Rethinking Single Variable Calculus for Life Sciences for Advancing Equity

Nandini Bhattacharya
University of California, Santa Cruz

Anna Sher
University of California, Santa Cruz

Calculus with Applications in the Life Sciences (Biocalculus) is an impactful and required course for all STEM majors at our institution, a large public university. A disproportionately high percentage of Latinx and students from low-income households (EOP) earn failing grades in this course. This study examines student learning outcomes and experiences based on project assessment (N=152) and student survey (N=130) to answer the following questions: (a) Did changing a course structure based on working within a teaching team change students' agency? (b) Did minoritized students achieve similar levels of conceptual understanding as their counterparts in the course, when the curriculum was designed with project-based learning situated within the teaching team? We found that the inclusive course structure provided minoritized students with a supportive environment and positively impacted their learning. We believe our specific implementation can be helpful to many large public universities with diverse student populations and relatively limited resources.

Keywords: Biocalculus, Teaching Team, Equity, Project-based Learning

Given the rise in the number of Hispanic Serving Institutions (HSIs) nationally, studying the impact of how we improve teaching calculus courses is of high priority. Equitable outcomes can be obtained by increasing the number of successful STEM majors among Latinx students and students from low-income households (broadly referred to as minoritized students). This course redesign project was implemented at a large research university, an HSI. As part of redesigning of the Biocalculus series, faculty worked closely with graduate student researchers (GSRs) in the summers of 2021-2024. We benefited from using their expertise to design eight authentic applied projects in the areas spanning from chemical reaction kinetics (for chemistry) to the Alee effect model (ecology and evolutionary biology) to delve deep into studying modeling (logistic and exponential models) and analyzing observations with conclusions. The GSRs also developed authentic section worksheets, aligned with the lectures and the projects' mathematical learning goals. The creativity of this approach accessed the elements of equity-focused design that helped undergraduate students showcase their strength in diverse forms of assessment where learners' agency was high because of the immediate cross-disciplinary applications (O'Brien & Reale, 2021) and alignment of students' motivations to learn the mathematics behind the science (Lee et al., 2014). It also impacted the graduate students' training as future faculty/team leaders, where they received close mentorship on aligning learning outcomes of concept(s) with authentic assessment and teaching material for better transparency and access within a learning community.

Theoretical Frameworks

Our course redesign project relied on two theoretical frameworks, Significant Learning by Fink (2013) and Backward Design (Wiggins & McTighe, 1998), both focused on achieving better transparency and equitable outcomes.

Fink's Significant Learning framework purposely engages students in six domains that are more likely to produce learning that endures well beyond the end of a course (Figure 1). The

domains relevant for our project are Foundational Knowledge - representing information and ideas; Application - developing skills, critical and creative thinking; Integration - connecting ideas (and people) using skills and content; Human Dimension - addressing learning about oneself and others; Caring - developing new feelings, interests, and values; and Learning How to Learn - promoting self-direction and metacognition. The Significant Learning framework was explicitly chosen to establish enduring learning in the calculus series as a motivator for long-lasting knowledge in the downstream science classes using the student's agency to learn the material as a dominant motivator.

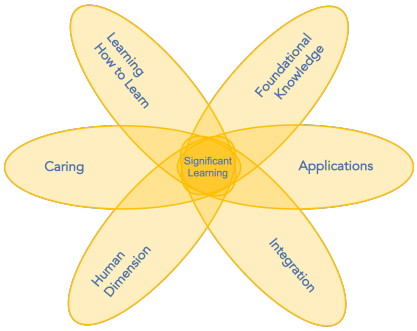

Figure 1. Significant Learning (adapted from Fink, 2013)

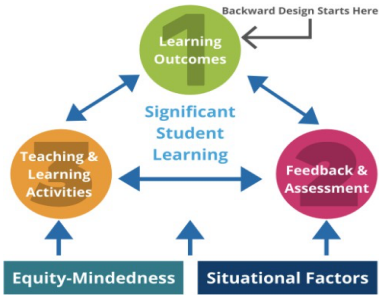

Figure 2. Backward Design (adapted from Wiggins & McTighe, 1998)

