Using Institutional Data to Identify and Address Educational Inequities in STEM

1. Overview

Students enrolling in higher education have become increasingly diverse but not all students have an equal opportunity to earn their degree. Students with historically marginalized genders, races, and ethnicities receive lower grades in science, technology, engineering, and mathematics (STEM) courses (Whitcomb et al., 2021), are more likely to switch from a STEM to a non-STEM major (Riegle-Crumb et al., 2019), and are less likely to earn a STEM degree than their majoritized peers (National Science Board, 2021). In parallel, researchers have increasingly more access to universities' institutional data and student learning data, offering unprecedented insight into student outcomes. Historically however, institutions have not leveraged their data for diversity, equity, and inclusion purposes (Peters, 2020), despite being in a central position to do so (Felix et al., 2021) and research into the presentation of learning data has "neglected" diversity, equity, and inclusion (Williamson & Kizilcec, 2021). Thus, there is a significant opportunity to use institutional data for understanding and addressing equity gaps across the curriculum in higher education. Yet, there are significant barriers around assessing, analyzing, and interpreting institutional data for equity that prevent large scale adoption. There is then a critical need to develop data analysis infrastructure specifically designed to analyze a department's current state of equity that could solve this problem and lower the barriers for institutions to identify and address DEI issues. Failure to act means that inequitable STEM environments will remain the norm, pushing out promising STEM students, resulting in lost economic opportunities for students and an insufficient number of STEM graduates to support the nation's needs (Holdren & Lander, 2012).

Our long-term goal is to take a data-driven approach to shrinking equity gaps with STEM. **The overall objective of this proposal, which represents the next step in obtaining our long-term goal, is to further develop our prototype departmental equity report and assess its potential in aiding departments to identify and close equity gaps**. Our central hypothesis is that providing departments with relevant equity data they could not easily obtain and analyze themselves will allow them to identify existing equity gaps in their courses and programs that they were not previously aware of and prompt action on closing them. This hypothesis is based on departmental leadership's reactions to our prototype departmental equity report (see section 6) and our theory of change (section 5). Our rationale is that without relevant, population-level equity data, departments must rely on fragmented or anecdotal data to determine the state of equity within their programs. With our data, departments will be able to pin-point areas of inequality across their programs that they would not otherwise and begin to take action to close these gaps. We are well-prepared to undertake the proposed research because of our previous use of equity data to drive change at the individual course level and research on how faculty respond to such data (section 6). Our university has also created extensive infrastructure for institutional data analysis for faculty and staff allowing for straightforward access to institutional data (Lonn & Koester, 2019).

We plan to test our central hypothesis and attain the objective of this proposal by pursuing the following specific aims:

1. Develop a departmental equity report that could be broadly deployed at higher education institutions to analyze inequities within STEM departments
2. Develop knowledge about existing equity concerns in STEM departments and how faculty expect data might be able to help close equity gaps
3. Understand how departmental actors interpret and respond to data highlighting persistent equity gaps within their sphere of influence.

Our proposed project is creative and original because while various institutions have developed internal and faculty-facing platforms to understand outcomes within single courses (see section 4), conducting such analysis across courses remains an area of open inquiry. This proposal is transformative because providing easy access to concrete measures of equity would allow for departments to treat equitable learning outcomes as a standard of educational quality in the same way that departments

currently use citations and external funding as measures of research productivity. We anticipate that the completion of these aims will result in increased knowledge about how learning analytics can support DEI efforts and what design and faculty support factors are necessary for future learning analytics efforts to be successful in doing so. This project will also result in a series of analyses that could be deployed at other institutions of higher education to assess equity within their programs. More broadly, this proposal opens new opportunities for learning analytics to contribute to DEI efforts and lowers the barriers for departments to enact data-informed DEI-related changes.

2. Intellectual Merit

We will develop an automated series of analyses that could be broadly deployed at higher education institutions. These analyses, along with supporting text, will constitute an automated *departmental equity report* that supports identifying and prompting action on inequalities within STEM departments. This goal will be accomplished through a series of focus groups with STEM departmental leadership, think-aloud interviews with STEM faculty and staff reading through the reports developed through the analyses, and surveys to assess longitudinal impact of STEM faculty and staff using the reports. Alongside these research activities, this proposal will accelerate development of our prototype of the departmental equity reports, allowing for interactivity and the ability to add in custom departmental data. The expected outcomes are 1) an automated series of analysis that can be deployed across departments and institutions to identity and prompt action on inequities in STEM, 2) an evidence base supporting the use of institutional data for identifying and acting upon inequities within STEM, 3) deeper knowledge about the DEI knowledge and experience STEM faculty bring when working with and interpreting DEI data, and 4) increased knowledge about how the visualization of such data influences how viewers make sense of the underlying data, leading to a series of best practices for developing analyses and visualizations to identify and prompt action on DEI issues.

3. Review of Relevant Literature

College students are more diverse with respect to racial and socioeconomic background compared to their predecessors (U.S. Department of Education, Office of Planning, Evaluation, and Policy Development and Office of the Under Secretary, 2016). Given broader changing demographics in the United States population, an increasingly diverse student body will remain the norm for institutions of higher education. However, the American education system does not support all learners equally. Instead, the history of the United States has been characterized by disparities in educational attainment (National Academies of Sciences, 2019). Higher education was designed for white men from affluent families and there have not been sufficient changes to support all students, especially within STEM. Racially and ethnically minoritized students earn lower grades in courses (Denaro et al., 2022) and students who are marginalized along multiple axes (such as socioeconomic status and continuing generation status) suffer an even greater penalty, both in STEM and non-STEM courses (Whitcomb et al., 2021). Research has also found that women are more likely than men to drop STEM majors, even if they have comparable grades to men who persist (Maries et al., 2022). In terms of degree attainment, many STEM areas have not reached gender parity in terms of degree awarded, with fields such as physics, engineering, and computer science stagnating at around 20% of degrees awarded to women (American Physical Society, 2021) and an even smaller percentage of degrees awarded to Black, Latinx, and Indigenous students.

At the same time, equity and excellence are “inextricably entwined” (The Boyer 2030 Commission, 2022). Across the world, the highest performing educational systems combine both high quality and equity (OECD, 2012) and within STEM, improved equity and representation in science can lead to better science, enriched societal benefits, and an improved workforce environment (Graves et al., 2022). At the individual level, STEM degree holders earn more than non-STEM degree holders and STEM employment continues to grow at a faster rate than employment in other occupations (National Science & Technology Council, 2018). More broadly, the national benefits of STEM cannot be realized without equitable access to and equitable pathways through STEM education (National Science & Technology Council, 2018).

