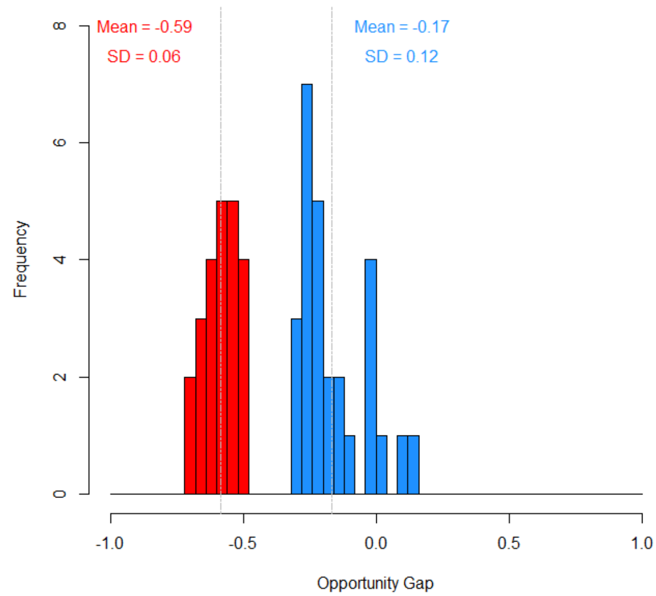

Figure 1 Histogram of the size of the opportunity gap for $n = 50$ course-instructor pairs. Red indicates syllabi in the large opportunity gap group. Blue indicates syllabi in the small opportunity gap group.

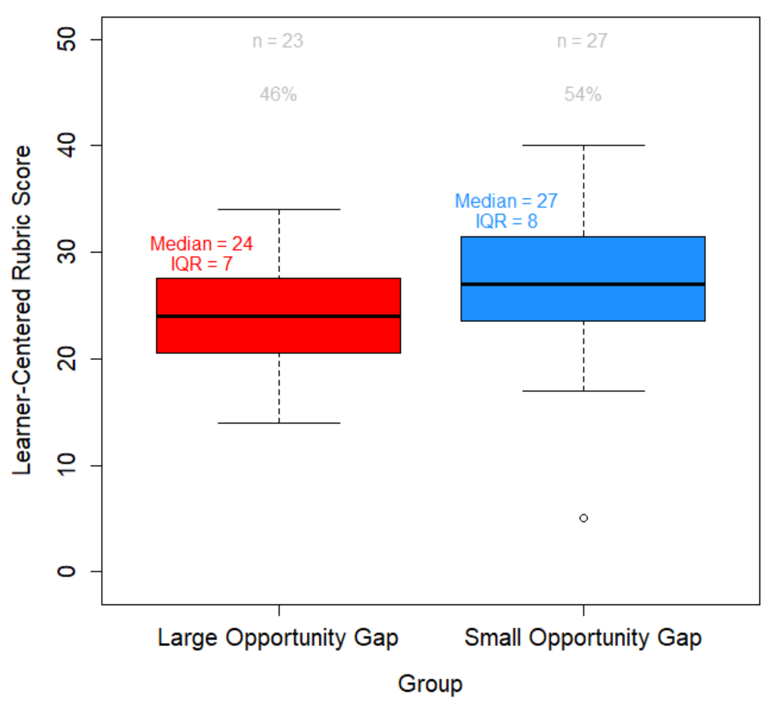

Figure 2 Boxplot comparing learner-centered rubric scores of the small opportunity gap group and the large opportunity gap group.

Appendix A Supplementary Information

A.1 List of Abbreviations

STEM Science, technology, engineering, and mathematics; **GP** Grade point; **IRR** inter-rater reliability; **AIC** Akaike Information Criteria

A.2 Supplemental Tables

Table A1 Correlation matrix for the rubric items

	Community			*Power and Control*					*Evaluation and Assessment*				
	Accessibility of Teacher	Learning Rationale	Collaboration	Teacher's Role	Student's Role	Outside Resources	Syllabus Tone	Syllabus Focus	Grades	Feedback Mechanisms	Evaluation	Learning Outcomes	Revision/ Redoing