Wiggins & McTighe's Backward Design Model for equity-mindedness encompasses teaching with transparency and goal orientation (Figure 2). Since enrollment for these courses is very large (~200-500 students), establishing an alignment with teaching goals, diverse assessment types, and teaching and learning practices is imperative to achieve equitable outcomes (Garcia, 2019; Yosso, 2005). The extensive teaching team, consisting of the instructor of record, graduate teaching assistants, undergraduate tutors, and supplemental instructional team, can share a guideline for how each week progresses. Consistent instruction and messaging become more seamless once we approach the task as a team (Kerr & Samuels, 2019). Creating a sense of belonging for the students is inherent to the value held by the community, which is collaborative and reflective of the instructor's values, with the hope of changing the perception of the courses from a weeder course to a course that launches STEM students into their majors (Bhattacharya et al., 2020).

Course structure in Biocalculus for Equity

The core value of the course design was based on collaborative norms and practices.The design elements promoted a teaching team approach that integrates learning in a discussion section with large lecture experience. The course curricula aimed to develop a coherent conceptual understanding of calculus that is authentically contextualized in sciences and used metacognitive activities using reflections and other similar tools for frequent formative assessments (Cizek, 2010; Ruiz-Primo, et al., 2010) that help students become better STEM learners (so that students cultivate a sense of belonging and STEM identity). The course redesign structure is described next.

Standardized delivery of the course content (ADA compliant) includes articulating learning goals and aligning them with diverse assessments across various topics to provide all students with similar experiences in learning calculus using Canvas and Gradescope as the primary technology tools. The course learning cycle is structured by giving primary material using videos

or otherwise (Modules) to create collaborative problem-solving opportunities during lectures to develop an active learning setting. After the lecture, students worked with their TAs and tutors on worksheets relevant to the mathematical concept (calculus content) contextualized in real-world applications (precursor to the project questions). An online question bank was created using open-stack resources organized by topics (and learning outcomes), using the weekly learning outcomes of the course to better align with the lecture (and also cut costs drastically for students) and provide essential metacognitive questions/activities (reflection questions) to help students become self-regulated learners (Ambrose et al., 2010). We provided students with various formative assessment tools to develop themselves as STEM learners and to promote equitable outcomes for different types of learners.

Above all, before the beginning of the academic year, every teaching team member (graduate TAs, undergraduate tutors, supplemental instructors, and instructors of record) received professional development to work in this new framework of an inclusive teaching model, prioritizing equitable outcomes. The professional development space opened a purposeful dialogue (Alexander, 2008) to help create alignment across all teaching and learning platforms, where teaching team members with different positions and knowledge of the curriculum helped make a scaffolded learning space. The teaching team met weekly to plan and address all emerging issues to address every student's success. We hypothesized that a team-based course structure that helps create a community allowed minoritized students to ask questions. The culture of problem-solving that is dialogic is the key to promoting a sense of belonging in STEM. Achieving equitable outcomes in the Biocalculus series courses will help retain a diverse student body in STEM majors, ultimately one of our institution's (and the nation's) primary goals for this decade. An institutional culture of commitment grounded in inclusivity rather than selectivity (obstruction) promotes success among URM STEM students (Chang et al., 2014).

Methods

This study included students in the Biocalculus course taught in Spring 2024, the third quarter of the academic year. A relatively large class (N=152) was diverse in academic and demographic backgrounds. Specifically, just over a third (36%) of the class were students from low-income family backgrounds (referred as EOP students). Hispanic/Latinx students constituted a third of the class, as did White, non-Hispanic students. Of note, Hispanic/Latinx students were significantly more likely to be from low-income households than their White, non-Hispanic peers: 64% of Hispanic/Latinx and 11% of White, non-Hispanic students in this course were EOP students (X^2 (df=1, N = 110) = 32.9, p < .001).

Most students (84%) were in their first year of college, and 60% intended to major in Biology-related fields. There were statistically significant differences in students' academic achievement in the first two quarters (before taking this course): Hispanic/Latinx and EOP students had significantly lower cumulative GPAs than White, non-Hispanic students and non-EOP students, respectively (Table 1).