As these inequities are the result of outcomes across individual departments and institutions, addressing these broader challenges requires reforms across many individual contexts. Providing departmental data can then inform faculty and staff about how these national inequitable trends play out in the local context where faculty and staff can intervene. Collecting data on student outcomes is a "critical first step" for engaging in equity conversations (McNair et al., 2020) and can dispel anecdotal myths about students (Shepard et al., 2021). Even if faculty are aware of national trends, they may not believe they are occurring within their local environment without such data (Dancy & Hodari, 2022). Seeing such equity gaps can then potentially prompt action to close them.

While using institutional data at higher education institutions to identify inequitable outcomes is not a new idea (Bauman, 2002), using such data to guide institutional reforms is a more recent phenomenon (Fischer et al., 2020). Universities regularly collect information about student course enrollments, course outcomes, majors, degree outcomes, demographics, test scores, and prior educational experiences. Insights from these data are often presented in dashboards for the university community. While dashboards have been extensively researched in the learning analytics literature, using them for the purpose of diversity, equity, or inclusion remains an underutilized application (Liu et al., 2021; Williamson & Kizilcec, 2021), prompting calls for greater research into the intersection of equity and advanced data analytics (Stephenson et al., 2022). As these "macro-level" data form a comprehensive and longitudinal picture of the students' progression through the university (Fischer et al., 2020), analyzing such data offers the unprecedented ability to understand inequities in course and degree outcomes at scale.

Despite the potential of using institutional data to advance equity, there are numerous challenges to realizing this potential. First, higher education institutions have been characterized as resistant to innovation and innovations to improve higher education often fail because they do not engage a sufficient number of users or gain institutional support (S. B. Wise et al., 2022). Problems such as these have led scholars to characterize changing higher education as a "wicked problem" due to the impossibility of gaining complete knowledge of the situation, a large number of stakeholders involved, large economic burdens in addressing problems, and an interconnected nature of the problem to other broader societal issues (Kolko, 2012). Yet, by framing student success in higher education as a wicked problem, potential solution paths emerge: solutions to the problem of inequities with STEM departments are not constrained to strategies that will have a direct impact on student learning and persistence and can, instead, include solutions that take into account the institution's practices and occur across units (Bass, 2020). Indeed, current evidence-based change approaches such as Departmental Action Teams and DeLTA, which use teams of faculty, staff, and students make sustainable changes to address a specific departmental problem, often do not focus directly on student learning and persistence, but rather, larger structural issues within individual departments and the institution as a whole that affect learning and persistence (Andrews et al., 2021; Ngai et al., 2020).

Second, using analytics to improve student equity requires a comprehensive institutional approach and a range of sophisticated strategies and practices (Stephenson et al., 2022). As such, there are significant barriers of entry for universities and departments to engage in this work (Amida et al., 2022; Brown et al., 2022; Knaub et al., 2016). At the institutional level, barriers include 1) limited availability of useful data, 2) a lack of sufficient documentation on how to use the data that does exist, 3) the busyness of analytics staff to assist with data, and 4) a lack of process and strategy around data. At the individual level, barriers include 1) not knowing the data exist, 2) a lack of familiarity with analyzing educational data, 3) limited data literacy, and 4) a lack of time to conduct such analyses. Through the use of pre-made, automated analyses created by experts in educational data analysis, data science, and equity, many of these barriers could be eliminated. Yet, if analyses are not performed and communicated carefully, they can be used to reinforce stereotypes and justify incorrect beliefs (McNair et al., 2020), exacerbating rather than ameliorating inequities in higher education.

Third, once the data are obtained and analyzed, the presentation of the data can have a significant impact on how the results are interpreted. Readers will immediately scan titles, text, and labels (Borkin et

al., 2016) and pull general statistics from positions, lengths, areas, slopes, and intensities (Szafir et al., 2016), informing initial perceptions of the data. Putting white or male as the first option in a legend can imply these are the default groups that everyone else should be compared to (Schwabish & Feng, 2021). The type of chart matters too; multi-category bar charts are less likely than line charts to cause viewers to confuse correlation and causation (Xiong et al., 2020). Moreover, there is evidence that charts can be more effective for persuasion when viewers do not have strong initial attitudes about the topics but tables can be more effective when viewers do have strong initial attitudes in opposition to the message of the visualizations (Pandey et al., 2014).

Fourth, conventional data visualization approaches may not be suitable for visualizing equity data. Depicting inferential uncertainty, such as confidence intervals, can cause viewers to underestimate variability in individual outcomes compared to depicting outcome uncertainty with prediction intervals (Hofman et al., 2020). Furthermore, when viewers saw visualizations that hide with-in variability, they were more likely to agree with personal explanations for the differences observed in the data compared to when they saw visualizations that emphasized with-in group variability (Holder & Xiong, 2022). Even when viewing the same bar graph visualization, viewers had various ideas about what the possible distribution of the underlying data could be, including that bars of different lengths to mean the data itself had little or no substantial overlap (Wilmer & Kerns, 2022). In the context of equity-focused data visualizations, we expect these incorrect interpretations could cause readers to incorrectly assume a deficit perspective where something intrinsic about the students is the cause of observed differences in the data (and hence, the students need to be fixed) rather than a systematic issue in which the classroom, department, or institution needs to be fixed.

Fifth, even if data are interpreted correctly, various cognitive biases might prevent faculty from taking action on observed inequities. This is important because the persuasiveness of data visualizations depend on the initial attitudes of the participant (Pandey et al., 2014). The fundamental attribution error states that readers will overplay dispositional factors and downplay situational factors when explaining an outcome (Ross, 1977), suggesting that readers might interpret equity gaps as the result of the individual's actions and beliefs rather than systematic factors. Second, readers may suffer from an anchoring effect where they focus too heavily on one piece of information to make a decision, which is known to occur with visual analytics (Cho et al., 2017). Next, viewers might trust the accuracy of data less when other people's expectations align with their own expectations rather than with the data show (Kim et al., 2018), which could be potentially problematic when changes require input and commitment from multiple members of the department. When readers encounter data that goes against their expectations, they may ignore it or reject it rather than update their explanation of the causes of the underlying data (Chinn & Brewer, 1993). Finally, the omission bias suggests that people consider the harm from actions they take to be worse than harm that results from not taking action (Katz & Dack, 2014). In the context of this project, we expect that faculty will believe that any harm caused by a proposed intervention would be worse than the harm marginalized students experience as a result of the academic status quo.

