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The Science Student Electronic Exit Ticket (SEET) System: Visualizations to Help Teachers Notice and Reflect on Classroom Inequalities

Ali Raza[1], Tamara Sumner[2] and William R. Penuel[3]

Abstract

This study examined the ways in which an equity analytics tool — the SEET system — supported middle school science teachers' reflections on the experiences of diverse students in their classrooms. The tool provides teachers with "equity visualizations" — disaggregated classroom data by gender and race/ethnicity — designed to support teachers to notice and reflect on inequitable patterns in student participation in classroom knowledge-building activities, as well as "whole class visualizations" that enable teachers to look at participation patterns. The visualizations were based on survey data collected from students reflecting on the day's lessons, responding to questions aligned with three theoretical constructs indicative of equitable participation in science classrooms: coherence, relevance, and contribution. The study involved 42 teachers, divided into two cohorts, participating in a two-month professional learning series. Diary studies and semi-structured interviews were used to probe teachers' perceptions of the visualizations' usability, usefulness, and utility for supporting their reflections on student experiences and instructional practices. A key result is that only the "equity visualizations" prompted teacher reflections on diverse student experiences. However, despite the support equity visualizations provided for this core task, the teachers consistently ranked the whole class visualizations as more usable and useful.

Notes for Practice

- Teachers can use data visualizations of student experience to reflect on classroom inequities in science lessons. "Equity visualizations" such as disaggregating data by gender, race/ethnicity can engage teachers in sensemaking about equitable instruction.
- For adopting visualizations of learning analytics in practice, teachers require ease-of-use, familiarity, and simplicity.
- Teachers need support to engage in sensemaking when using visualizations of equity from their classroom to use them more frequently as compared to visualizations that don't break down data by gender, race/ethnicity ("whole class" visualizations).

Keywords

Learning analytic dashboards, equity visualizations, studies of teacher adoption and use, learning sciences, science education

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Corresponding author [1]Email: a.raza@colorado.edu Address: Department of Computer Science and Institute of Cognitive Science, University of Colorado Boulder, 552 UCB, Boulder, CO 80309-0552. ORCID iD: https://orcid.org/0000-0002-2438-6054
[2]Email: sumner@colorado.edu Address: Department of Computer Science and Institute of Cognitive Science, University of Colorado Boulder, 552 UCB, Boulder, CO 80309-0552. ORCID iD: https://orcid.org/0000-0002-8785-3238
[3]Email: william.penuel@colorado.edu Address: Institute of Cognitive Science, University of Colorado Boulder, 552 UCB, Boulder, CO 80309-0552. ORCID iD: https://orcid.org/0000-0001-7096-6669

1. Introduction

Students in public schools in the US have become increasingly diverse with respect to gender, race/ethnicity, culture, and socioeconomic status. In response to these changing demographics, teachers and schools are looking for approaches and tools to help them create equitable classrooms, that is, classrooms where all students are able to participate in rich and engaging learning experiences (Brown, 2021; Penuel & Watkins, 2019). In our work, we define equitable classrooms as those where students' participation in and contributions to classroom knowledge-building activities cannot be predicted by their race/ethnicity, gender, or culture. However, research has repeatedly shown that creating equitable classrooms can be challenging for teachers. For instance, in science classrooms, multiple studies have documented how students experience inequity in their classrooms based on their race/ethnicity, gender, or home language (Carlone, 2004; Warren & Rosebery, 2011; Wright et al., 2018). In small group work, differences in student status based on their race/ethnicity and gender have been shown to undermine their participation in collaborative knowledge building (Theobald et al., 2017).

Recently, there have been significant advances in the nascent field of "equity analytics," which explores how learning analytic paradigms can be used to help teachers create and sustain equitable classroom learning environments (Reinholz & Shah, 2018, 2021). Equity analytics applications systematically gather data about student participation in classroom activities and provide visualizations of these data, disaggregated by gender, race/ethnicity, and other important social identities. One purpose is to identify inequities in participation, which Shah and Lewis (2019) define as misalignments in distribution of participation and opportunities for participation in classroom learning activities. Another purpose is to support teachers in using data visualizations to notice patterns of student inequities in participation and use this information to modify their instructional practices. In this study, we examined how teachers used this novel equity analytics system, focusing on understanding how, when and why they choose to use — or not use — the provided equity visualizations. The two research questions motivating this study are these:

RQ1. Do teachers notice differences in students' classroom experiences when presented with equity visualizations?

RQ2. What kinds of visualizations do teachers prefer, and why?

To answer these questions, here, we present a novel web-based application — the Science Student Electronic Exit Ticket (SEET) system designed to support middle and high school science teachers to create more equitable classroom experiences. Teachers use this system to collect student experience data in the form of short surveys, asking students how they participated in or contributed to knowledge-building activities in class that day. The application provides teachers with several ways of visualizing their student data, including three "equity visualizations" that have been carefully designed to support teachers to notice differences in student participation across race/ethnicity and gender, and three "whole class visualizations" that depict student experience data for the class as a whole. The three equity visualization types emerged from a year-long, iterative co-design process with middle school science teachers (Raza et al., 2020; Raza et al., 2021).

We conducted a mixed-methods study with 42 middle school science teachers who used the SEET system over a two-month period. Our methods included a diary study, where teachers filled out a reflective questionnaire every time they used the system, as well as semi-structured interviews that probed them about their visualization preferences and their rationale for choosing different visualizations. Our study found that the "equity visualizations" prompted teachers to notice and reflect on inequities in student participation based on race/ethnicity and gender. However, teachers greatly preferred the "whole class visualizations" that did not prompt noticings to the "equity visualizations." This study aims to contribute to the learning analytics field by looking at teachers' use of data visualizations to inform their own efforts to promote more equitable educational opportunities in classrooms.