Table 1. Cumulative GPA at the enrolled institution by socioeconomic background (EOP) and race/ethnicity

	EOP (n=58)	non-EOP (n=105)	Hispanic/ Latinx (n=56)	White, non-Hispanic (n=54)
Mean	2.88	3.09	2.79	3.26
Std. Dev.	0.55	0.66	0.55	0.62
t-test	t(161)=-2.07, p<.05		t(108)=-4.19, p<.001	

To address the first research question, *Did changing a course structure based on working within a teaching team change students' agency?,* we used a student survey developed by the University of California Santa Cruz Assessment for Learning Excellence and Equity Center (ALEEC). The survey measures students' learning experiences in a collaborative course setting, including series of questions about student attendance and engagement during the section, reflections on the helpfulness of the section, and a sense of belonging to a community of peers. These questions were developed based on multiple studies of course- and program-learning outcomes and student focus groups. Distributed by ALEEC as a confidential, online survey at the end of the course, the survey yielded an 80% response rate and a representative sample. Survey data was merged with the demographic information, deidentified, and analyzed to examine group differences based on demographic backgrounds. We strive to provide actionable results and conduct equity analyses by focusing on specific, conceptually important points of difference (Sher & Sung, 2020). For example, students' responses about the helpfulness of attending section were collected on a 5-point scale and then dichotomized to focus on the distinction between students who indicated a moderate to high level of helpfulness (*somewhat helpful, helpful or very helpful*) vs. a low level (*a little* or *not at all helpful*). This approach allows us to report group-specific results in percentages and compare groups using Chi-square analyses. In addition, we developed an overall measure or construct for a sense of belonging to a community of peers and used t-test for examining group differences.

A rubric-based assessment was conducted to address the second research question, Did minoritized students achieve similar levels of conceptual understanding as their counterparts in the course when the curriculum was designed with project-based learning situated within the teaching team? After students uploaded their projects into Canvas, TAs used a criteria-based rubric developed by the faculty to evaluate students' skills as part of grading in Gradescope. Each specific skill was measured with four defined levels of proficiency, ranging from full proficiency (fully and correctly answered), general proficiency (minor mistakes), partial proficiency (major mistakes or omissions), to limited/no proficiency (completely incorrect or not attempted). Similarly to our work with the survey data, the rubric assessment data was extracted and merged with the demographic information, deidentified, and analyzed to measure skill-specific levels of achievement and examine significant group differences using Chi-square analyses (Sher & Sung, 2020).

Results

The survey allowed us to examine several measures of students' agency and belonging to a community. Students' attendance was very high for both lectures and discussion section. The majority (74-75%) attended most (at least 70%) lectures and section meetings. This high attendance reflects the team-based course structure and is atypical in such large courses. Most importantly, there were no differences in attendance between minoritized students and their counterparts.

Because the course redesign gave special attention to improving students' experience in the discussion section, the survey asked students about section's helpfulness for their learning. For most students, experience in section was moderately to very helpful. Notably, 80% of Hispanic/ Latinx students reported that a TA-led section helped them complete homework assignments, compared to 70% of White, non-Hispanic students (this difference did not reach statistical significance). Nearly three-fourths of Hispanic/Latinx students reported that their participation in section helped them prepare for exams; in this aspect, the activities in section were somewhat more helpful for Hispanic/Latinx students than their White, non-Hispanic peers (X^2 (df=1, N =

86) = 3.35, p = .067). Another important finding is that nearly 70% of Hispanic/Latinx students found their experiences in section helpful for feeling more comfortable in this class, and they were similar in this regard to their classmates. See Figure 3.