Taken together, these studies suggest that using data to identify and prompt action on educational inequities requires explicit design considerations to ensure that intended message is communicated. By having a team of experts develop the data visualizations, individual faculty do not need to be experts in data visualization and the relevant literature. In addition, as many of these studies were conducted with crowdsourced participants rather than scientific researchers, there is an opportunity to see how robust these findings are to populations expected to be experts in data interpretation such as STEM faculty.

4. Relations to other work

We are aware of existing projects that have used institutional data to prompt change at their institutions; however this project will extend such efforts into department-level data. The Know Your Students tool at the University of California Davis provides grading data at the individual course level. In contrast, the University of California Irvine created Comprehensive Analytics for Student Success

(COMPASS) for both individual course-level grading analytics and grading analytics aggregated across the whole department split by demographic groups (Denaro et al., 2022). To our knowledge, these existing tools do not allow analyses across a department while still allowing for the data disaggregation needed to easily explore trends across courses. These efforts then provide an opportunity to understand student success in a department desegregated by individual courses as well as alternative measures of equity such as time to degree and retention. Our proposed project addresses that need.

Furthermore, these existing platforms for using institutional data have been developed solely for their own institutions rather than for broader deployment across institutions of higher education. This project will develop analytics through the departmental equity report that, with the support of future funding, could be adapted to other institutions, potentially expanding the number of institutions making use of such tools to implement changes.

5. Guiding frameworks

This proposal is guided by four frameworks and concepts: 1) the Cycle of Progress for Sustainable Change, 2) Critical Data Driven Decision Making, 3) Cognitive frames, and 4) QuantCrit. These are summarized in Table 1 and explained below.

Table 1. Frameworks guiding this project

Frameworks	Description	Related Project Activities
Cycle of Progress for Sustainable Change	Awareness of questions leads to actions that develop understanding which prompt action followed by reflection on the process	Showing faculty and staff departmental equity reports to raise awareness of issues; using 4 short surveys to assess how these reports spurred action
Critical Data Driven Decision Making	Using data to make decisions occurs in the context of individual's identities and beliefs as well as in the political and organizational context	STEM departmental leadership survey and focus groups and individual interviews before seeing departmental equity report to understand contextual factors for interpretation
Cognitive Frames	How individuals interpret a situation, affecting what is seen and ignored	Understanding responses from the individual faculty and staff interviews
QuantCrit	Numbers are not neutral and data cannot speak for itself	Using appropriate framing and visuals to communicate equity gaps

We also employ a guiding assumption: we do not assume that learning analytics can solve every education problem or even play a role in solving every educational problem (Uttamchandani & Quick, 2022). Instead, we consider how learning analytics has a role in addressing the problem of educational inequity. Based on our theory of action (described below), we believe that providing equity data can raise awareness of issues and prompt action.

The Cycle of Progress for Sustainable Change, developed in part by advisory board member Marco Molinaro (section 10), is the theory of action for this project and consists of four parts: awareness, understanding, action, and reflection (Rehrey et al., 2020). First, in awareness, faculty are provided with data that helps them shape questions for further investigation. Second, in understanding, faculty uncover answers to their questions, by exploring data and reading relevant literature. Third, in action, the faculty develop and test interventions to address the problems they have uncovered. Finally, in reflection, faculty analyze the impact of their interventions and decide on next steps. These reflections often lead to new questions which restart the cycle. Under this theory of action, we expect that providing faculty with equity data showing inequities within their department will lead to them asking questions about their causes and developing interventions to close these gaps.

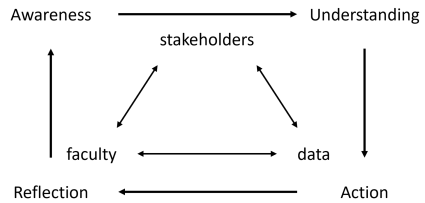

Figure 1: The cycle of progress for sustainable change (adapted from Rehrey et al. 2020)

Second, we pull from the data-driven decision making literature and will use the Critical Data-Driven Decision Making Framework to guide how we believe this process happens. This framework posits that the process of using data to make decisions and drive change does not occur in a vacuum but instead occurs in the context of individual's identities and beliefs and the political and organizational context of the individuals engaged in the change process. Under this framework, inequities are assumed to be the result of educational institutions working as designed and that "that functioning is inherently problematic and oppressive" (Dodman et al., 2021). More broadly, it assumes that change efforts do not need to fix the students and instructors. This framework then informs our need to understand the underlying institutional, departmental, and individual contexts of the individuals who will be using our departmental equity reports to identify and address inequities.

Third, we use cognitive frames to guide the interpretation of how an individual's beliefs may affect their interpretation of the program equity reports (Bensimon, 2005). Bensimon defined a cognitive frame "as the way an individual understands a situation" and "informs what questions may be asked, what information is collected, how problems are defined, and what action should be taken." Just as cognitive frames make certain things visible, they also function as "cognitive blinders" rendering other things invisible to individuals. Initial work with cognitive frames suggests that unless change makers have an equity cognitive frame, they notice and question patterns of educational inequity and view inequality in the context of exclusion and discrimination, changes to make higher education more equitable are unlikely to occur (Bensimon, 2005). Interventions to address educational inequities, such as our departmental equity report, must then use an equity cognitive frame to ensure inequities are correctly identified.

Finally, to construct the departmental equity reports, our work will be guided by the QuantCrit framework (Gillborn et al., 2018). Under this framework, numbers are not assumed to be neutral, racism is central to understanding the results we find, categories are neither natural nor given, and data cannot speak for itself. We will apply this framework by critically examining the choices we make as designers and how these choices may affect the interpretation of results by users and their views of the underlying reality. Given that moving from institutional data to a set of analyses requires a complex set of steps involving data cleaning, analyses and visualization as well as many subjective choices (Bowers & Krumm, 2021), there are significant opportunities for the choices made by us as developers to affect how information is presented to users (Tsai et al., 2021). As noted elsewhere, even the decision to collect certain data reflects decisions about organizational and societal priorities and hence, is already framed by interpretation (Henig, 2012).

6. Preliminary Work

Analysts in our Center for Research on Learning and Teaching (CRLT) previously developed a course equity report which provides instructors with background on their students in terms of demographics, majors, and previous courses along with course specific outcomes such as grades. These reports have been used to guide change in lower-level courses within our Foundational Course Initiative, a CRLT-led initiative that partners with department teams to redesign courses that are pivotal for students' career paths, engaging faculty from across STEM disciplines.