2. Theory and Related Work

This section describes the theories influencing the design of the SEET system as well as related prior work on equity analytics systems and teachers' use of learning analytics dashboards and visualizations.

2.1. Teacher Use of Learning Analytics Dashboards and Visualizations

Visualizations are a key component of many learning analytics dashboards for teachers. There has been extensive research examining how a variety of visualization types can support teachers to reflect on whole classroom activities, including bar charts, line graphs, dot plot charts, lollipop charts, timelines, node-link diagrams, and heatmaps (Ahn et al., 2019; Li et al., 2021; Dourado et al., 2021; Vieira et al., 2018; Wise & Jung, 2019). Studies of these systems highlight the challenges teachers face when trying to interpret student data. Factors such as ease-of-use and perceived usefulness have been shown to impact dashboard use (Ali et al., 2013; Dazo et al., 2017). Recent research suggests that visualizations requiring a "learning curve" can impede teacher adoption of learning analytics dashboards (Arthars & Liu, 2020). These usability challenges can limit the kinds of inferences teachers are able to draw from their student data (Li et al., 2021). Research suggests that as teachers become more proficient in dashboard use, they are able to draw more connections between their pedagogical knowledge and their classroom data (Molenaar & Knoop-van Campen, 2018). Another factor hindering teachers' effective use of learning analytics dashboards is the lack of alignment between what the dashboard is visualizing and the teacher's "pedagogical intent" or goals for their classroom (Lockyer et al., 2013).

Understanding teachers' sensemaking processes as they use different dashboards and visualizations is a rich and critical area of inquiry within learning analytics (Verbert et al., 2020). Teachers' sensemaking processes often have three distinct stages: 1) teachers' come to the visualization with an area of curiosity, 2) they interpret data by "reading" the visualization, and 3) they generate explanations of the patterns they observe (Wise & Jung, 2019). While teachers may have an established

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area of curiosity, they do not necessarily come with predefined questions looking for answers (Molenaar & Knoop-van Campen, 2018; Wise & Jung, 2019). Furthermore, different teachers draw different meanings from the same visualization, which Ahn et al. (2019) refer to as the "one chart many meanings" phenomenon. In their study, this variability arose from differences in teachers' instructional practices and classroom contexts. This body of work suggests that there are complex interactions between the types of data being visualized and the types of representations being used in the sensemaking process, necessitating further studies when introducing new visualizations, data types, and representations. Here, "sensemaking" refers to educators' noticings and interpretations of student experience data that arise both from their own goals and from interacting with data (see also Campos et al., 2021).

Despite this extensive body of research into visualization types for supporting teacher reflection, most visualizations don't support disaggregation of classroom data by gender or race/ethnicity for equity purposes (Williamson & Kizilcec, 2021, 2022; Vieira et al., 2018). As a result, there have been efforts and calls within the learning analytics field to design tools for equity, diversity, and inclusion (EDI) to support learning for all learners (Wise et al., 2021; Ochoa et al., 2020). In this study, we extend this body of literature by examining how novel equity visualizations support teachers to reflect on inequities evident in student experience data and how this relates to their instructional practices.

2.2. Constructs and Instruments for Characterizing Student Experience

At the core of any approach to developing an equity analytics system lie two key decisions: 1) what constructs will be used to measure and characterize student participation in, or perceptions of, the learning environment; and 2) how information on these constructs will be gathered. Reinholz & Shah (2018) developed a classroom observation tool ("EQUIP") that relied on measures of student discourse, such as type of discourse (content-focused or logistics-focused), length, and wait time. In this work, a trained observer was sent to classrooms to score student discourse using the framework. These data were used in visualizations that enabled teachers to examine student talk during a particular lesson and over time, disaggregated by gender and race/ethnicity. Commercial applications are also emerging in this space. For instance, the PERTS system builds on constructs such as students' feelings of belongingness, the perceived relevance of their schoolwork, whether they received feedback from their teacher, and other constructs (PERTS, 2010). In this approach, surveys ask students to reflect on the past week and answer a series of questions tied to these constructs.

In our own study, we used three constructs to measure and characterize students' classroom experience: coherence, relevance, and contribution. Prior research indicates that these three constructs together provide a good predictor of equity in science classrooms (Penuel et al., 2018; Penuel & Watkins, 2019). Coherence refers to student perspectives of the progressions of their learning experiences, and whether these progressions were driven by student questions, ideas, or investigations (Reiser et al., 2017, 2021). Coherence is particularly salient in contemporary science classrooms as a marker of the degree to which students are engaged in "figuring out" a scientific phenomenon or developing solutions to a design problem. As noted by Reiser et al. (2021, p. 1) "coherence arises when students see their science work as making progress on questions and problems their classroom community has committed to address, rather than simply following directions from textbooks or teachers." The relevance construct is rooted in expectancy value theory (Eccles, 1983), which highlights the importance of enabling students to make connections between their interests and identities and classroom activities. These relevance connections can lead to motivation, engagement, persistence, and self-regulation in learning (National Academies of Sciences, Engineering, and Medicine, 2018). We chose "contribution" as our third construct as student contributions in science classrooms as partners in knowledge building are considered critical in contemporary science reform (Schwarz et al., 2017) as classrooms shift from a model where the teacher is the sole instructional, knowledgeable, and authoring agent. Rather, in science classrooms, the goal is to position students to be epistemic agents, i.e., "individuals or groups who take, or are granted, responsibility for shaping the knowledge and practice of a community" (Stroupe, 2014, p. 488). Further, this view is in line with supporting active learning in science classrooms where students engage in their learning by collaboratively building on small or large group discussions (Arthurs & Kreager, 2017).

