Real Analysis Professors' Noticing of Equity Gaps and Minoritized Students' Perspectives

Amy Been Bennett
University of Nebraska-Lincoln

Johan Benedict Cristobal[1]
University of Nebraska-Lincoln

Yvonne Lai
University of Nebraska-Lincoln

Cleve Young
University of Nebraska-Lincoln

Addressing equity and opportunity gaps in undergraduate education requires change across systems, including the pedagogies and orientations of the undergraduate faculty whose courses and departments perpetuate these gaps. Hence research on how undergraduate faculty notice quantitative and qualitative evidence of inequitable experiences has the potential to advance reform efforts. We conducted an interview-based study of 5 mathematicians who were presented with data analytics indicating equity gaps in proof-based courses at their university, and statements from minoritized students in these courses about their experiences. We found that the faculty may hold split inclusive and exclusionary frames about students and mathematics; that there may be a persistence of personal experience as an interpretive lens; and that qualitative and quantitative evidence may elicit different frames of instruction and students. We discuss these findings through the lens of a noticing framework.

Keywords: proof-based course, equity, mathematicians, noticing

Background

Equity and opportunity gaps are well-documented in undergraduate mathematics education (e.g., National Academies of Sciences, Engineering, and Medicine [NASEM], 2016; Solomon & Craft, 2016; Leyva, 2016). Recent scholarship points to the need for centering minoritized students' views of undergraduate instruction (e.g., Larsen et al., 2016; Leyva et al., 2021a, Leyva et al., 2021b). Yet systemic change requires not only articulating mechanisms of marginalization, but also change in the orientation of undergraduate faculty whose courses and departments may reinforce gaps. Thus, research on how undergraduate faculty may view evidence of inequity can advance reform efforts. Such research can identify affordances and barriers to using qualitative and quantitative evidence regarding equity to shift instructor orientation.

This study contributes to this area by examining how undergraduate faculty frame and attend to data on equity gaps or data about minoritized students' perceptions. We focused our study on mathematics faculty who had taught real analysis, a course with a widespread 'weed-out' reputation (e.g., reddit r/math, 2018) and yet also recommended for inclusion into mathematics major programs (Mathematical Association of America, 2015). We act on the theory that a course with this kind of reputation and role may be one that amplifies impact on identity, particularly for minoritized students. We address the research question: *What do real analysis professors notice in data about the performance and experiences of minoritized students in real analysis courses where equity gaps exist?* By investigating this question, we aim to gain insights into how instructors may interpret and address equity issues in their classrooms.

Conceptualizing Equity

Equity can be viewed from dominant and critical perspectives, and we use both here. From a

[1] The second, third, and fourth authors contributed equally and are listed alphabetically.

dominant perspective, equity can be conceptualized as "the inability to predict mathematics achievement and participation based solely on student characteristics such as race, class, ethnicity, sex, beliefs, and proficiency in the dominant language" (Gutierrez, 2002, p. 153). Equity 'gaps' can be quantified from this perspective, for instance via disparities in performance or persistence among students of different backgrounds (which may be perpetuated within an instructional and institutional environment) (e.g., National Center for Educational Statistics, 2011). For all that such "gap gazing" (Gutierrez, 2008, p. 357) may obscure asset-based views and perpetuate a static view of equity, these statistics can call attention to inequity and are often used to substantiate calls to action (e.g., NASEM, 2023).

From a critical perspective, equity concerns identity and power. This perspective "builds upon the idea that mathematics is a human practice that reflects the agendas, priorities and framings that participants bring to it" (Gutierrez, 2011, p. 21) which complicates the desire to quantify 'gaps' within. Instead, this perspective aims to document the experiences of individuals as they face situations which diminishes their identity or their power. A critical perspective is needed in cultivating asset-based – and anti-deficit – views, and to humanize the experiences of those from historically marginalized populations.