In partnership with this effort, PIs Hayward and Matz, and postdoctoral fellow Young, conducted focus groups with twenty course instructors to gain feedback about specific features of the course reports and how instructors use them. Results from the focus group indicated that faculty generally found the reports useful and used them to think about diversity, equity, and inclusion issues such as who enrolled in their course (Matz et al., 2023). For example, one participant noted "*The course report captures the students who enroll in the class. It doesn't tell us anything about the students who were filtered out or [kept] from enrolling in the class in the first place. There's also a big question about why there aren't more students with [more marginalized identities] taking my class.*"

When asked about how the reports might be used, instructors reported mixed reactions around who should have access to the reports, when they should be provided, and whether the reports should be

reports at all or presented in an alternative interactive format. Instructors also expressed concerns that many faculty might not know how to make use of the information in the report. One instructor said "*When a report like this would go to the randomized person in my department, the vast majority of people other than me [department chair], [another participant], and former associate chairs for curriculum, would be like, 'I have no idea what any of these data are, what any of them mean, and how they might be actionable*.'" Others echoed concerns that departmental leadership would be the best place for these reports given that information should be aggregated across courses and otherwise, acting on the information is "*kind of left too much up to an individual and how much they care*."

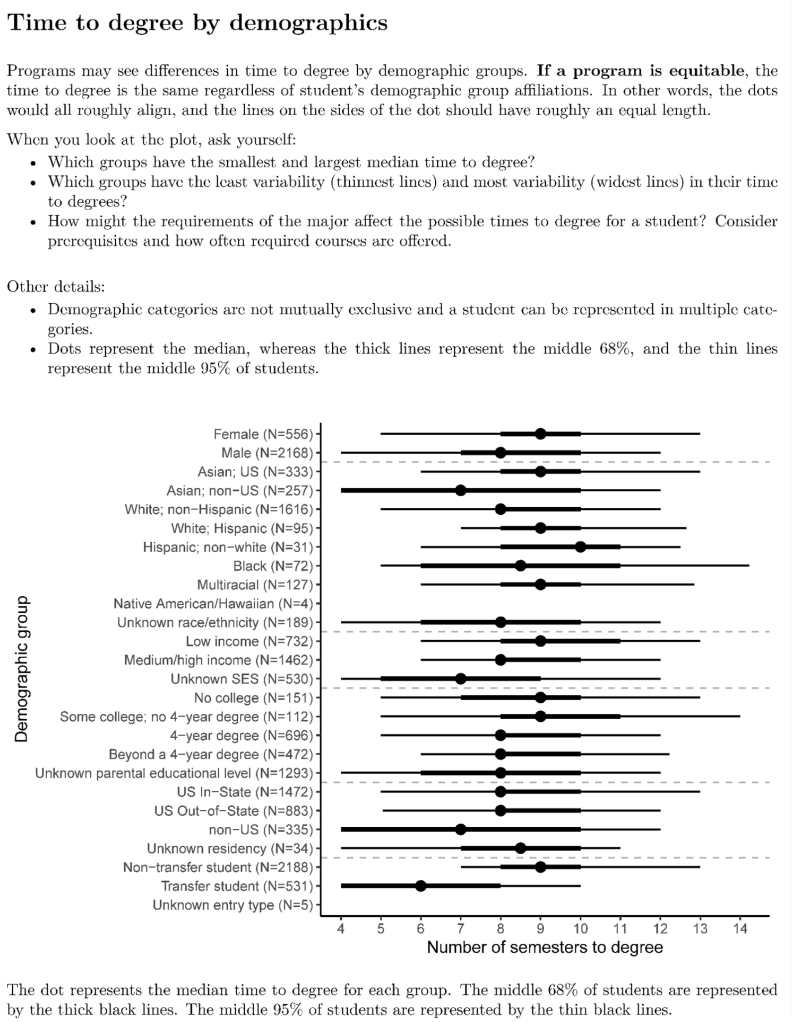

Figure 2: Sample page of the departmental equity report for an anonymized STEM department at the University of Michigan.

Hearing the challenges and concerns raised by focus group participants and observing recurring patterns of inequity across courses, we created a prototype of a departmental equity report to examine equity across courses in a department rather than focus on individual courses. Using institutional data at the University of Michigan, these departmental equity reports allow users to compare grade distributions across courses and examine grades by demographic groups such as sex, race, first generation status, and socioeconomic status. Recognizing that understanding equity at a departmental level also requires broader outcome measures, the reports include time-to-degree and completion rates for students who declare a major within the department. The reports are generated using the R programming language (R Core Team, 2021) and specifically with the use of R markdown, which integrates text and figures in a single document. The reports can be generated with limited input from the user after setting initial parameters like the department of interest. The accompanying text provides details to help readers understand the goal of each plot, how to interpret the plot, and what insights they should come away with, addressing concerns around potential issues about data literacy and framing the results raised by the literature. An example page from the departmental equity reports is shown in Figure 2.

To gain feedback on the initial design, the prototype report was shared with departmental leadership in the astronomy department, math department, school of Business, and Residential College. Informal feedback suggested a desire to integrate data collected by the departments themselves into the reports to understand aspects that are not covered by available institutional data (such as student surveys and post-degree outcomes). The faculty and staff in these initial conversations also had various responses to

seeing visualizations depicting equity gaps in their departments, ranging from wanting to take immediate action to disagreeing that equity gaps are a problem in their department until they were unable to provide additional alternative explanations. Initial feedback also suggested that the report could not be too long or readers would be overwhelmed. As a result, the prototype report now consists of five high-level visualizations to summarize key grade and degree outcomes and then appendices with additional visualizations that address common follow-up questions asked by departmental leadership and in line with our theory of action that suggests that viewing the data will prompt follow-up questions.

Some of these meetings led to departments taking further action, suggesting that these reports can support change. For example, faculty in one department asked for a follow-up meeting with additional department leadership and for additional analysis about specific degree programs. Faculty in another department incorporated data visualizations from their departmental equity report into part of their curriculum review that examined pathways through the major after faculty and students expressed concerns about the "*limited number of pathways through [their] major*". They used our data visualization to argue that "*it is very difficult, if not impossible, for students who enter without AP credit to complete our major in eight semesters*", noting that taking additional semesters is "*not financially viable for all students*."