We draw on experience sampling methodologies (Larson & Csikszentmihalyi, 2014) for collecting data on student experience. Such methods are good means for measuring the frequency and patterns of cognitive and affective processes in everyday situations, such as classroom-based learning activities (Zirkel et al., 2015), At the end of a class, students complete a short survey asking them to reflect on the lesson they just experienced that day. These surveys are not administered daily but at the discretion of the teacher who selects specific lessons on which to gather feedback. Each student responds to a short survey containing 10 questions delving into aspects of their classroom experiences that are aligned with each of the three constructs. For each question, students choose "yes," "no," or "not sure." Table 1 lists all the survey questions in each construct of student experience.

Table 1. Student Experience Survey Questions for Three Constructs

Coherence	Relevance	Contribution
1) We work together to determine what ideas are most persuasive. 2) The teacher guides us to share our prior experiences or ideas about a phenomenon or topic to inform what we will do next. 3) Today we started class by reminding ourselves what we learned in the last class.	1) Today's science lesson was personally meaningful. 2) I found today's lesson interesting. 3) If people in my city or town understood the science we learned in today's lesson, they would do something that could help make our city or town a better place.	1) The teacher encourages us to build on and critique one another's ideas. 2) Everyone's ideas are heard. 3) Did you share any ideas aloud today with the whole class, a small group, or a partner? If you answered yes to the last question, did any of your ideas influence the class or help others?

3. Study Design and Methods

This study was conducted during a virtual professional learning series for middle school science teachers. The purpose of the professional learning series was to support teachers to improve their instruction by creating more equitable participation and learning opportunities in their classrooms. Teachers collaborated in small groups, meeting four times over a two-month period for two hours at a time. All participating teachers used the visualizations and SEET system workflow described below throughout the series. Teachers received training on the SEET system and visualization interpretation as part of the series. The training for the SEET system was live demoed for 15 minutes to all teachers who were part of the series on how to collect student data and reflect on visualization. Further, to support the training, short recordings were also provided to teachers to access during the series. The professional learning series was conducted twice, consecutively, with two different cohorts of teachers.

We chose to focus on the middle grades level because it is a critical period for student decisions to go into STEM careers (Tai et al., 2006). Further, there is evidence that interest levels decline during these years (Basu & Barton, 2007). The length and intensity of the professional learning offered is consistent with that of other widely available opportunities for science teacher learning in the middle grades (Banilower et al., 2018).

3.1. Learning Analytics Visualizations and the Equity Analytics Tool

3.1.1. The visualizations

The six visualizations used in this study render student classroom experience data organized around three constructs described in the previous section: coherence, relevance, and contribution. These visualizations were co-designed with secondary science teachers during a longitudinal, iterative design process described elsewhere (Raza et al., 2020, 2021). Three of the visualizations, which we refer to as the "whole class set," show only whole classroom responses for each of the three constructs. The remaining three visualizations we refer to as the "equity set," as they show views of student classroom experience data broken down by gender and race/ethnicity.

Whole Class Visualization Set. Figure 1 provides examples of each of the three whole class visualizations. The "overall bar chart" (Figure 1a) shows the percentage of students who responded "yes" to one question about student experience as well as the number of students who attempted the question. It is important to note that this visualization is not a single bar chart, but rather 10 small bar charts displaying the response rate for each question in the survey (see Figure 4 in the appendix as an example). This approach of showing "small multiple bar charts," builds on the work of Heer et al. (2010). The "over time by constructs" (Figure 1b) line chart displays the average of all questions corresponding to a single student experience construct. That is, this visualization shows a line chart with interactive legends that enables the viewer to selectively show or hide student responses associated with particular constructs. The "over time by questions" (Figure 1c) line chart depicts change over time, by question responses, across multiple lessons. The y-axis shows the percent of "yes" responses, and the x-axis shows the date. Questions belonging to a specific construct can be opened and closed by clicking on the legend. This chart also provides an interactive legend similar to the one described for the previous visualization.

Equity Visualization Set. Figure 2 provides examples of each of the three equity visualizations, which are extensions of those described above with extra functionality to disaggregate student responses by race/ethnicity and gender. The "disaggregated bar chart" by gender and race/ethnicity (Figure 2a) shows data for one lesson. The y-axis shows the demographic data and the number of students, while the x-axis shows the percentage of students responding "yes" to the particular question. As described above, this visualization shows one of these bar charts corresponding to each question. The "over time by gender and race/ethnicity" (Figure 2b) line chart shows the percentage of "yes" responses to all of the student experience questions for a specific demographic marker such as female, non-binary, or African American. The "choropleth

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heatmap" (Figure 2c) displays gender and race/ethnicity data on the y-axis. A colour encoding is used in each matrix to represent student data: when more students respond "yes" to a question, the colour intensity will be higher. When hovering over any cell in the matrix, a tooltip will display the question, percent "yes" answer, and number of students responding. Figure 4 in the appendix provides a full view of dashboard.

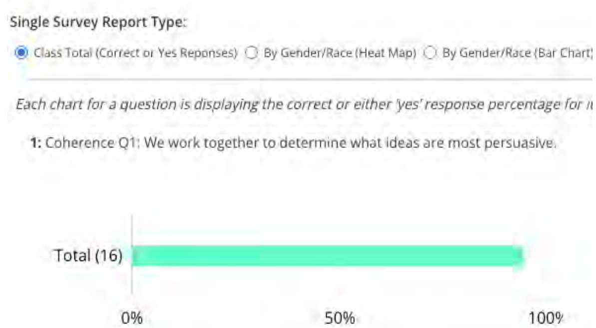

Figure 1a. Overall bar chart.