Inequitable Experiences in Departments of Mathematical Sciences

As a report of the American Mathematical Society (2021) detailed, departments of mathematical sciences have had a long history of racial discrimination, and this discrimination continues to impact equitable participation in the mathematics community today. Recent scholarship making deliberate efforts to elicit and situate the perspectives of minoritized students largely underscore three arguments. First, minoritized students continue to encounter negative experiences that impact their identities in mathematics (Apkarian et al, 2024; Leyva et al., 2022; Leyva et al., 2024). Second, researchers and practitioners can and must find more ways to recognize and showcase the creativity and cultural assets of students from historically marginalized populations (Adiredja et al., 2020; Valdovinos Gutierrez & Ko-Wong, 2024). Third, instructors can disrupt or reinforce inequities, through their actions (Ball, 2024; Cawley & Wilson, 2023; Reinholz et al., 2024).

Building on this scholarship, an emerging area of work examines what happens when departments and instructors are asked to engage with evidence toward these arguments. For instance, Bolick and Voigt (2023) used data analytics to document inequities for undergraduate mathematics leadership teams to consider in transforming mathematics at their institutions. Adirejda et al. (2024) showed preliminary evidence that professional development of undergraduate mathematics faculty such as critical conversations around race and gender and funds of knowledge interviews may lead to instructors taking a more humanizing view of instruction. These efforts show promise that programmatic consideration is possible through engagement with qualitative and quantitative data. At the same time, one area that has received less attention is instructors' framing of forms of evidence toward particular courses that they have taught and are likely to teach in the future, and over which they have relative autonomy. This focus is important to understand because it explicitly leverages instructor agency.

In courses such as real analysis, instructors often hold primary responsibility for managing and shaping the classroom experience. In this sense, instructors are on the 'front lines' of education, with the autonomy to foster an inclusive learning environment – or not. Given that instructors have significant control over classroom dynamics, meaningful change in addressing equity gaps requires a deep understanding of how instructors perceive and interact with these issues. Specifically, it is essential to explore how instructors frame, recognize and respond to

data indicating performance disparities and to accounts detailing the experiences of minoritized students–in sum, how they *notice* signals of inequity.

Theoretical Framework

We use Louie et al.'s (2021) Frame-Attend-Interpret-Respond (FAIR) framework to conceptualize *noticing.* This framework embeds the practices of attending, interpreting, and responding (e.g., van Es, 2011) within a broader action of framing. Following the work of van Es and colleagues, in teaching and reflecting upon teaching, an instructor *attends* to particular features of instruction (and does *not attend* to other features), whether consciously or subconsciously; *interprets* these features, such as in terms of student identity, potential, and competence; and *responds* to this attending and interpreting in what they say or do in the classroom or how they plan for teaching.

Louie et al. (2021) argued that *noticing* necessarily occurs within sociopolitical contexts, for classrooms are social environments where power dynamics exist (with the instructor and among students), thus learning environments are neither socially isolated nor politically neutral. As such, those who have the responsibility of noticing in learning contexts should be aware of their framings of the situation, including the local, institutional, and cultural aspects. Other framings may be related to the students, the discipline of mathematics, or interactions that occur in the learning environment, and these framings may come from a deficit or anti-deficit perspective, albeit unknowingly at times. *Frames* create "expectations for how the emerging activity should unfold" (Hand, 2012, p. 251) and may draw on unseen, dominant assumptions and cultural values that guide the actions within noticing (Louie et al., 2021); and hence *framing* shapes *attending*, which in turn shapes *interpreting* and *responding*.

Mathematics and mathematical ability may be framed in exclusionary and inclusive ways (Louie, 2017). For instance, framing mathematics as a "fixed body of knowledge to be absorbed" can serve to exclude learners, whereas framing mathematics as "about making sense of ideas and understanding connections" may promote inclusion through meaning making; and framing mathematical ability as "hierarchical" is exclusionary, whereas framing mathematical ability in terms of the potential for "everyone [to have] both intellectual strengths and areas for growth" can lead to naming and seeing competence in students (p. 496). Instructors may also frame their observations of teaching from a deficit- or asset-based view of their own teaching capabilities.