7. Proposed research

To achieve our overall objective—to develop departmental equity reports and the foundational knowledge about them that could be broadly used at higher education institutions to analyze and address inequities within STEM departments—this project includes one foundational activity and three research questions. These are summarized in Table 2.

Table 2: Timetable for proposed activities for this project and which research question they contribute to.

	Foundational Activity	Research Areas
Fall 2023		-Develop and test DEI survey and focus group protocol (RQ1) -Send out DEI survey to STEM departmental leadership (RQ1) -Recruit departmental leadership for focus groups (RQ1)
Spring 2024		-Conduct focus groups (RQ1) -Begin initial focus group data analysis (RQ1)
Summer 2024	-Refine departmental equity reports based on needs identified during focus group feedback (RQ 1)	-Finish focus group data analysis and write up (RQ1) -Develop individual interview protocols and surveys (RQ1)
Fall 2024	-Generate departmental specific reports for participants (RQ 2)	-Conduct interviews with individual STEM faculty and staff about the reports (RQ2)
Spring 2025	-Create infrastructure to upload departmental data into reports (RQ 3)	-Analyze interview data and surveys (RQs 1 & 2) -Follow up with participants about how they've used the reports for first time (RQ2)
Summer 2025	-Create interactive version of the reports (RQ 3)	-Finish interview data and surveys data analysis (RQs 1 & 2) -Development of interview protocol for interactive reports (RQ3) -Begin developing publications (RQs 1 & 2)
Fall 2025		-Conduct interactive reports interview (RQ3) -Follow up with participants about how they've used the reports for the second time (RQ 2) -Continue developing publications (RQs 1 & 2)
Spring 2026		-Interactive report interview data analysis (RQ 3) -Continue developing publications (RQ 2)
Summer 2026	-Iterate interactive reports based on interview feedback (RQ 3)	-Follow up with participants about how they've used the reports for the third and final time (RQ 2) -Finish interactive report interview data analysis (RQ 3) -Finish developing publications (RQs 2 & 3)

Foundational activity: **Develop an interactive version of the departmental equity report that allows for STEM faculty and staff to customize analyzes to their specific departmental contexts.**

In this portion of the project, we propose to create two key functionalities for our departmental equity report based on feedback from our predecessor course equity report and initial feedback on our departmental equity report prototype (section 6): 1) the ability for users to dynamically filter and create analyses within the existing report and 2) the ability for users to bring in their own departmental data (e.g., survey responses, post-graduation outcomes, student organization participation) and run a series of pre-made analyses on that data, provided the data is arranged in a pre-specified format. Given that our theory of action assumes that current data will lead to faculty to develop new questions to be answered by data (section 5), our departmental equity report needs to be able to meet this need. We propose that allowing user customization of the reports by altering current analyses and supplementing existing data can achieve that aim. Without doing so, our report would not address many of the barriers that prevent faculty from engaging with equity data in the first place.

From our focus groups on course equity reports, we identified that many instructors have similar questions that lend themselves to one-size-fits-all analyses, such as those in our prototype departmental equity report, but that many instructors also had variations on those questions that would require individualized analyses such as customizing the time frame of the analyses to see if a change to their course resulted in the desired outcome. One participant said "*If I have the ability [in the report] to play with the time period, I might be able to parse out the effects of some of the changes that I put in place*."

In addition, the student data warehouse does not contain all data that might be relevant to a department when determining inequities. For example, our student data warehouse does not contain data about post-graduation outcomes, individual assignment grades, or student affect in response to instruction, some of which individual departments may have collected from its students. Joining such additional data with institutional data could allow for additional insights (Fischer et al., 2020). Given that many of the barriers to using learning analytics likely remain with this departmental data, a predefined set of analyses where departments can upload their own data is essential.

Research question 1: **What DEI experience, knowledge, and infrastructure exists in STEM departments interested in using these tools?**

Background: From the critical data-driven decision making framework (Dodman et al., 2021), drawing meaning from data, generating actionable knowledge, making decisions, and implementing changes all occur within the context of an individual's identities and beliefs and the larger political and organizational context. Previous work has found that faculty have widely varying beliefs about the underlying causes of inequities in STEM ranging from individual student "deficits" to systemic causes with women and people of color, generally supporting the latter (Russo-Tait, 2022), as well as to what degree DEI values align or go against traditional academic views (German, 2020). Even among self-described progressive academics, DEI knowledge is relatively limited and when problems are known, they may be described as only happening in "places far far away" (Dancy & Hodari, 2022). Yet, knowledge without framing inequities as the results of various structures has been identified as a possible reason for faculty not to support institutional changes to close the equity gaps (Cech et al., 2018).

In terms of infrastructure, previous work has found that leadership and organization policies play a significant role in any data-driven change effort. Deficit thinking can occur when leadership encourages data to be used as an accountability measure, when students are viewed as numbers instead of people, and when there is an unsafe professional environment for data use (Lasater et al., 2021). When issues are framed through a deficit-thinking lens, both instructors and non-instructors (MTurk workers) have been found to give them lower priority than when issues are framed as the result of structural injustices (Quinn & Desruisseaux, 2022). In contrast, encouraging and distributed leadership has been found to be essential for using data to address educational problems (Schildkamp et al., 2019).

Research Plan: To understand how these crucial aspects influence how faculty and staff will make use of the data provided in the departmental equity reports, we will conduct a series of surveys, focus groups, and individual interviews. To understand the organizational context of the departments interested in using these tools, we will develop and distribute a survey to the department chair, directors for

undergraduate and graduate education, and the DEI lead, a faculty or staff member responsible for leading and resourcing DEI initiatives with the department, of all STEM departments on campus (as applicable). The survey will use a series of closed and open-response questions to probe at 1) previous and existing DEI goals and efforts in the department, 2) who is viewed as responsible for DEI efforts in the department, 3) what questions the department has about equity outcomes, and 4) what role they believe data plays in addressing DEI issues.The surveys will explicitly state that responses will *not* be used to evaluate departments but rather to understand current practices and how the university may be better able to support departments in achieving their equity goals. We do this because previous research has found that using data in an evaluative manner could cause instructors to feel threatened (Lasater et al., 2021). By asking multiple leaders within a single department, a measure of data triangulation is built into the survey. At the end of the survey, we will include a question asking if the participant would be willing to participate in a focus group to share more detail about their departmental context with the research team and a question asking to nominate three potential faculty or staff who might be interested in participating in the departmental equity report testing as snowball sampling is an effective method of recruiting participants (Parker et al., 2019).

