Examined Inquiry-Oriented Instructional Moves with an Eye Toward Gender Equity

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When considering undergraduate mathematics education, gender equity is an ongoing issue and it has been suggested that inquiry-based instruction could make classes more equitable for men and women. In this study, we analyze data from 42 undergraduate instructors and courses and 681 students in the context of inquiry-oriented instruction in either abstract algebra, differential equations, or linear algebra. Specific instructional units were video recorded, watched, and coded to see how teachers distributed opportunities to participate in whole class discussion, how these opportunities were taken up by students, and what teachers did with student ideas. Mathematically substantial opportunities were not distributed equitably between men and women, which was consistent with inequitable student participation observed. Further, instructors tended to leverage women's ideas less than men's ideas when building on formalizing students' mathematical contributions.

Keywords: Inquiry-oriented instruction, Gender, Equity, Whole class discussion

Many teachers use direct instruction that requires rote memorization and, thus, does not support student understanding of mathematical concepts (Quan-Lorey, 2017). This plays a role in engagement and comprehension in undergraduate mathematics courses if students' primary experience with mathematics is through memorization or procedural methods (Chang, 2011). Alternate teaching methods, like inquiry-oriented instruction (IOI), can be useful in prompting students to think critically and immerse themselves in the mathematics they are learning. IOI is a type of inquiry-based learning (IBL), a student-centered method of teaching revolving around "ill-structured but meaningful problems" (Laursen, Hassi, Kogan, & Weston, 2014, p. 407), involving the use of novel, problem-solving tasks that require students to be engaged and active learners (Rasmussen & Kwon, 2007; Kuster, Johnson, Keene, & Andrews-Larson, 2017). These tasks usually involve multiple solution methods, require students to make connections, and call for the use of problem-solving skills. As students inquire into mathematics, teachers inquire into students' reasoning so it can be leveraged in classroom discourse to create shared understandings that can then be formalized mathematically (Rasmussen & Kwon, 2007). Students' work on tasks is leveraged in whole class discussions where students must explain and justify their reasoning whether through their teacher's request or without prompt. IOI has been associated with improved student outcomes (e.g. Rasmussen & Kwon, 2007; Bouhjar, Andrews-Larson, Haider, & Zandieh, 2018). Laursen et al. (2014) found that IBL improved self-reported cognitive, affective, and collaborative gains in all students and leveled significant differences in cognitive and affective gains that existed between women and men in non-IBL courses. However, IOI does not guarantee an equitable distribution of opportunities to participate and engage in mathematical discourse. Our study examines this issue in 42 undergraduate mathematics classes by exploring the following research questions:

1. How did teachers distribute opportunities for students to contribute to whole class discussion, and how did this differ by gender?

2. How were these opportunities to contribute taken up by men and women?
3. In what ways did instructors leverage contributions from women and men?

Theoretical Framework

Laursen et al. (2014) argue that IBL "leveled the playing field by offering learning experiences of equal benefit to men and women" (p. 412). Johnson, Andrews-Larson, Keene, Melhuish, Keller, and Fortune (2018) did not find this to be true, as results in their study showed that men benefit more from IOI as evidenced by significantly different performance of men and women. This difference in findings leaves questions: Does IOI equally benefit men and women? Does it even the playing field? Does it disproportionately advantage men?

We follow Leyva's (2017) argument that gender differences in mathematics are socially constructed and Black's (2004) argument that teacher-student interactions and teacher expectations can shape students' identities and participation in the mathematics classroom. Esmonde (2009) also states that identity development in mathematics in crucial when considering equity. This suggests that a focus on teacher-student interactions will help future research concerning identity development and, thus, equity. In our study, we want to examine interaction patterns in the classroom to better understand gender-based differences in students' experiences in hopes that this will offer insight into differences in outcomes.

Data Sources and Methods of Analysis

Our data comes from a broader NSF-funded study focused on providing undergraduate instructors with support for teaching linear algebra, abstract algebra, and differential equations in inquiry-oriented ways. This analysis focuses on video data of 42 instructors teaching units that varied in length from about 2-4 hours of instructional time. In these videos, a total of 681 students were observed; 452 of these students were identified by coders as men and 229 were identified as women. In this analysis, coders relied on visual and audio cues (e.g. voice, clothing, names or pronouns used) to infer the gender of students. As a result, all claims are based on researchers' binary interpretations of students' gender, a limitation of our study.