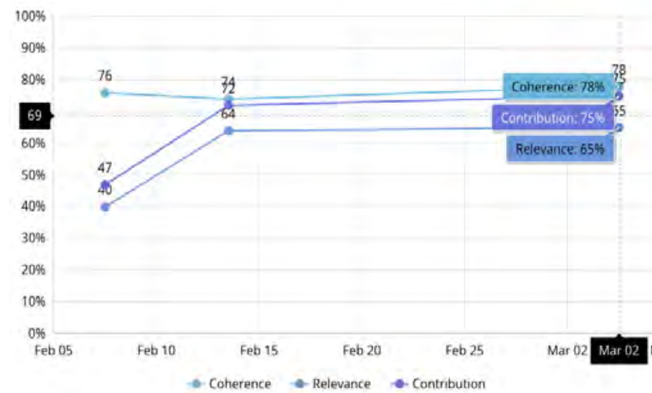

Figure 1b. Over time by constructs.

Figure 1c. Over time by questions.

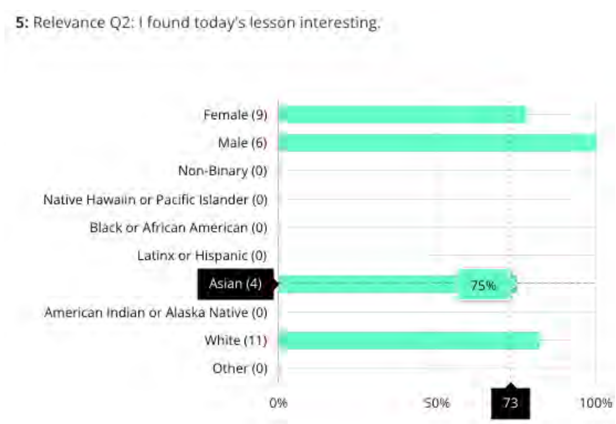

Figure 2a. Disaggregated bar chart.

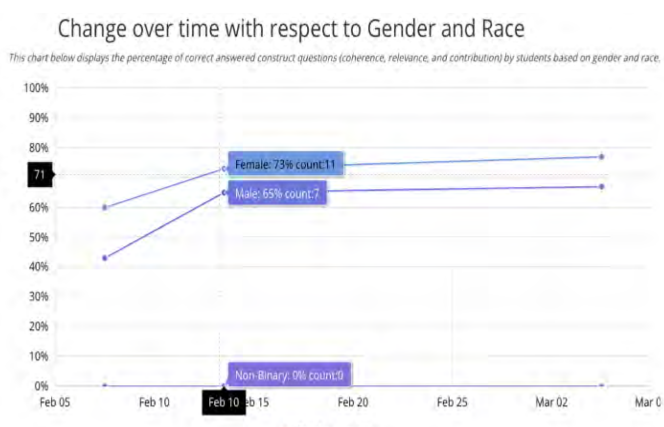

Figure 2b. Over time by gender and race/ethnicity.

Figure 2c. Choropleth heatmap.

3.1.2. Teacher and student interactions with the SEET system

Teachers use the SEET system to collect information about student perceptions of their classroom experiences during a specific lesson. The high-level workflow is shown in Figure 3. The workflow is initiated when teachers administer a student experience survey (Step 1) to a particular classroom and students respond (Step 2). Student responses are automatically tabulated and visualized to support teacher sensemaking (Step 3). In the fourth stage, teachers select new instructional strategies to implement in their classrooms (Step 4), and the cycle begins anew. Before using the system for the first time, students are explained the purpose of the SEET system and how their data will be used, both by their teacher and with a recorded video prepared by the research team.

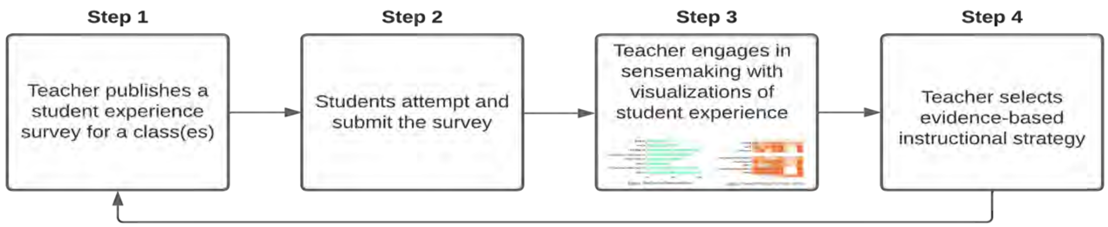

Figure 3. Teacher workflow using the SEET system.

3.1.3. Student anonymity

This equity analytics system is designed to protect student anonymity so that they feel comfortable providing their teachers with this feedback. The system generates a unique identification code for a student to use that school year. Students enter their demographic data, such as race/ethnicity, gender, and language at home, once when they sign up for that class. Thus, there is no tracking of students across courses, over time. To further protect anonymity, the system does not report results for groups of 2 or less.

3.2. Participants

Two separate cohorts of middle school science teachers were recruited for spring and fall semesters in 2021. Teachers across the United States were recruited using social media (Twitter) and through professional organizations such as the Council of State Science Supervisors. For this study, we are treating these cohorts as one sample since we focus on their use and interpretation of the visualizations, which were the same across the two professional learning series. This study sample consisted of 42 teachers (33 female, 9 male) from 19 different US states. The teachers were majority white (27), with the remaining 15 teachers identifying as African American or Black (2), Asian American (4), Latinx or Hispanic (2), Native American (1), or other (6). Three of the teachers had less than 2 years experience; the average teaching experience was 12 years. All teachers were compensated at an hourly rate for their participation in the workshop series and research data collection, averaging between $300 to $500 per teacher. The IRB at University of Colorado Boulder approved this study. As stipulated in the IRB, teachers fully consented to participate in the research, while we were allowed to send an information form home to students without requiring parental consent, because the system does not collect or display individually identifiable student data.

3.3. Data Collection

The two data sources used in this study were diary study entries and semi-structured interviews.