Using an estimate of thirty STEM departments at the University of Michigan with an average of four leadership positions in each (some departments have multiple undergraduate and graduate education chairs and not all departments have a DEI lead), we have a potential sample size of 120. Reasonably, with compensation, we expect that half would complete the survey and half of them would volunteer for the focus groups. In that case, we expect to recruit 30 members of departmental leadership for the focus groups and a total of 50 STEM faculty and staff (including focus group participants, allowing for some participants to withdraw from the study) to participate in the larger departmental equity report study described in the following paragraph and research questions. In addition to monetary compensation for each participant, the department would be provided with their specific equity report for participation in the focus group and subsequent studies. From our course equity report focus groups, we were able to recruit our desired number of focus group participants without offering compensation and hence, we expect to be able to recruit more with a financial incentive.

To understand the departmental context, we will develop and test a focus group protocol with the thirty departmental leaders. This focus group will expand upon the questions asked in the survey (e.g., previous and existing DEI goals, questions the participants have about DEI) as well as additional questions such as what barriers the department has encountered when trying to make changes.

To understand the individual participant's identities and beliefs, we will develop and test an interview protocol and interview the identified participants who have agreed to participate in the study. These include the thirty focus group participants and STEM faculty and staff recruited by members of the focus group for a total of fifty participants. We choose a relatively large initial sample to ensure even if some participants withdraw from the study, we still have a sufficient sample size. Given that many of the questions we wish to address with individual participants are open-ended, survey fatigue represents a potential threat to validity and thus, we choose to conduct interviews even though they are more time intensive on the research team (Field, 2020). This interview will ask about the participant's knowledge of and experience with diversity, equity, and inclusion, their previous experience using data to answer educational questions, and what types of DEI questions they would like to answer and how they would like to do so. At the beginning of the interview, each participant will complete a short questionnaire to capture key demographic information such as gender, race, and position type.

For all three sub-projects, all surveys will be conducted using Qualtrics. To reduce barriers to attending focus groups or interviews and concerns about recording meetings, all focus groups and interviews will be conducted over Zoom. Previous research suggests that conducting interviews virtually does not negatively affect the thematic content of an interview (Namey et al., 2020). To analyze the qualitative data, we will identify emergent themes through cutting and sorting (Ryan & Bernard, 2003) and

constant comparison (Lincoln & Guba, 1985). PIs Hayward and Matz, along with Young, previously used these methods in the focus group study on the course equity reports (Matz et al., 2023).

Expected Outcomes: Results from these studies will inform interpretations of interview data collected in later stages of this research in accordance with the Critical Data-Driven Decision Making Framework. In addition, the results will advance knowledge around DEI within STEM departments by providing a snapshot of the current state of DEI within a subset of a single university with a commitment to DEI (*DEI 1.0 Unit Strategic Plan Summaries | Diversity, Equity & Inclusion | University of Michigan*, n.d.). We expect that results from these studies will also inform what resources need to be created to better support people working with the departmental equity reports and who might have less familiarity with DEI work.

Research question 2: **How can pre-made programmatic equity data analysis support the identification of equity issues and prompt action among STEM faculty and staff?**

Background: Previous work has established that data can push instructors to challenge existing assumptions about learning and to reflect critically on practices (Lachat & Smith, 2005) as well as challenge deficit thinking (Lasater et al., 2021). Data can also sound the alarm on educational issues and encourage dialogue that challenges existing practices and points toward solutions (Myers & Finnigan, 2018). Efforts in curricular analysis suggest that pre-made learning analytics analyses can help with these as well as provide “concrete evidence” for problems in the department and identify problems the department would have otherwise missed (Armatas & Spratt, 2019). Further, pre-made analyses can circumvent data access barriers and allow departments to take advantage of learning analytics and educational research knowledge without needing to have an in-house expert (Armatas & Spratt, 2019). These pre-made analyses could potentially alleviate documented issues including 1) data collection and analysis taking too much time which yields less time for planning changes, 2) limited equity-focused data literacy skills, and 3) limited strategies for changing practice (Miller, 2019). At the same time, data does not have meaning in itself and instead, results from readers sensemaking the data through their expectations, projections, judgements, and assumptions (Fjørtoft & Lai, 2021). Therefore, design choices need to be informed by how faculty interpret the data.

Research Plan: To understand how the departmental equity reports support the identification of equity issues, we will conduct hour-long think-aloud interviews with the 50 faculty and staff who have completed the initial interviews as they read the report. Think-aloud interviews provide a real-time snapshot of a participant's thought process and involve minimal dialogue with the interviewer to minimize the influence of the interviewer (Reinhart et al., 2022). Such an approach allows us to gain insight into how faculty and staff will interpret the data within the report while maintaining an authentic setting as possible for conducting such research.

At the start of the interview, participants will be provided with a report containing the data from their department. Participants will be asked to describe what they notice in the reports, what conclusions they are drawing, and what questions they have. Pilot implementations have found that it is only possible to discuss a few plots during an hour and therefore, a series of five summary visualizations were created to provide a high-level summary of grade outcomes, time-to-degree, and graduating grade point average. This summary will be the focus of the interview but participants will have the full report to refer to. The targeted participants will be both departmental leadership (chair and DEI lead) and as faculty and instructors without formal leadership roles. We do so as success models for departmental change, such as Departmental Action Teams (Ngai et al., 2020) include representatives in the department with varying roles. The interviews will again occur on Zoom, taking advantage of screen sharing. Analysis will again use cutting and sorting and constant comparison to develop themes.

As we do not assume that simply providing data will lead to change (A. F. Wise & Jung, 2019), we will use short surveys to assess how these reports did or did not prompt action. These surveys will also generate pilot data on the promise of the departmental equity reports for identifying and promoting action on equity issues within STEM departments. Participants will be emailed a short survey before the initial interview and at approximately 6 months, 12 months, and 18 months after the initial interview. These

surveys will ask who, if anyone they've talked to about DEI issues over the past 6 months, any DEI related changes they have made or attempted to make in their sphere of influence, what barriers they have encountered in making or attempting to make those changes. For surveys sent out after the interview, we will also ask who, if anyone, they've shared the report with, and what those people's reactions or questions were. We expect that if the reports are prompting action, participants would report making DEI changes, sharing the report more broadly in their department, and talking to others in their department about DEI issues. By polling participants three times, we will also be able to assess the report's longitudinal impact. We expect that if the reports are having a longitudinal impact, participants would continue to make DEI-related changes and continue to talk with colleagues about DEI issues. The initial survey will serve as a baseline for each participant.