Study Context

At the University where the study took place, the mathematics department hosted a presentation of data analytics that analyzed "DFW rates" for the department's courses over a three-year period. Here, a DFW rate of a course means the percentage of students in that course who received a D or F in the course, or who withdrew from the course. The analysis revealed that underrepresented students—defined by the University as those identifying as African American, Hispanic, and/or Indigenous—had higher DFW rates in an introductory real analysis course compared to their represented peers. Specifically, at the time, the DFW rate for real analysis was 25% for represented students and 35% for underrepresented students. In this same period, the DFW rate for real analysis for continuing college-going generation students was 24%, whereas it was 27% for first generation students.

Following this presentation, two of the authors surveyed and conducted interviews of underrepresented students about their experiences in real analysis. We discuss these surveys and interviews here because the data from these protocols were written into the protocols of the study presented in this report. Given that the University is predominantly white, students who identify

as Black/African American, Hispanic/Latinx, Asian/Asian American, Native American, or Native Hawaiian/Pacific Islander are often visible minority groups on campus. In line with Shah's (2019) recommendation to avoid treating Asian identities as a monolithic "model minority," we included Asian students in our study to better understand their experiences in upper-level mathematics courses.

In all, 27 students participated; all were current or former undergraduate mathematics majors who identified as Black/African American, Hispanic/Latinx, Asian/Asian American, Native American, or Native Hawaiian/Pacific Islander and who had taken or planned to take at least two of the following junior-level, proof-based courses: introduction to proof, introduction to abstract algebra, and real analysis. Data collection consisted of three phases: informational survey, primary interview, and secondary interview. The brief informational survey included background items related to students' identity, work obligations, and school obligations (cf. Jett, 2009). This survey asked questions about the number of hours students worked while taking these math courses, if they had to commute to campus, and whether they identified as a first generation college student. Similar to Herzig (2002), we structured the primary interview as a chronological mathematical autobiography. The secondary interview allowed us to co-construct a narrative with participants based on their responses to the primary interview. This narrative structure provided a space for students to clarify and further elaborate on their stated experiences in mathematics (Leyva et al., 2021a). The secondary interview also allowed us to conduct a member-check for validity purposes.

Overall, 13 students completed the survey and both interviews, and an additional 14 students completed an extended survey where selected interview questions were written as multiple choice questions. The surveys and interviews highlighted ways that real analysis was felt as gate-keeping; that students have responsibilities outside of class that influence their participation and engagement; and how students' experiences of the class depended heavily on the instructor, including how they attended–or seemed not to attend–to students' questions and contributions. A more comprehensive description of this part of the study is found in Bennett and Lai (in press).

Methods

The participants of the present study were five instructors spanning assistant, associate, full professor levels at the University. All five taught at least one of the three courses for mathematics majors in the past three years; most had taught more than one of these courses during multiple semesters. The professors (with pseudonyms N, P, T, V, Z) completed an informational survey and participated in a hour-long, semi-structured interview. Four of the five professors identified as white (the fifth chose not to respond), and all five answered "English" for the primary language that they think about or "do" math in, although this was at times different from their "native" language. None of the five identified as first-generation college students.

In the interview, we presented professors with quantitative and qualitative data in the form of DFW rates from Fall 2018-Summer 2023 and quotes from students in the above-described interviews. In particular, we showed them four responses to the question "What do you wish your professor knew?", which students interpreted broadly, and two responses to "What does it take to succeed in real analysis?" As the professors viewed the quantitative data, we asked probing questions, such as, "What drew your attention to this part?", "What do you think is the 'problem' that is being addressed?", and "Are there things that could change this outcome?" We allowed professors to choose which student quotes to which to attend. We asked questions such as, "What drew your attention to that student's experience?", "What's your understanding of what this student is trying to convey?" "Do you think a student might feel this way in your

course? What would you do?" These questions were meant to elicit a talk-aloud of acts of noticing, in particular *attending*, *interpreting*, and *responding*.