Diary Study. The diary study method asks participants to systematically record qualitative or quantitative data about their experiences, building a "diary" as they log individual entries over time (Rieman, 1993). In this study, teachers were asked to use the SEET system and complete diary entries: 1) the first time they collected and viewed their student experience data; and 2) after each time they tried a new instructional strategy in their classroom. Teachers made diary entries over the two-month professional learning series. Each "diary" consisted of an anonymized folder containing a shared Google document with a template for each entry. The template was divided into areas that posed different questions to prompt teacher reflections, such as "What patterns do you notice in the data, and what do you wonder about?" To answer this prompt, we provided a three-column table with these headings:

- Things I notice
- Things I am wondering about
- Which visual representation I am looking at for patterns?

Semi-Structured Interviews. We conducted a semi-structured interview ranging from 10–15 minutes with each teacher after the conclusion of the professional learning series. These interviews were conducted online using the Zoom video conferencing tool, and all interviews were video-recorded and transcribed. During the interview, the researchers shared their screen and showed the interview participant a figure containing all six visualizations. Participants were asked to "rank each visualization in relation to how useful they were to your practice, from most to least useful, and also provide a rationale for your rank." After each participant responded to this prompt, the researcher repeated the rank and allowed the teacher to change their ranking if desired.

3.4. Data Analysis

We merged all teacher reflections from their individual diary entries into one data source. We analyzed data collected from the diary study to address whether teachers noticed differences in race/ethnicity and gender when examining equity visualizations. We then organized teacher reflections by visualization type, i.e., the six visualizations described earlier. One of the authors then analyzed these reflections line-by-line to see which visualization prompted "noticings or wonderings" related to equity and/or one of the three constructs (coherence, relevance, contribution) adopting a deductive approach (Creswell & Clark, 2017). To count as an equity-related reflection, the teacher needed to explicitly refer to students' race/ethnicity or gender in their diary. Similarly, to count as a construct-related reflection, the teacher had to explicitly mention one of the three constructs. Another author then checked the tally of each reflection mapping to equity and/or one of the three constructs to resolve any errors.

To answer the second research question — What visualizations do teachers prefer and why? — we turned to the semi-structured interview data. Because teachers were being asked to reflect on each visualization, we cleaned and merged the interview data from each teacher into a visualization-specific data source, one for each visualization type. To analyze these data, we used inductive coding following a grounded theory approach (Charmaz, 2006). Two authors conducted an initial analysis and created six code books, one for each visualization type. One author wrote code definitions and shared them with the other coder. Both coded the transcripts line-by-line. The two authors then met multiple times to reach reliability in any category with a percentage agreement of less than 80 percent; disagreements were discussed until consensus was reached (Miles & Huberman, 1994). After finalizing the inductive code books, the two authors met multiple times to refine and review the categories and to create cross-visualization themes. This approach enabled us to identify both visualization-specific attributes that influenced teacher rankings as well as general themes (not specific to any particular type) that influence teacher rankings.

4. Results

Our results are organized around the research questions posed in the Introduction.

4.1. RQ1: Do teachers notice differences in students' classroom experiences when presented with equity visualizations?

In this study, teachers recorded 248 "noticing and wondering" reflections in their diaries. Of these 248 reflections, 35 considered students' race and/or gender, while 213 considered the three constructs of student experience (coherence, relevance, and contribution). As shown in Table 2, only the equity visualizations (Figure 2a, 2b, 2c) prompted teachers to reflect on how race/ethnicity or gender may impact student classroom experiences. Teachers reported zero reflections related to race/ethnicity and gender when using the whole class visualization. Both sets of visualizations — equity and whole class — prompted reflections on student experience related to the three constructs, with the whole class visualizations prompting 76% of the construct-related reflections compared to only 24% by the equity visualizations.

Table 2. Teacher Noticing and Wondering with Different Visualizations

Diary Study Reflection	Equity Set	Whole classroom	Total Reflections
Related to Race/Ethnicity and Gender	35 (100%)	0 (0%)	35
Related to Constructs	52 (24%)	161 (76%)	213
Interview Reflection			
Related to Race/Ethnicity and Gender	71 (92%)	6 (8%)	77

These excerpts from teachers' recorded reflections illustrate how these two types of reflections differ based on visualization type. For instance, when Teacher 13 interacted with the Bar Chart Disaggregated by Race/Ethnicity and Gender (Figure 2a), they commented, "I am not surprised that the girls ranked lower in all three of these questions (contribution). Although there are a significantly higher number of girls in this class, the boys tend to speak up more, share more, discuss more, et cetera." This contrasts with the reflections of Teacher 10 when interacting with the whole class Overall Bar Chart (Figure 1a): "Students are still not able to make connections of the concepts they are learning with real life. Students still feel that their ideas do not influence the class or help others." In this reflection, the bar chart prompted the teacher to think about relevance and contribution for the students as a whole.

We saw comparable results in the interview data, where equity set visualizations prompted most reflections on race/ethnicity and gender (92%), compared to the whole class visualizations (8%, Table 2). All three of the equity visualizations prompted reflections on gender and race/ethnicity during the interviews: Over Time by Gender and Race/Ethnicity (54%, Figure 2b), Heatmap (21%, Figure 2c), and Disaggregated Bar Chart (17%, Figure 2a). Interestingly, most equity reflections focused on gender (29 out of 42 teachers, or 70%), while only 16 out of 42 (38%) of teachers commented on race/ethnicity. Teacher 29 talks about this disposition to focus on gender in her interview:

Oh, I think it does a lot for me actually … I'll focus more I guess [on] the gender than the race, since I do have more of one student, but the gender it really helps me understand … am I, like tailoring my teaching more towards the boys or … do the girls feel like they're not being heard. … am I hearing more boys' voices and my calling on them more than the girls, etc., so I think that I don't ever really pay attention to that um and so just having the data in front of me I can be like Okay, let me be intentional about what I'm doing now.