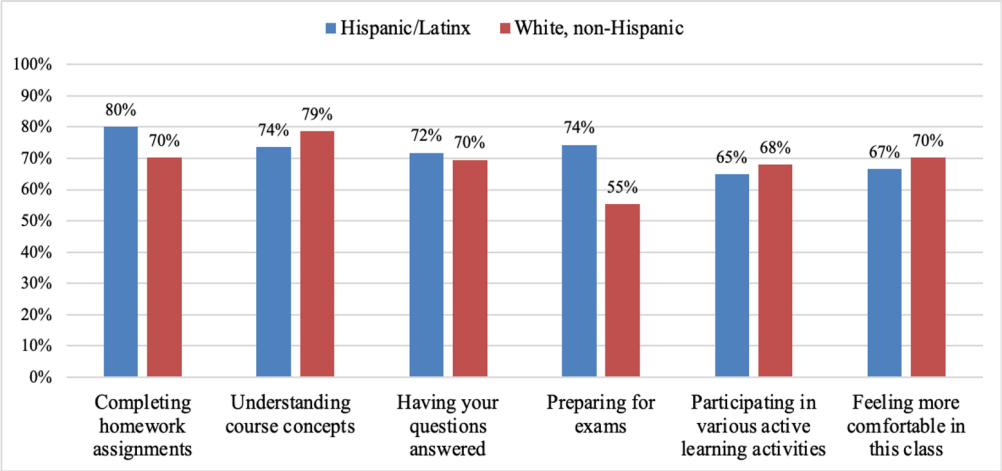

Figure 3. Equity analyses of section's impact on learning by race/ethnicity (percent of somewhat helpful to very helpful)

In addition, 65-71% of students from low-income backgrounds reported positive experiences in the section that helped them complete homework, understand course concepts, and have their questions answered. Of note, just over half (57%) of EOP students thought that their participation in the section helped them prepare for exams and for active learning activities in class (as a group, they were not significantly different from their peers). Also, just over half of EOP students indicated that section was at least somewhat helpful for feeling more comfortable in the class, which was significantly lower than 73% of non-EOP students (X^2 (df=1, N = 128) = 4.22, p < .05). See Figure 4.

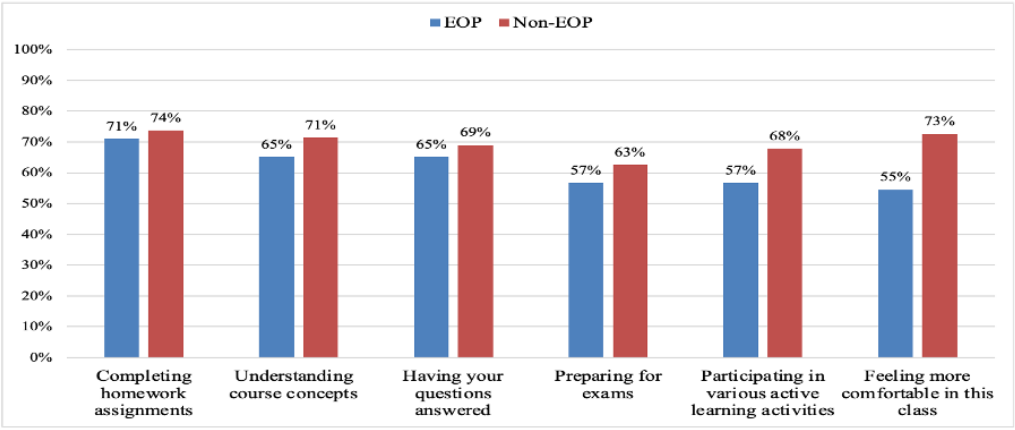

Figure 4. Equity analyses of section's impact on learning by socioeconomic background (percent of somewhat helpful to very helpful)

Such a multifaceted positive impact of the discussion section on student learning was likely possible thanks to the positive and inclusive environment created by trained graduate student TAs. When asked directly about feeling welcome and supported in section, most (89-90%)

students, including minoritized students, somewhat to strongly agreed that they felt welcome and supported, without any statistically significant differences between groups.

Another series of questions focused on students' relationships with other students in their class, designed to measure their feeling of belonging to the community of peers. In this class, most students reported high levels of connectedness to peers: the vast majority (80-86%) said that they *probably* or *definitely* had a student they could talk to, reach out for help, and share if they struggled academically. Most (87%) felt that students in this class could ask questions or give wrong answers without feeling judged by other students. As many as 70% of students reported having *probably* or *definitely* made meaningful connections with other students in this class. See Figure 5.