To analyze responses, we organized professors' noticings of the quantitative and qualitative data into tables structured by the FAIR framework (Louie et al., 2021), focusing first on how they *attended* to, *interpreted*, and *responded* to the data presented. Similar to Hand (2012) and Louie and colleagues (2021), we then analyzed the noticings to look for themes to help us understand how professors *framed* students' experiences in real analysis. In articulating frames, we described how professors noticed in deficit or anti-deficit ways and the impact on frames about students, mathematics, and interactions, using Louie's (2017) exclusionary and inclusive frames as an analytic starting point.

Findings

In this section, we present three main findings from our analysis of professor noticings.

Split of Asset-based/Inclusive and Deficit-based/Exclusionary Frames

A key finding in the analysis is the complicated nature of asset-based/inclusive frames and deficit-based/exclusionary frames; how a professor can hold both kinds of frames when discussing the qualitative evidence. Professor N enjoyed teaching real analysis. He loved his real analysis course when he was an undergraduate and attributes it as being his inspiration "to be a math major and become a mathematician," affirming the view that real analysis can be a gateway. Furthermore, he shared that he tells this story with his students whenever he teaches real analysis. In this way, Professor N holds an inclusive frame of mathematics.

When asked how real analysis compared to other similarly advanced undergraduate mathematics courses, Professor N pointed to his experience teaching a linear algebra course. While he does not teach linear algebra as proof-based, he shared:

> I have them justify things, but I'm not looking for what I would consider to be a properly written form of proof. I'm just looking for something kind of a weaker level of justification... [Real analysis] has been quite a bit harder for the students. I mean, there's some that just seem to really struggle with understanding epsilon-delta proofs, and it's a real challenge to get them past the class sometimes.

We understood Professor N as having framed students as either capable or not. While the gap in DFW rates was "disturbing" to him, it was also "unsurprising" that there was a gap, as students will have varied levels of preparedness and capabilities. Professor N is an example of how two opposing frames can coexist simultaneously yet not create a disequilibrium of personal beliefs about mathematics or students when discussing the quantitative performance data.

Persistence of Personal Experience as Interpretive Lens

A second central finding in our work is how professors primarily relied on their personal experience as an interpretive lens for noticing the presented data. This manifested as professors attending to and interpreting the student quotes in light of their own teaching experiences, sometimes regarding the goals or improvements they have in mind for their classes.

In his response to "What do you wish your professors knew", a student, Vince, shared how the "lack of representation of underrepresented students in math courses could discourage a student from organizing study groups or reaching out to others for support." When prompted to discuss one of the four student quotes, four of the five professors said that Vince's response "caught my attention" or were interesting in some way. Professor N said,

> I think what Vince wrote is the one that most caught my attention just because again,

> affirming this fear I have that underrepresented students are still kind of left out. But the guilt I have about the fact that I don't really know how to solve that or at least I haven't figured out a way and I haven't really done a great job of addressing this very real issue.

Professor N connected Vince's statements to his own beliefs and feelings about teaching, particularly about being inclusive in his classroom. In addition to his feelings of "fear" or "guilt", other professors conveyed their personal emotional reactions to what students shared, feeling "crushed" or "shocked" by some of the students' experiences. Similarly, Professor T attended to what Vince was saying in light of his own musings about teaching: "I think that Vince's was the most thought provoking to me, just because I think Vince talks about some of these things that have been on my mind the last couple of semesters."

We also found it noteworthy how the professors made evaluative statements of the presented student quotes based on their own perceptions and experiences. For instance, comments such as, "I think I agree with [student]", or "I absolutely believe the things she's talking about with her experiences" emphasized the (in)validity of students' accounts. At times, the evaluative statements seemed to justify dismissing what students said, like "I think his impression…is somewhat unrealistic." However, this perception of "unrealistic" is based on the reality of the professor, not on the lived experiences of the student.