The interview data also highlighted some of the ways in which the equity visualizations supported teachers to reflect on patterns in their classroom, with teachers reporting that some visualizations helped them to view how specific groups participated in class (by gender and race/ethnicity) or supported them to view intersectionality across groups (for instance, Black girls). Teacher 40 talks about the value of the Heatmap (Figure 2c) for supporting their equity reflections: "As time went on, I began looking more at the heatmap and I was using the heatmap to see which students were responding in which way. So is it mostly you know how do Hispanics see themselves how do white see themselves how do the females and males and the Asians, how did they all see themselves to perceive themselves within the classroom and what is it that I can do to quickly tweak my teaching in order to see changes in the Heatmap."

Some teachers also mentioned that looking at equity visualizations featuring gender and race/ethnicity could be "emotionally hard" to make sense of. For instance, Teacher 6 described that he did not like the Disaggregated Bar Chart (Figure 2a) because it forced him to look at intersectional data combining gender and race/ethnicity:

I think, in my brain, I find it harder to kind of combine the idea that, for example, like it's disaggregated in like you know he's seeing that. You see, like the total for gender and then you see the total for race and like that can be kind of a little bit of dissonance in my brain. … or Black girls I'm not doing you know enough so I think maybe that's why I gravitate towards that one least.

4.2. RQ2: What kinds of visualizations do teachers prefer, and why?

To answer this question, we analyzed data collected from interviews with teachers, asking them about their use of the different visualizations available in the system. As part of the interview, teachers were asked to rank order the six visualizations based on the amount that they used them, where a ranking of 1 corresponds to their most used visualization and a ranking of 6 is least used; they were also asked to provide rationale justifying these rankings.

As shown in Table 3, teachers ranked all the whole class visualizations higher than any of the equity visualizations. This preference for the three whole class visualizations held across teachers' individual rankings of visualizations as well as the sum of rankings across all the teachers. We provide the sum of rank as another view to show any differences between "Whole Class" or "Equity Set" visualizations preference.

Table 3. Teachers' Rankings of Six Visualizations

	Whole Class visualization			Equity Set visualization		
	Over Time by Constructs	Overall Bar Chart	Over Time by Question	Disaggregated Bar Chart	Over Time by Gender and Race/Ethnicity	Choropleth Heatmap
Median Rank	2.5	3	3	4	4	5
Sum of Rank	102	98	110	125	130	148

To better understand why teachers ranked visualizations in a particular way, we coded the rationale they provided in their interview for each ranked visualization. Our codes examined teacher perspectives on the ease-of-use of particular visualizations, whether they indicated that the visualization was useful for reflecting on equity, and their perceptions of the utility of the visualization for their classroom context. Individual codes were then grouped into higher-level themes (Table 4).

The Choropleth Heatmap was ranked lowest by teachers, while relatively simple visualizations such as the line and bar charts were ranked highest. This preference for simple encodings is underscored throughout the interview data. For example, Teacher 1 ranked the overall bar chart as her first preference, noting, "you got to physically see the 0% – 50% – 100% — you could watch the numbers change from question to question… the bar chart, in my opinion, is the easiest to read and the fastest to get the information you want from it and it's the simplest." Our qualitative coding of the interviews found that many teachers expressed similar opinions, citing the bar chart's overall ease of use: simple/easier (24), helpful/quickest (9), faster to get information (6), feels confident in reading (4), likeness (2), good insight (3).

Teachers reported that both of the whole class "over time" line charts were easy-to-use, with the Over Time by Construct visualization supporting them to easily spot high level trends, while the Over Time by Question visualization better supported exploration of the data. For instance, Teacher 3 describes their use of the Over Time by Construct visualization (ranked #1) to spot trends: "I like looking at the lines. For me, it was just a quick visual of the directionality of where I was heading with my data, And then I could really dig in more." Whereas Teacher 14 describes how they used the Over Time by Questions visualization (ranked #1) to explore their classroom data:

> *…the one that was most useful to me, or the one that I spent the most time looking at, was Over Time by Question. Because that allowed me to see growth over the three data collection points or times and how specific questions were associated with that, as opposed to Over Time by Construct, which is where you had questions … grouped together that didn't tell you necessarily exactly what the responses were...*

When reflecting on her use of the heatmap (ranked last, #6), Teacher 2 remarked "I don't like the heatmap. All the rest are great. … I must not be very smart … Maybe because my data is not as big. … I didn't get anything … that I couldn't get out of the other charts, but that's just me, because I don't know how to use it." Frustrations with the heatmap visualization were evident across many teachers, with others citing issues such as it being hard to read or make sense of (17), hard to interpret the colours, difficult to remember the meaning of the colours, too many colours (13), no previous experience/familiarity (17), and a high learning curve (8).

It is important to note that not all teachers found the heatmap difficult to use. Teacher 3 ranked it highly (top rank of #1). He justified this high ranking by explaining that it provided all the information he wanted in one place, and he had prior experience with similar visualizations: "Because … everything [is] in one place and it's really easy to make really targeted decisions there. …we all come from really different backgrounds and … I used to be in geospatial science [so I'm] pretty comfortable with … visualizations like that." A few other teachers also found value with this type of visualization, indicating that the heatmap was useful in these ways: helpful in displaying gender/race/ethnicity (8), overall/summarizing (6), liked colour shading (5), useful tool (5), easy for targeted decisions (4).