Table 1. Codes, subcodes, and subcode definitions

Code	Subcode	Definition
Solicitation Method – (how is speaker selected)	Group	Instructor calls on a group and a particular student speaks
	Individual	Instructor calls on a student by name
	Volunteer	Instructor calls on a student volunteering to talk
	Random	Instructor uses randomization to identify a speaker
	Not Called On	A student interjects without being called on by instructor
Teacher Solicitation (question type)	N/A	Teacher does not ask the student a question
	Other	Teacher asks a general question (e.g., "What did you think?")
	What	Teacher asks a student to read part of a problem, recall a fact, or give a numerical/verbal answer
	How	Teacher asks for a student's solution method
	Why	Teacher asks why something is true/false
Student Talk	Other	Student asks a question or says something nonmathematical
	What	Student reads part of the problem, recalls a fact, or gives a numerical/verbal answer to a problem
	How	Student explains solution method

	Why	Student explains why something is true/false
Teacher Evaluation	N/A	Teacher does not respond to the student's contribution
	Revoice	Teacher repeats student contribution
	Evaluation	Teacher explicitly says the student is correct/incorrect
	Elaborate	Teacher expands on or formalizes the student's idea
	Follow-Up	Teacher asks a new question based on the student's contribution and a new student responds

To examine how teachers distributed opportunities for students to participate in whole class discussion, we used Reinholz and Shah's (2018) observation tool, Equity Quantified in Participation (EQUIP), as a basis for our coding scheme and rules. We refer to our unit of analysis as a *sequence* of talk, where a sequence starts when a new student speaks and ends when another student speaks. With this definition, any length of interaction between the teacher and student is coded as one sequence. On the other hand, if two students are having a conversation, then a new coded sequence begins each time a student speaks so this situation would create many back-to-back lines of code. In this report, we draw on four EQUIP codes (Reinholz & Shah, 2018), given in Table 1. Solicitation Method and Teacher Evaluation were modified for this study, to capture greater nuance in how teachers used student thinking.

Interrater Reliability

There was a total of 104.8 hours of video; and 20% of these videos were double-coded. The coding team consisted of three graduate students. One was the *master coder*, who all of the other students were compared against. Videos were assigned randomly to the three coders, each of whom coded approximately one third of the data. The coders completed double-coding in multiple phases, discussing the results after each phase. Once all videos were double-coded to acceptable reliability (at least 80% agreement on each code), the coders individually completed the remainder of their videos. The coding team met regularly to discuss coding issues that arose to maintain consistency. To compute interrater reliability, we used Krippendorff's alpha (Hayes & Krippendorff, 2007), which is a generalization of Cohen's kappa. An alpha value was calculated for each main level code and each non-master coder; all of these values were over 0.8, which is considered good reliability, the highest category that can be achieved (Carletta, 1996).

Equity Ratios

After all the videos were coded, we used R statistics to aggregate all occurrences of codes and subcodes, and computed equity ratios, which is a ratio of the actual participation of a group to the expected participation of a group based on the demographic composition of the class (Reinholz & Shah, 2018). For instance, if a class was comprised of 40% women, the *expected participation* would be 40% of whole-class talk. An equity ratio less than one means that the observed group is underrepresented (compared to an *equal* classroom), a value greater than one means overrepresentation, and a value equal to one means that the participation of the observed group is proportional to the group's representation in the population (e.g. mathematically equal). While equality is not the same as equity, research shows that underrepresented populations tend to receive less than a proportional share of participation opportunities, so equality can be used as a baseline to move toward equity (Reinholz & Shah, 2018). As outside observers we refrain from describing participation as equitable but can identify participation that is *inequitable.*

Preliminary Findings

For our analysis, we examined how teachers distributed opportunities to participate in whole class discussion by first looking at who teachers called on and then by what kinds of questions they asked, disaggregated by gender. We then considered the nature of student contributions and what teachers did with these contributions, also disaggregated by gender. When organizing and analyzing findings, we look at the speaker selection and the content of interactions teachers have with men and women. We found that when teachers called on students individually or by group, men and women responded at rates comparable to their representation in the population, but this was not the case when teachers called on volunteers or allowed students to speak freely. Overall, teachers asked women less mathematically substantial questions and used women's ideas less when formalizing mathematics. We support our claims by using gender equity ratios to quantify and compare the kinds of questions instructors asked, the kinds of contributions students made, and what teachers did with those contributions.