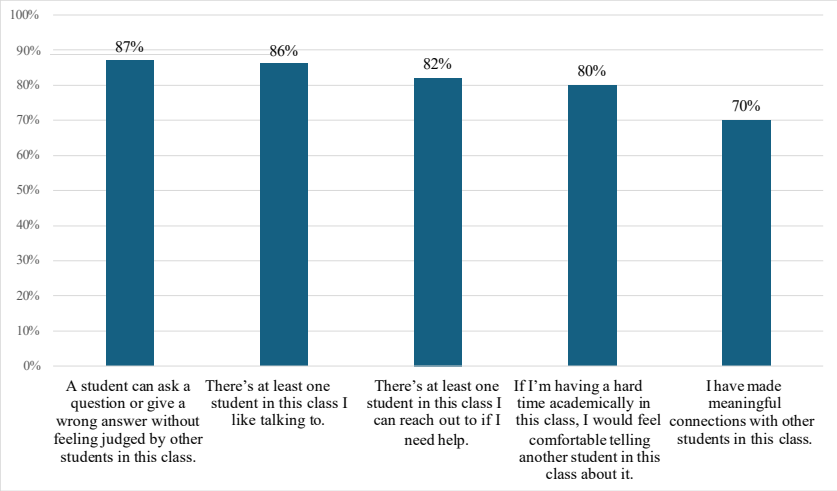

Figure 5. Students reporting belonging to the community of peers (percent of probably yes to definitely yes, based on the entire class)

We found that minoritized students experienced similarly strong belonging within the community of peers using two approaches to compare groups: (1) an overall measure or a construct based on the average across the five items on a Likert-like scale[1] (Cronbach's alpha=0.91), and (2) item-specific responses, analyzed with a focus on the more definitive responses (*yes* or *definitely yes* vs. other responses). Table 4 shows the overall measure of belonging for minoritized groups of students and their peers based on socioeconomic status and race/ethnicity.

Table 4. Equity analyses of the overall belonging to the community of peers by socio-economic background (EOP) and race/ethnicity

	EOP (n=43)	non-EOP (n=77)	Hispanic/ Latinx (n=38)	White, non-Hispanic (n=45)
Mean	4.33	4.45	4.37	4.63
Std. Dev.	1.20	1.12	1.08	0.99
t-test	$t(118)=-0.58$, $p=.56$		$t(81)=-1.15$, $p=.25$	

[1] Survey question: "Based on your interactions with other students in this course, how true are the following statements?" Responses are on a 6-point scale: 1=Definitely not, 2=No, 3=Probably not, 4=Probably yes, 5=Yes, 6=Definitely yes.

One of the major learning assessments was a project designed for students to demonstrate their conceptual understanding of rate of change in the biological context. We evaluated students' proficiencies in four related skills/concepts using a criteria-based rubric with four levels of proficiency, ranging from *full* to *limited or no* proficiency. Our faculty consider that expected proficiency in a specific skill is achieved by the whole class or specific group when close to 75% or higher percentage of students demonstrate *general* or *full* proficiency. In this class, most students (91-98%) demonstrated *general* or *full* proficiency in each of the measured skills (Table 5). Equity analyses showed that both minoritized students and their peers demonstrated high levels of proficiencies in each skill. Moreover, about 70% of minoritized students demonstrated *full* proficiency in estimating the instantaneous rate of change using the dataset (Skill 3), and in explaining the differences in the estimations and interpreting observed change using calculus in context (Skill 4).

Table 5. Results of project-based assessment of students' conceptual understanding of rate of change (N=152).

