Exploring Computing Students' Sense of Belonging Before and After a Collaborative Learning Course

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ABSTRACT

Prior work has found that women tend to report lower sense of belonging compared to men in STEM and computing contexts, which may discourage women's persistence. Collaborative learning has been shown to improve students' sense of belonging in some STEM and computing courses relative to traditional lecturing; however, these studies tend to focus on a single course or the first implementation of such pedagogical changes. Our study explores whether these trends generalize by measuring students' sense of belonging across three non-introductory computing courses that have consistently used collaborative learning activities over three semesters. We ask the following research question: Is collaborative learning generally associated with an increased sense of belonging, especially for women? We found that while there were variations across courses, students' reported sense of belonging improved in all courses. Notably, women's reported sense of belonging improved 15% whereas men's reported sense of belonging improved by 11%. Our findings complement prior studies by providing evidence of a relationship between increased sense of belonging and collaborative learning, and suggest students' sense of belonging is malleable beyond the first year. These findings challenge critiques of past studies as being isolated to single courses or conducted only immediately after an effort to change a course, suggesting pedagogical changes may hold promise in improving students' affective outcomes.

CCS CONCEPTS

• **Social and professional topics** → **Computer science education**; • **Applied computing** → **Collaborative learning**.

KEYWORDS

collaborative learning, online learning, linear regression, undergraduate education

ACM Reference Format:
Morgan M. Fong, Shan Huang, Abdussalam Alawini, Mariana Silva, and Geoffrey L. Herman. 2024. Exploring Computing Students' Sense of Belonging Before and After a Collaborative Learning Course. In *Proceedings of the 55th ACM Technical Symposium on Computer Science Education V. 1 (SIGCSE 2024), March 20–23, 2024, Portland, OR, USA*. ACM, New York, NY, USA, 7 pages. https://doi.org/10.1145/3626252.3630850

1 INTRODUCTION

Cultural stereotypes and hostile learning environments can signal to students from historically underrepresented groups that they do not belong in science, technology, engineering, and math (STEM) and computing [40]. This lowered sense of belonging may discourage students from pursuing or persisting in STEM and computing, hindering efforts to promote diversity, equity, and inclusion [6, 19, 31, 40]. Institutions and instructors have pursued a variety of interventions, such as early extracurricular outreach programs, residence programs, and the use of inclusive pedagogies [4, 29, 35] to help students from historically underrepresented groups feel like they belong in computing spaces. In this paper, we explore the use of collaborative learning pedagogies on students' sense of belonging in three computer science (CS) courses over three semesters.

Broadly speaking, collaborative learning "is a *situation* in which *two or more* people *learn* or attempt to learn something *together*" (original italics) [9]. Practically speaking, collaborative learning takes many forms like Process-Oriented Guided Inquiry Learning (POGIL) and pair programming. Collaborative learning centers student interaction for the majority of class time with maybe a few

SIGCSE 2024, March 20–23, 2024, Portland, OR, USA

ACM ISBN 979-8-4007-0423-9/24/03…$15.00
https://doi.org/10.1145/3626252.3630850

interruptions by the instructor. In our study, we distinguish collaborative learning from instructor-led interactive activities, such as think-pair-share or peer instruction where students interact with peers for only a few minutes interspersed between lecture content. Across different implementations, collaborative learning has been shown to improve student performance, attitude, and persistence [8, 14, 26].

Compared to individual or traditional learning, collaborative learning pedagogies have been shown to improve student performance [2, 12, 27, 34, 44], interpersonal skills [2], affect and attitudes [44], self-efficacy [48], and persistence [27] at a variety of educational stages and across STEM disciplines. This study was motivated in particular by recent quasi-experimental studies that each demonstrated that collaborative learning improves students' sense of belonging at the university level [18, 36, 46]. While these studies represent a variety of disciplines (e.g., CS, biology, and calculus), they were focused on careful implementation in a single course in a single semester. To complement these past studies, we explored whether these positive effects of collaborative learning would generalize across different instructors teaching different courses over different semesters.

Three courses at our institution, Computer Architecture, Numerical Methods, and Database Systems switched to using collaborative learning in 2020 and have persisted in using collaborative learning since. We have collected sense of belonging data in all of these courses since Spring 2022, giving us three semesters of data. Our study complements prior work by observing the relationship between collaborative learning and sense of belonging when collaborative learning is the status quo rather than an experimental treatment, and by exploring whether women, who are historically underrepresented in CS, report an increase in their sense of belonging disproportionately relative to men. This study design interrogates whether collaborative learning is a viable tool for promoting equity for women in CS courses. Thus, we ask the following research question:

RQ: To what extent is collaborative learning associated with an increased sense of belonging, especially for women?

2 LITERATURE REVIEW

2.1 Sense of Belonging

Sense of belonging has been defined in numerous ways with varying levels of specificity across a range of contexts. In contrast, Allen et al. [1] use a component-based approach that provides a useful lens to distinguish between the focus and context of interventions targeting sense of belonging. More specifically, Allen et al. [1] identify four components of sense of belonging: competencies for belonging (e.g., social skills, cultural norms), opportunities to belong (e.g., making time and space to develop belonging), motivations to belong (e.g., individual's need to belong with a community), and perceptions of belonging (e.g., how an individual feels why they belong to a community).

Focusing on the undergraduate student experience, past work has studied various interventions that may address students' motivations and perceptions of belonging at the institution level, such as extracurriculars and residence programs [4, 29] or identity-based affinity groups [15].