Community													
AccessibilityOf Teacher	--	0.22	0.00	0.24	0.04	0.38**	0.20	-0.09	0.07	0.25	-0.01	-0.01	0.10
Learning Rationale		--	0.30*	0.40 **	0.18	0.25	0.13	0.24	0.38**	0.51**	0.41**	-0.11	0.37**
Collaboration			--	0.13	0.41**	0.27	0.10	0.13	0.32*	0.44**	0.70**	0.05	0.26
Power and Control													
Teacher' s Role				--	0.00	0.10	0.18	0.19	0.31*	0.11	0.16	-0.09	0.26
Student' s Role					--	0.21	0.03	0.35*	0.26	0.20	0.50**	0.09	0.20
Outside Resources						--	0.03	-0.10	0.14	0.42**	0.21	-0.08	0.35*
Syllabus Tone							--	0.42**	0.27	0.19	0.12	0.27	-0.10
Syllabus Focus								--	0.35*	0.16	0.21	0.57**	-0.01
Evaluation/ Assessment													
Grades									--	0.39**	0.48**	0.24	0.18
Feedback Mechanisms										--	0.50**	0.06	0.12
Evaluation											--	0.04	0.32*
Learning Outcomes												--	-0.17
Revision/Redoing													--

*p < 0.05. **p < 0.01

Table A2 Correlation matrix for rubric factors

	Community	*Power and Control*	*Evaluation and Assessment*
Community	--	0.51**	0.54**
Power and Control		--	0.55**
Evaluation and Assessment			--

*p < 0.05. **p < 0.01

Table A3 Interrater reliability after consensus. Weighted kappa provided

IRR After Consensus		
	weighted. Kappa	z.stat
Accessibility of Teacher	0.98	6.70
Learning Rationale	0.94	6.44
Collaboration	0.92	6.33
Teacher's Role	0.90	6.11
Student's Role	0.78	5.36
Outside Resources	0.96	6.60
Syllabus Tone	0.85	5.99
Syllabus Focus	0.95	6.51
Grades	0.82	5.65
Feedback Mechanisms	0.88	6.10
Evaluation	0.96	6.59
Learning Outcomes	0.99	6.77
Revision/Redoing	0.76	5.25
Average	0.90	
Length of Syllabus	1	6.86

Table A4 The top 5 models regressing the log odds of being in the small opportunity gap group

Step 1:					
	Model				
Covariate	A	B	C	D	E
Accessibility of Teacher	--	--	--	--	--
Learning Rationale	TRUE	TRUE	TRUE	TRUE	TRUE
Collaboration	--	--	--	--	--
Teacher’s Role	--	--	--	--	--
Student’s Role	TRUE	TRUE	TRUE	TRUE	TRUE
Outside Resources	TRUE	TRUE	TRUE	TRUE	TRUE
Syllabus Tone	--	--	--	--	--
Syllabus Focus	TRUE	TRUE	TRUE	TRUE	TRUE
Grades	--	--	TRUE	--	--
Feedback Mechanisms	--	--	--	--	--

Evaluation	--	--	--	--	--
Learning Outcomes	--	--	--	--	TRUE
Revision/Redoing	--	TRUE	--	--	--
Length of Syllabus	--	--	--	TRUE	--
AIC	61.64	62.41	62.75	62.90	62.94

Step 2:					
	Model				
Covariate	A	B	C	D	E
Learning Rationale	TRUE	TRUE	TRUE	TRUE	TRUE
Student' s Role	--	TRUE	--	--	--
Outside Resources	--	--	--	--	TRUE
Syllabus Focus	--	--	--	--	--
Community	--	--	TRUE	--	--
Power and Control	TRUE	TRUE	TRUE	TRUE	TRUE
Evaluation and Assessment	--	--	--	--	--
Length of Syllabus	--	--	--	TRUE	--
AIC	59.75	60.46	61.10	61.21	61.58

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Declarations

Availability of data and materials

All data generated or analyzed during this study are included in this published article [and its supplementary information files].

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Study conception and design: ME, KD, BKS, MD; data collection: ME, KD, JMS; rubric scoring: ME, JMS; analysis: KD; interpretation of results: ME, KD, BKS; draft manuscript preparation: ME, KD, BKS, MD, PC. All authors reviewed the results and approved the final version of the manuscript.

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Ethics approval and consent to participate

This study was approved by the University of California Irvine Institutional Review Board (IRB #2018-4211)

Consent for publication

The authors consent to publication.