Skills and concepts:	Full proficiency	General proficiency	Partial proficiency	Limited or no proficiency
1. Interpret the average rate of change using an experimental dataset	82%	9%	1%	8%
2. Interpret reaction rate in the context of the problem	84%	12%	3%	1%
3. Estimate the instantaneous rate of change using the dataset	69%	29%	1%	1%
4. Explain the difference in the estimations and interpret observed change using calculus context	77%	18%	1%	4%

Discussion

Our study evaluated the impact of a redesigned course on student agency and conceptual understanding in the first course of the Calculus series for Life Sciences. We used direct assessment of project-based learning and a student survey to measure how minoritized students responded to a teaching team structure and frequent formative assessments aligned with learning goals. We found that all students, including Hispanic/Latinx and EOP students, demonstrated high levels of engagement and learning in an inclusive community of peers supported by a teaching team. While many minoritized students found discussion sections taught by trained graduate student TAs helpful for various aspects of their learning and social experiences, some students from low-income backgrounds still need more support to feel comfortable in a calculus class. Ultimately, our work hopes to add value to the national efforts to achieve equity in student math preparation for pursuing STEM fields by reimagining the role of the teaching team within a learning community, fore-fronted with equity-minded assessment structure using projects. We believe our specific implementation can be helpful to many large public universities (such as ours) with diverse student populations and relatively limited resources.

Acknowledgments

This work was supported by the Graduating and Advancing New American Scholars (GANAS) grant, a Career Pathways HSI Title V project.

References

Alexander, R. J. (2008). *Towards dialogic teaching: Rethinking classroom talk* (4th ed.). Dialogos.

Ambrose, S. A., Bridges, M. W., DiPietro, M., Lovett, M. C., & Norman, M. K. (2010). *How learning works: Seven research-based principles for smart teaching.* Jossey-Bass.

Bhattacharya, N., Sánchez Ordaz, A., Mosqueda, E., & Cooper, C. R. (2020). Redesigning the gateway college Algebra course with inclusive and asset-based pedagogy: Rethinking "servingness" at a Hispanic-Serving Institution. In G. Garcia (Ed.), *Practice: Defining "servingness" at HSIs* (pp. 97-116). Information Age Publishing.

Chang, M. J., Sharkness, J., Hurtado S., & Newman, C. (2014). What matters in college for retaining aspiring scientists and engineers from underrepresented racial groups. Journal of Research in Science Teaching, *51*(5), 554-580 *Journal of Research in Science Teaching*, *51*(5), 554-580.

Cizek, G. J. (2010). An introduction to formative assessment: History, characteristics, and challenges. In H. L. Andrade & G. J. Cizek (Eds.), *Handbook of formative assessment*. Routledge.

Fink, L.D. (2013). *Creating significant learning experiences: An integrated approach to designing college courses*. Jossey-Bass.

Garcia, G. A. (2019). *Becoming Hispanic-serving institutions: Opportunities for colleges and universities*. Johns Hopkins University Press.

Kerr, E. F., & Samuels, M. (2019). Using graduate and experienced undergraduate students to support introductory courses. In S. Kradtap Hartwell & T. Gupta (Eds.), *From General to Organic Chemistry: Courses and curricula to enhance student retention*. ACS Publications.

Lee, J. S., Blackwell, S., Drake, J., & Moran, K.A (2014). Taking a leap of faith: Redefining teaching and learning in higher education through project-based learning. *Interdisciplinary journal of problem-based learning*, *8*(2), 19-34.

O'Brien, E. & Reale, J. (2021). Supporting learner agency using the pedagogy of choice. Unleashing the power of learner agency. In S. Hase & L. M. Blaschke (Eds.), *Unleashing the power of learner agency*. https://edtechbooks.org/up/choice

Ruiz-Primo, M. A., Furtak, E. M., Ayala, C., Yin, Y., & Shavelson, R. J. (2010). Formative assessment, motivation, and science learning. In H. L. Andrade & G. J. Cizek (Eds.), *Handbook of formative assessment*. Routledge.

Sher, A., & Sung, P. (2020, November 18-20). *Translating assessment findings to improve equity in learning outcomes* [Conference presentation]. 45th Annual Conference for California Association for Institutional Research (CAIR). https://cair.org/wp-content/uploads/2021/01/REVISED-Sher-Sung-Translating-Assessment-Findings-to-Improve-Equity.pdf

Wiggins, G. & McTighe, J. (1998). *Understanding by design* (1st ed.). Association for Supervision and Curriculum Development. Yosso, T. J. (2005). Whose culture has capital? A critical race theory discussion of community cultural wealth. *Race Ethnicity and Education*, *8*(1), 69-9