We likened this phenomenon to the notion of listening to respond rather than listening to understand. When personal experience is the listener's primary lens, they bring what others say back to their own context.

Qualitative and Quantitative Evidence May Elicit Different Frames

When reading the statements of students' experiences, the professors seemed to acknowledge that people's stories are complex and there does not exist an immediate solution to address the challenges experienced. After reading that some students expressed feeling unsupported and underrepresented in their mathematics courses, Professor V said, "I know there's no magic solution and I don't know that there's anything short term that we can do, but maybe there's things that we can put in place to support and represent the students." Similarly, Professor T underscored the importance of seeing Vince as a whole person in the classroom:

> I think what Vince is talking about is having professors that really fundamentally don't understand his experience. [...] Vince wishes that professors understood his experience, what experiences and what aspects of his life and identity are coming along with him to this classroom.

Professor T expressed that professors should get to know students on an individual level in order to understand their experiences and full selves, not just as learners of mathematics.

In contrast, four of the professors viewed the quantitative data from a classroom level, rather than an individual level. This led to ponderings about what solutions might exist "for all" students in proof-based courses. Professor Z said, "There are things that work well for everybody. I don't know things that would work well for a specific student population, but what works well for everybody is additional support inside and outside the classroom." Four of the five professors mentioned that "getting students to talk to each other" or implementing active learning strategies were a viable solution to the institutional performance gaps presented in the quantitative data. In most cases, the qualitative data helped the professors problematize and shift away from "for all" solutions for the challenges that minoritized students face, to viewing and listening to students on an individual level.

Discussion and Conclusion

We discuss our three main findings through the lens of the FAIR framework (Louie et al., 2021). In Table 1, we illustrate professors' framing of students, mathematics, and the presented student narratives. Our analysis revealed that it was important to understand professors' framing of students and mathematics *prior* to analyzing their FAIR noticings of the data. During our session, we will share similar tables for each professor analyzing their noticings of both the qualitative student narratives and quantitative student achievement data (i.e., DFW rates) and how these align with or draw on their framings of students and mathematics in the context of proof-based courses for mathematics majors. We found that frames of students, mathematics, and data differed depending on the type and presentation of the data (i.e., qualitative narratives or quantitative rates and graphs). For instance, our third finding suggested that although professors interpreted student quotes as complex puzzles that should be addressed on a personal level alongside students, they interpreted quantitative performance data needing a "for all" solution (e.g., Leyva et al., 2022). We will share how the two tables compare across professor framings and noticings of the two data types.

Table 1. Noticings of students' real analysis experiences with the FAIR framework

Students	**Framing** students as people with many responsibilities, different capabilities, and intersecting identities		
	Attending to students' experiences and their (un)success in math	**Interpreting** student challenges as complex puzzles to solve	**Responding** inclusively to the identities of individual students
Mathematics	**Framing** real analysis and proof-based courses as rigorous and necessary		
	Attending to the difficulty of the subject shared by students	**Interpreting** the difficulty of the course as unavoidable	**Responding to** quotes with worry, but not knowing a remedy
Qualitative Data (Student Narratives)	**Framing** qualitative data from students as sometimes trustworthy, valid, and compelling and sometimes unbelievable or unhelpful		
	Attending to the validity of what students say	**Interpreting** student quotes in light of their own experiences	**Responding to** quotes with an evaluative statement

Finally, the protocol we used to prompt professors to notice (i.e., to state what stood out in the student quotes, rephrase what the student is trying to convey, and describe how the account could inform their own practice) was effective in focusing the discussion on the students' experiences while rooting the conversation in practical implications for teaching. We wonder how conversations about institutional performance gaps and improving student experiences are facilitated in meetings of departmental stakeholders, and if attendees are similarly given the space and structure to attend to, interpret, and respond to presented data. We encourage those working toward equitable changes in mathematics departments to first attend to and understand what students are sharing in their accounts of classroom experiences before looking for large-scale solutions and implications for teaching.

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