Expected Outcomes: Results from these studies will generate knowledge about how pre-made equity analyses can encourage positive change within STEM departments. The longitudinal aspects of the survey can also determine the timescale of the changes and how the analyses propagate through the department. We expect that these results can also contribute to addressing concerns of limited evidence of the benefits of learning analytics beyond the classroom (Macfadyen, 2022).

In addition, these studies will generate knowledge about effective data visualization and communication practices around equity data to identify issues and prompt action. Such knowledge will inform future versions of our departmental equity report and we expect the knowledge to generalize to future efforts as well.

Research question 3: **What is the type and format of data that is most effective for identifying equity issues?**

Background: Data interpretation does not occur in an objective manner and instead is filtered through the lens of the user (Schildkamp, 2019). That is, the same data can have different meanings to different people. Previous work has found that people tend to search for and see data that supports their existing views while missing data that might go against their views (Coburn & Turner, 2011). Further, if data is hard to interpret or if the data reflects badly on the department, users might disengage from the change process (Dazo et al., 2017; Lasater et al., 2021). If the program equity reports are not designed to guide users in their analysis, users could potentially miss equity gaps in their programs, and not address them.

Additionally, the format of data visualizations affects the insights that can be drawn from them (Hegarty, 2011). Even the process of creating a data visualization results in a focus on some data over other data (Farrell & Marsh, 2016). Previous work has found that approaches that give users freedom to explore the data fully often don't provide direction about what to look at (Echeverria et al., 2018), meaning that users could miss the point of the visualizations. At the same time, allowing disaggregation and allowing comparisons across classes has been found to be useful (Farrell & Marsh, 2016), which more naturally lends toward an interactive format.

Research Plan: This part of the project then seeks to advance knowledge about the benefits and tradeoffs of presenting equity data in interactive formats which allow for greater freedom to explore the data and customize the analyses versus presenting equity data in a static format which allows for a fixed view of the data and directed exploration of the data with a standard set of reflection questions. To understand how the type and format of the data affects identifying equity issues, we will conduct a final interview with 10 of the 50 previous participants, aiming for equal numbers of participants who identified wanting to interactively interact with the data and those who did not express such inclinations. If there are more than 10 eligible participants, we will select participants to maximize the diversity of those participating in this study based on department, position type, gender, and race.

In this interview, participants will again be guided through a think-aloud protocol as they interact with a dynamic version of the reports developed through our foundational activity. To limit the differences in the static and interactive version of the reports and to not introduce possible confounding factors, only the five summary visualizations from the previous interview will be tested as interactive visualizations and the default data view will show the same data as the static reports. Using the same cutting and sorting

procedures used to analyze the previous interviews, these data will be analyzed to identify the types of equity issues surfaced by participants as well as how they talk about them. Identified equity issues from participants will then be compared to the equity issues identified by the participants in their previous interview to determine how the format of the equity artifact affects the identification of equity issues.

Expected Outcomes: Results from these interviews will generate knowledge about the affordances and limitations of static versus interactive visualizations for identifying equity issues that can be useful for future research efforts. More broadly, we expect findings from this research area to inform how the understanding step of the Cycle of Progress for Sustainable Change, our theory of action, happens in practice. In addition, the results will generate knowledge about which formats of data are seen as effective in measuring potential progress on equity issues by participants.

8. Dissemination and Propagation

First, preliminary results and completed projects will be presented at broadly-targeted conferences and presentations such as the Learning Analytics and Knowledge (LAK) conference and the American Educational Research Association (AERA) annual meeting. In addition, the University of Michigan provides various conferences, symposia, and talks that can be used to share results from this work with the larger university community. As our institution is part of the Sloan Equity and Inclusion in STEM Introductory Courses Initiative (SEISMIC), a consortium of 10 large public universities focused on equity in large, foundational courses, results can also be shared at the SEISMIC annual meeting, potentially opening avenues for adapting the departmental equity reports to the local contexts at peer institutions. The departmental equity reports could also serve as a starting point for additional equity measures currently being developed by SEISMIC under NSF award #2215398.

Second, results will be published in peer-reviewed journals targeted toward learning analytics and STEM education researchers as well as more general academic audiences including the Journal of Learning Analytics, Plos One, and the International Journal of STEM Education. These articles will be published as open-access articles whenever possible to support broader access to articles. As allowed by journal policies, articles will be uploaded to pre-print servers such as arXiv and edarXiv to further broaden access and to possibly increase impact (Feldman et al., 2018). Links to all publications will be included on our project website. Links to publications will also be shared through our Center's social media channels (~8,500 Twitter followers) to potentially increase reach and impact within the academic community (Lamb et al., 2018; Luc et al., 2021) and outside of the academic community which prior work suggests is possible given the potential audience size (Côté & Darling, 2018).

Additionally, results and procedures developed from these projects will be shared with STEM education researcher and practitioner audiences through blogs such as *Disruptor,* run by the AAAS-IUSE partnership. PI Bell and postdoctoral fellow Young have previously published on this blog (Young, Rypkema, et al., 2022) and Young has extensive experience sharing research through blogs (Young, Lewis, et al., 2022).

To ensure that other institutions can make use of the reports developed through this project, all codes along with instructions for formatting institutional data will be uploaded to a public GitHub repository. To ensure potential users can find this repository, the repository will be linked to the project website and cited as appropriate in publications.

9. Personnel

A collaboration of University of Michigan researchers (Table 3) will carry out this research. Relevant to this proposal, the team has expertise in learning analytics, qualitative and quantitative STEM education research, data visualization, and institutional change. Through the Sloan Equity and Inclusion in STEM Introductory Courses Collaboration (Hammond et al., 2022), PI Matz has experience working with educational analyses developed to run across different institutions (Matz et al., 2017), providing expertise in how the departmental equity report compares and contrasts with equity tools at other institutions.