How Teachers Distribute Opportunities to Contribute to Whole Class Discussion

We organize our findings about teachers' distribution of opportunities to participate to highlight two key aspects of this phenomenon: how they select a speaker and the kind of question they ask. Equity ratios (ERs) for how teachers selected speakers (Solicitation method) and the kinds of questions they asked (Teacher Solicitation) are shown in Table 2.

Table 2. Equity ratios for opportunities for men and women to speak given by teachers

	Solicitation Method: Called on...				Teacher Solicitation: Question Type				
	Group	Individual	Volunteer	Not	N/A	Other	What	How	Why
# Sequences	147	374	372	2545	1295	515	1201	123	303
ER Men	1.02	1.00	1.12	1.07	1.05	1.04	1.09	1.08	1.10
ER Women	.95	1.01	.77	.86	.91	.92	.82	.85	.80

**Note:* Subcodes are organized so that our view of the mathematical rigor of each increases from left to right.

When teachers call on individuals or groups, women participate relatively proportionally to their representation as evidenced by equity ratios of 1.01 and .95, respectively. We interpret this to mean that teachers are treating men and women relatively equally when calling on students by name, and that when teachers call on a group, men and women tend to speak proportionally to their representation in the population. Contrarily, women are much more underrepresented when the teacher asks for a volunteer (ER .77) or in instances where students freely interject (ER .86).

The equity ratios for question type broadly suggest that in interactions with women during whole class discussions, teachers ask mathematically substantive questions (what, how, why) at disproportionally low rates (ERs < 1). We note that women received N/A (a student spoke without the teacher asking a question) and Other category questions (e.g. "What do you think about this) at considerably more equal rates.

How Opportunities Were Taken Up by Students

When women took opportunities to participate in whole class discussion, they were contributing mathematically substantive ideas (What and Why) at underrepresented rates in whole class discussion, as evidenced by the equity ratios shown in Table 3. Interestingly, *how* contributions (which are likely more procedural in nature) are distributed relatively equally between men and women. The link between Student Talk and Teacher Solicitation is also notable as student responses tend to be linked to the teachers' questions.

Table 3. Equity ratios for how students respond to instructors' prompts

	Student Talk			
	Other	What	How	Why
# Sequences	778	2099	209	351
ER Men	.96	1.11	1.02	1.09
ER Women	1.07	.79	.97	.83

**Note: S*ubcodes are organized left to right from least to most mathematically substantive student talk.

What Teachers Did with Student Contributions

Teachers revoiced and elaborated on women's contributions at rates much lower than their representation in the population, as shown by the equity ratios in Table 4. Elaborate often involved the teacher using a student's idea to formalize a mathematical idea and revoice was sometimes used to repeat a student's idea so that the class can hear it or because the teacher is thinking through the student's idea themselves. In either case, teachers leveraged women's ideas in this way at inequitable rates.

Table 4. Equity ratios for how instructors use student contributions

	Teacher Evaluation				
	N/A	Revoice	Evaluation	Elaborate	Follow Up
# Sequences	1397	482	186	846	524
ER Men	1.03	1.17	1.04	1.11	1.03
ER Women	.95	.67	.93	.79	.94

**Note*: Subcodes are arranged left to right from the least to most mathematically substantive use of student contributions.