Table 4. Themes Influencing Teachers' Ranking of Each Visualization

Visualization	Theme name (Code Frequency)
Overall Bar Chart	Visually easy to read (30); Supportive (9); Provide overall classroom data (22); Help with starting analysis (15); Helpful in seeing one question at a time (14)
Over Time by Constructs	Visually easy to read (29); Helps inform teaching (11); Provided an overall view of student experience (15)
Over Time by Question	Visually easy to read (11); Too much going on (10); Facilitates granular look at data (36); Did not find the need to use (4)
Disaggregated Bar Chart	Easier to read with confidence (22); Facilitates granular look at data, including equity-oriented data (18); Visualization not useful (11); Data not useful (3)
Over Time by Gender and Race/Ethnicity	Mixed perceptions of readability (6); Facilitates granular look at data, including equity-oriented data (57); Helps inform teaching (9); Data not useful (15); Diverging perspectives on equity (4)
Choropleth Heatmap	Complex to read and interpret (41); Little familiarity with this chart type (26); Facilitates granular look at data, including equity-oriented data (18); Helps inform teaching (6); Diverging perspectives on utility (21); Data not useful (4)

4.2.1. Perceived ease-of-use based on simplicity and familiarity

When providing rationale as to why they preferred visualizations such as the whole class bar and line charts, teachers cited reasons based on the simplicity of the representation and/or their prior familiarity with the representation. For example, when explaining why they liked both bar charts (Overall and Disaggregated), teachers cited reasons such as simple/easier (24), helpful/quickest (9), faster to get information (6), feels confident in reading (4), familiarity with bar chart helped with disaggregated bar chart (3), likeness (2), not too much data (2), and past usage (1). For instance, Teacher 10 cited her familiarity with bar charts as the reasons she ranked the Overall Bar Chart second: "I usually use the bar charts in my classroom … But my classroom has one wall, the coordinate plane. You will see all the coordinate planes on one wall and the other one has …

their goals… so I think, because I have been talking to [students] about bar charts a lot so maybe that's the reason." Similarly, Teacher 7 explains why she rated the Disaggregated Bar Chart second, behind the Overall Bar Chart that she ranked first: "… the next most helpful would be the disaggregated bar chart. I'm just a bar chart person. That was the simplest."

Teachers' perspectives on the ease-of-use of the Choropleth Heatmap were polarized. A few teachers (12) found it easy-to-use, often citing their prior familiarity with these types of representations. In these cases, teachers reported that the use of colour to denote the percentage of students responding "yes" positively contributed to their practice by providing a quick snapshot of the day's lesson across equity markers (race/ethnicity and gender). In their interviews, they described the heatmap in the following ways: supporting their overall/summarizing (6), liking the colour shading (5), and helping them to identify patterns (3). For instance, Teacher 33 ranked the Heatmap third, noting that it provides a quick overview of student experience: "It's really easy to see based on the colour quickly … I just thought it was fascinating to see either how students responded similarly or responded differently to the same question." Most teachers, however, reported finding the heatmap very difficult to use, often citing the use of colour as being problematic (Figure 2c). For instance, teachers reported that the colours make the heatmap representation hard to read or make sense of (17); colours make interpretation difficult, it is difficult to remember the colour codings, or there are too many colours (13); and too much data in one display (2). For example, Teacher 3 narrates why she ranked it sixth: "… my mind just doesn't think in this way of the heatmaps … I couldn't tell you exactly what it is, but … there's so much stimulating the mind."

4.2.2. Barriers to using equity visualizations

When talking about why they did not prefer the equity visualizations, two themes emerged from the teachers' interviews: 1) their classroom context and 2) their own perspectives on equity. With respect to their classroom context, some teachers (13) said there was little reason to look at visualizations disaggregated by race/ethnicity and gender since there was very little racial or gender diversity in their classrooms. Teachers noted that in some cases, there may have been only one or two Black students, or one transgender student, in their classroom. In such cases, the SEET system would not have displayed this information due to the protocol for preserving student anonymity, which prevents the system from displaying data from two or fewer students in a group. We see evidence for this concern in the teacher interviews across all three equity visualizations: less useful due to lack of sample (4), not a large enough sample size (7), small sample size made it less useful (3), and not all students were included in race/ethnicity (1). For example, Teacher 5 talks about how limited gender diversity restricted her use of the Disaggregated Bar Chart, which she ranked sixth: "You know it's female and male. There weren't very many kids that identified as non-binary. Maybe only had one or two. And then it's just the white and I just don't have [other races]." Similarly, Teacher 24 talked about how lack of classroom diversity limited her use of Over Time by Gender and Race/Ethnicity visualization, ranked third: "I think [race is] just really not applicable … I just have such a homogenous group that … there's really nothing to look at there…"

The second barrier to use stemmed from teachers' own equity beliefs. Specifically, a small number of teachers (7) reported that showing classroom participation data disaggregated by race/ethnicity and gender did not reflect their personal interests or their personal beliefs about classroom equity. For instance, Teacher 19 explained that she was not personally interested in viewing one of the equity visualizations, noting, "Over time by gender… I'm not personally interested in that." Teacher 9 cites differences in personal beliefs, describing how she views equity through the lens of equal access to resources: "…it's equality, we are talking about equity. Where does this thing affect gender and race? The public school system is providing equal opportunity. There are the same table, chairs, same teachers. Everything is the same." These perspectives contrast with those expressed by many teachers who noted the value of understanding student participation disaggregated by race/ethnicity and gender. Teacher 15 discusses the value of looking at data reported by gender: "But I will say gender plays more important role. Because — especially in science and math classes — I have seen that male students, they try to dominate, they try to ignore female voices. And females are usually not chosen by the group as the leaders." While Teacher 8 discusses how they value looking at classroom data disaggregated by race/ethnicity: "I always want to see how my Latinos and everybody in general … white people also benefit from seeing people of colour excel … it helps build their understanding that we are equals … and that's a good thing."