Table 3: Personnel collaborating with the PI, their expertise, and expected contributions to the project			
Name	Role	Expertise & relations to project	Expected contribution
Caitlin Hayward (PI)	Director of Research and Development, Center for Academic Innovation	Expert in learning analytics, data visualization, educational motivation, gameful pedagogy, and curricular innovation	**Administration**: feedback on research design and analysis; recruitment of departmental partners on campus; advising of postdoctoral fellow.
Eric Bell (Co-PI)	Professor and Chair of Graduate Studies, Department of Astronomy	Experience in using institutional data to assess and foster equity in courses & co-curricular spaces	**Administration**: feedback on research design and analysis; advising of postdoctoral fellow.
Becky Matz (Co-PI)	Senior Research Specialist, Center for Academic Innovation	Expert in qualitative and quantitative STEM education research, course transformation, and institutional change	**Research**: research support on developing focus group and interview protocols; reliability of qualitative analysis with interview and focus group data
Nicholas Young	Postdoctoral Fellow, Center for Academic Innovation	Expert in quantitative STEM education research, data visualization, and science communication, designer of departmental equity report prototype	**Research & development**: developing focus group and interview protocols; collecting and analyzing focus group and interview data; developing departmental equity reports; lead on quantitative data wrangling, including surveys

10. Approaches to gaining feedback

To assess the success of this project, an advisory board of three scholars will meet with us annually. Acknowledging that this project seeks to advance equity in STEM, we have been intentional about assembling a diverse group of scholars to serve on the advisory board in terms of gender, race, institution type, and position type. All advisory board members will be compensated for their time.

Marco Molinaro is the Executive Director for Academic Analytics in the Office of the Provost at the University of Maryland at College Park. Molinaro has expertise in creating applications for academic analytics, technology for instruction, curriculum development, and evaluation. ***Nia Dowell*** is an Assistant Professor of Education at the University of California, Irvine. She has expertise in cognitive psychology, discourse processing, group interaction, and learning analytics. ***Amelia Stone-Johnstone*** is an Assistant Professor of Mathematics at California State University Fullerton. She has expertise in mathematics education, equitable instruction, teacher professional development, and systematic change.

Advisory board members will advise the project on an annual basis and as needed. The board will meet with the research team before beginning any work to discuss goals and ensure the team is ready to begin, and then hold annual meetings to review progress and receive team updates. As appropriate, the board will be asked to provide feedback on drafts of manuscripts. The board will draft an annual report of the team's accomplishments and areas for improvement. To do so, the board will have access to team meeting minutes and project documents such as interview protocols, publications, and presentations.

For more specific feedback, the advisory board will ask the team to respond to a series of questions during each annual meeting. Following year 1, the advisory board will ask 1) Is the team following the research plan? 2) Has the team developed the necessary interview protocols? 3) Did the team incorporate feedback from the initial meeting? 4) Is the team following the postdoctoral mentoring plan? Following year 2, the advisory board will ask 1) has the team completed the necessary interviews? 2) Has the team developed the report's interactive components 3) Is the team incorporating recent related literature into their findings? Following year 3, the advisory board will ask the team 1) did the team achieve the project's goals? 2) How have the research team shared the results from this project internally and externally? 3) How will the team sustain progress made from this project?

The reports generated from these advisory board meetings along with our responses will be submitted to NSF as part of our annual report. PI Matz has found such reports to be effective for

evaluation in both prior small- ($300K; 1708664 & 2120252) and large-scale ($2M; 1725520) IUSE projects. We contend that, per the IES/NSF Common Guidelines (Institute of Education Sciences & National Science Foundation, 2013), peer review from the panel and program officer (PO), these advisory board activities, ongoing communication with the PO, and peer review on publications together constitute a rigorous plan for obtaining external, objective, and useful feedback for the project.

11. Broader Impacts

The data infrastructure underlying these reports are built capacities and do not depend on external funding. Therefore, we expect the departmental equity reports to be useful beyond the funding period and continue to make an impact. We also expect the departmental equity reports created from this proposal will enable departments to identify and address pressing inequities within their programs Additionally, this project will train the participating STEM faculty in working with departmental-level equity data. More broadly, we expect that participants will have increased knowledge about inequities in STEM and how they manifest in their department. The knowledge generated from this proposal is also expected to provide guidance to others about training faculty in the use of department-level equity data. As research-intensive institutions are increasingly making institutional data accessible to their researchers, the tools developed from this report are expected to be applicable to and deployable at institutions similar to Michigan. Doing so can contribute to the full STEM participation of currently marginalized groups such as women and underrepresented minority students and result in more equitable STEM education.

12. Prior NSF Support

PI Hayward does not have previous NSF support. The IUSE solicitation specifically encourages inclusion of personnel new to NSF as a mechanism to expand project impact and for building capacity (National Science Foundation, n.d.). Citations for publications from previous NSF support to PIs Bell and Matz are included in the References Cited section.

Eric Bell. 1) Islands no more: The important mergers of nearby galaxies and their effects (2007065; $454,023; 8/20-7/23); 2) Measuring the Effects of Dust Attenuation on the Luminosities and Morphologies of Disk Galaxies (1514835; $307,235; 9/15-8/18). **Intellectual Merit (IM)**. We quantified the effects of dust and mergers on galaxies; results include the first ever measurement of the effects of dust on galaxy structure metrics and the discovery of a relationship between the largest mergers experienced by galaxies and their satellite galaxies (Bell et al. 2017; Carrillo et al., 2017; Devour & Bell, 2016, 2017, 2019; D'Souza & Bell, 2021; Harmsen et al., 2017). **Broader Impacts (BI)**. i) A collaborative effort to create, use, and monitor the effectiveness of active learning and inquiry-based activities in intro astronomy classes, including the impacts of independent research projects on student attitudes and learning, and ii) The individualized STEM workforce training of 4 graduate students, a postdoc, and an undergraduate research group of 30 students, including African American, Latinx, and Filipina students.

Becky Matz. Collaborative research: Creating assessments for student understanding of core chemistry ideas in introductory biology (1708664 & 1708589; $297,905; 9/17-8/22). The project's purpose was to develop and test the efficacy of activities that integrate core chemistry ideas with biological phenomena. **IM**. The activities we developed are aligned with the NRC framework for 3-dimensional learning (National Research Council, 2012), incorporating scientific practices, core ideas, and crosscutting concepts. Analyses of student responses have shown instructors how students are (and are not) connecting ideas between chemistry and biology as well as what additional curricular supports are needed (Green et al., 2020, 2021; Martinez et al., 2020, 2021; Matz et al., 2018, 2019; Roche Allred et al., 2020, 2022). **BI**. The activities provided opportunities for >2,000 students in introductory courses to connect ideas across disciplines. Instructors at both universities in the project continue to use the activities though the project has ended. We mentored 1 postdoc and 10 undergraduates (5 gave talks or posters at national conferences, 3 are authors on articles (2 lead), and 1 began a Ph.D. in chemistry education and was recently offered an NSF Graduate Research Fellowship Program award!).