Discussion

When examining trends in our findings regarding how teachers distribute opportunities to students, we looked at it in two parts: student selection and student-teacher interactions. In analyzing student selection, we found that there was more equitable participation when students were called on individually or by group. Calling on a group could be more equitable because this method creates a smaller pool of students to speak, which creates space for women to share their ideas. Men were more likely to interject or contribute their ideas when asked to volunteer. When examining trends in teacher-student interactions, we notice an interesting link between Teacher Solicitation and Student Talk. Teachers asked women less mathematically substantive questions, suggesting women had fewer opportunities to contribute mathematical ideas in whole class discussion. This might explain why teachers revoiced and elaborated on women's ideas at lower rates, as women were not prompted to give as many mathematically significant contributions. Though teachers likely did not mean for this to happen and are probably unaware of this inequity, the prevalence of these inequities in discussions in mathematics classrooms merits notice and discussion. The fact that the equity ratio for teachers calling on individual students by name was extremely close to 1 suggests that teachers intend for contributions in whole class discussions to be equal between men and women. In the future, we plan to explore the variation of these equity ratios by content area (abstract algebra, differential equations, and linear algebra) as the differences appear to be considerable and this could help explain what gives rise to these phenomena and any links to student outcomes.

References

Black, L. (2004). Differential participation in whole-class discussions and the construction of marginalized identities. *Journal of Educational Enquiry, 5*, 34-54.

Bouhjar, K., Andrews-Larson, C., Haider, M., & Zandieh, M. (2018). Examining students' procedural and conceptual understanding of eigenvectors and eigenvalues in the context of inquiry-oriented instruction. In S. Stewart, C. Andrews-Larson, A. Berman, & M. Zandieh (Eds.), *Challenges and Strategies in Teaching Linear Algebra* (pp. 193-216). Cham, Switzerland: Springer.

Carletta, J. (1996). Assessing agreement on classification tasks: the kappa statistic. *Computational Linguistics*, *22*(2), 249–254.

Chang, J. M. (2011). A practical approach to inquiry-based learning in linear algebra. International Journal of Mathematical Education in Science and Technology, 42, 245-259. doi: 10.1080/0020739X.2010.519795

Esmonde, I. (2009). Ideas and identities: Supporting equity in cooperative mathematics learning. *Review of Educational Research*, *79*, 1008-1043. doi: 10.3102/0034654309332562

Hayes, A. F., & Krippendorff, K. (2007). Answering the Call for a Standard Reliability Measure for Coding Data. *Communication Methods and Measures*, *1*(1), 77–89. https://doi.org/10.1080/19312450709336664

Johnson, E., Andrews-Larson, C., Keene, K., Melhuish, K., Keller, R., & Fortune, N. (2018). Inquiry and Inequity in the Undergraduate Mathematics Classroom. Manuscript submitted for publication.

Kuster, G., Johnson, E., Keene, K., & Andrews-Larson, C. (2017). Inquiry-oriented instruction: A conceptualization of the instructional principles. *Problems, Resources, and Issues in Mathematics Undergraduate Studies, 0*, 1-18. doi: 10.1080/10511970.2017.1338807

Laursen, S. L., Hassi, M-L., Kogan, M., & Weston, T. J. (2014). Benefits for women and men of inquiry-based learning in college mathematics: A multi-institution study. *Journal for Research in Mathematics Education, 45*, 406-418.

Leyva, L. A. (2017). Unpacking the male superiority myth and masculinization of mathematics at the intersections: A review of research in gender in mathematics education. *Journal for Research in Mathematics Education*, *48*, 397-433. Retrieved from: http://www.jstor.org/stable/10.5951/jresematheduc.48.4.0397

Quan-Lorey, S. (2017). Roots of mathematics anxiety in college students. Journal of Mathematics Education at Teachers College, 8(2), 19-30. Retrieved from http://journals.tc-library.org/index.php/matheducation/article/view/1224/744

Rasmussen, C. & Kwon, O. N. (2007). An inquiry-oriented approach to undergraduate mathematics. *Journal of Mathematical Behavior, 26*, 189-194. doi: 10.1016/j.jmathb.2007.10.001

Reinholz, D. & Shah, N. (2018). Equity analytics: A methodological approach for quantifying participation patterns in mathematics classroom discourse. *Journal for Research in Mathematics Education, 49*, 140-177.