5. Discussion

In this study, we examined how middle school science teachers used visualizations, investigating teacher perceptions of the usability, use, and utility of these visualizations, as well as the factors that influenced these perceptions. Our core finding is that the equity visualizations functioned as intended; that is, these three visualizations prompted teachers to reflect on how student participation patterns varied by race/ethnicity and gender. This finding contrasts with the whole class visualizations, which rarely prompted such equity-oriented reflections. Our second finding is that most teachers greatly preferred the whole class visualizations, for a variety of reasons, and used them much more frequently, despite the fact that they had volunteered to participate in a two-month long professional learning series in order to improve the equity of student participation in their science classrooms. Teachers reported that ease-of-use, simplicity, and familiarity with common chart types — such as bar and line charts — heavily influenced what visualizations they chose to use. These preferences mean that they may be less likely to generate ideas about how to address equity if they don't use those visualizations. Further, they might have a simpler view — possibly too simple — about how best to achieve equity of experience in their classrooms.

While this study shed light on our two research questions, it also raised intriguing new questions and opportunities for the learning analytics field when designing equity analytic dashboards for use by K–12 teachers.

5.1. Better Support for Teachers' Data Visualization Literacy

We observed that teachers underutilized the equity visualizations, preferring the ease of whole class visualizations. From a design perspective, we need further investigation into new visualization types that embody simplicity and familiarity while still providing access to finer-grained data on student participation by race/ethnicity and gender. However, equity visualizations necessarily embody more complex data types, suggesting that new visualization literacies may be needed (Ali et al., 2013). For instance, we used colour in the Choropleth Heatmap to show student response patterns. There was a polarity in teacher responses, with most disliking this use of colour while others found it very helpful to their sensemaking. These differences appeared to stem from prior experience and training in different chart types (Arthars & Liu, 2020). Future research might focus on how to design learning opportunities for both pre-service and in-service teachers (Shah & Coles, 2020) to prepare them to work with visual learning analytics tools. Prior research also suggests that past personal experiences with visualization types can influence the trust people have in them (Peck et al., 2019). Trust is likely an important attribute for visualizations displaying sensitive data by gender and race/ethnicity, raising a question for visualization designers: how does the usability of equity visualizations influence trust in teacher practitioners and other education stakeholders?

5.2. Specific Supports for Race/Ethnic and Gender Sensemaking

There are extensive calls in the literature to focus on equitable learning experiences with visualization dashboards centered on diversity, justice, and equity (Williamson & Kizilcec, 2021; Williamson & Kizilcec, 2022; Wise et al., 2021). Teachers often cited a lack of racial diversity in their classrooms, or their own perspectives on equity, as reasons for not using the equity visualizations. Yet, in all cases, these classrooms included a mix of genders, so there were many opportunities for teachers to use the visualizations to pursue gender equity goals. One line of research looks at how to embed equity visualization dashboards into teacher preparatory programs (Shah & Coles, 2020) in order to build teacher capacity to engage in this type of sensemaking. Another potentially fruitful line of research studies the types of "routines" that teachers could systematically enact to support their sensemaking (Nguyen et al., 2021). We can imagine the creation of supporting routines going hand-in-hand with the design and deployment of new equity analytic systems.

5.3. More Research Needed

In our study, all visualizations prompted strong emotional responses in teacher reflections, as in other studies (Wise & Jung, 2019; Campos et al., 2021) our findings suggest that emotions always accompany teachers' use and interpretation of visualizations. These observations lead us to ask the following questions: Which distinct negative and positive emotions can cause barriers and opportunities to teacher reflections with different visualizations? How can we support teachers' emotional resilience and emotional regulation when using equity visualizations?

5.4. Limitations

This study only investigated the use of a narrow set of visualization types (bar charts, line charts, and choropleth heatmaps) organized around a specific type of student experience data (coherence, relevance, and contribution) disaggregated by race/ethnicity and gender. Future work can explore how other equity-oriented visualization types with novel student experience data can impact teachers' sensemaking. Further, the variability in teacher preferences regarding visualizations suggests further inquiry into exploring what visualizations are more productive for certain tasks in teachers' sensemaking.

A second limitation of this study relates to the lack of racial diversity in many of these teachers' classrooms. Many teachers cited that they did not use the equity visualizations because there were no patterns in student responses across races/ethnicities to examine. In this study, classroom diversity was not required for teacher participation. In fact, in most US schools, racial isolation is more common than integration, making this a reality to accommodate in future studies. Further, the sample of teachers drawn for this study was not diverse, which might have implications as to how teachers prefer representations to pursue gender and racial equity goals.

Finally, a third limitation is that our study focused on only two dimensions of inequity in schools. While racism and sexism are institutionalized processes that contribute to ongoing inequities of participation in STEM, other dimensions matter as well. Opportunities to participate in high-quality learning experiences vary by students' socioeconomic status, home language, and special education status, which all contribute to inequity (Office for Civil Rights, 2018).

6. Conclusion

In this paper, we investigated the usability, use, and utility of equity-focused visualizations for teachers of student classroom experience data compared to whole class ones. We found that only equity visualizations disaggregating data by race/ethnicity and gender prompted teacher perceptions of their classroom equity. We also found several barriers to teacher use of these equity visualizations, such as ease-of-use, familiarity, lack of diversity in their classrooms, and personal perspectives on equity. This study contributes to the nascent field of designing for social justice in learning analytics, focusing on how an equity visualization dashboard can aid teachers in their workplace practice. In our future work, we aim to further develop and study the accompanying professional learning series, and to examine how these professional learning series and the SEET system can be embedded within school district infrastructures. We also intend to study how instructional support leaders within school systems — such as coaches or district leaders — can support teachers in using these equity visualizations to inform and guide new instructional practices.

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Appendix

Figure 4. SEET system dashboard view of overall bar chart visualization.