Additionally, pedagogical changes at the classroom level may provide additional opportunities to build students' sense of belonging. For example, Moudgalya et al. [35] compared the differences in students' sense of belonging before and after 30 faculty across 21 institutions implemented collaborative learning in the form of POGIL in introductory CS courses. For women, Black, and Hispanic students, sense of belonging correlated more strongly with interest to pursue CS courses compared to their peers. However, they did not find a statistically significant difference in sense of belonging between students in POGIL and non-POGIL versions of a course. This result stands in contrast to prior work and warrants further interrogation of whether collaborative learning improves sense of belonging. Indeed, Sax et al. [41] caution that collaborative learning by itself may not be a strong enough factor alone to influence positive changes in sense of belonging due to the wide variation in how collaboration is structured and implemented in classrooms. In Section 3, we detail the similar ways in which collaboration was structured and encouraged in our context.

2.2 Collaborative Learning

In CS contexts, pair programming [47] and POGIL [20] are popular ways of implementing collaborative learning by having students work in pairs or small groups in a structured manner that intentionally focuses on process.

Computer-supported collaborative learning (CSCL), a subset of collaborative learning, studies the ways in which computers can help mediate collaboration (e.g., by enforcing roles, providing automated feedback) [22]. While older work on CSCL in distance-learning contexts were mostly focused on text-based communication due to technological limitations [10], they still highlighted important features such as social presence (e.g., use of emoticons) [16] and other group awareness tools that translate aspects of in-person collaboration to online settings (e.g., notifying users of who made changes to a shared document, making participation rates among group members transparent to the team) [3]. However, Kreijns et al. caution that social affordances, such as building community and sense of belonging, are not given in CSCL spaces [24]. Rather, CSCL implementations need to carefully consider how the environment not only provides opportunities to belong, but also develops competencies for belonging. For example, anonymous avatars that hide visible identities such as race may limit the effects of stereotype threat [28], but the lack of facial expressions may reduce social presence which in turn may lower satisfaction [16].

Prior work recommends small and diverse (e.g., racial and gender composition; prior experience) groups [17, 23, 33, 43]. Use of structured roles (e.g., "navigator" and "driver" in pair programming) and rotation of such roles can help avoid stereotypical role adoption (e.g., women frequently taking on the recorder role) [11, 32]. Yet even when implementations follow these guidelines, inequitable group dynamics can still emerge [42]. In addition to instructor-assigned, criteria-based group formation strategies, students may also prefer to work with their friends. Working with friends may improve the collaborative learning experience for students since they may be familiar with each other's communication and working styles [13]. However, students working with friends may also

Table 1: Summary of course characteristics. Semesters with a cross symbol (+) indicate terms where an online section was available for students.

Course Title	# of Group Activities per Week	Semester	Modality	Smallest Group Size	Largest Group Size	Able to Re-form?	Random Group Formation
Computer Architecture	2	SP22	In-person	2	3	Yes	Women ≥ 50%
		FA22	In-person	2	3	Yes	Women ≥ 50%
		SP23	In-person	2	3	Yes	Women ≥ 50%
Numerical Methods	1	SP22+	In-person / Online	2	4	Yes	Women ≥ 50%; ≥ 1 person with linear algebra experience
		FA22+	In-person / Online	2	3	No	Women ≥ 50%
		SP23+	In-person / Online	2	3	Yes	Women ≥ 50%
Database Systems	2	SP22	In-person	3	4	No	TA-assigned
		FA22	In-person	3	4	No	TA-assigned
		SP23	In-person	3	4	No	All CATME assigned

feel reluctant to disagree or be critical of their friends, which may negatively impact collaborative processes [30].

3 COURSE CONTEXTS

We first describe similarities between the three courses, Computer Architecture, Numerical Methods, and Database Systems before discussing course-specific policies and structures. The instructor for each course remained the same across semesters. The last three authors each taught one of these courses. See Table 1 for a summary of each course's characteristics (e.g., modality, group formation).

In Fall 2020, all three courses shifted to using a flipped classroom model, delivering course content through pre-recorded videos before class. During class time, students were assigned collaborative learning activities delivered through PrairieLearn [37]. Students worked on these assignments in teams, receiving feedback on the correctness of their answers from the autograders in the LMS and assistance from course staff (some combination of the instructor, graduate teaching assistants (TAs), and undergraduate course assistants). Students in a group earned a collective grade on these assignments and earned individual grades on other assignments. Students were encouraged to work with random peers for the first two weeks of class to help them find groups, after which all students were able to sign up to work with a group of their choosing. For students who chose not to sign up with a specific group, they were randomly assigned based on instructor-specified criteria, further detailed for each class in subsequent sections.

In our analysis, groups in which students chose to sign up with a group were labelled "Pre-form." Students who chose to be randomly assigned were labelled "Random." Students who chose to change groups halfway through the semester were labelled "Re-form."

3.1 Computer Architecture

Computer architecture is a 4-credit hour required course for CS majors and is typically taken by second-year undergraduate CS majors. The course met twice a week for 1.75 hours each with students working collaboratively during both class sessions. The instructor typically gave a brief lecture on the relevant topics for that day's collaborative learning activity and solved a few sample problems. Students were encouraged to attend class and required to work in a team. After this brief lecture, students worked in groups for the remainder of class time. Questions in the collaborative learning activity were either more complex versions of the pre-class activity or provided more synthesis of concepts. Question types included multiple choice, fill-in-the-blank, programming, and open-ended reflection questions. For example, the pre-class activity on MIPS assembly covered basic examples such as determining struct size and computing string length, followed by the associated collaborative learning activity where students used MIPS to program pointers, access data memory, and implement a function to check whether a string is a palindrome. These activities also had reflection prompts to encourage discussion among teammates.

Students who did not sign up with a group were pseudo-randomly assigned a group by a graduate research assistant. Groups were assigned such that students who self-identified as women or non-binary were not in the minority within groups (i.e., at most one man for a group of two or group of three). Students worked with the same group for the first half of the semester, then they were offered the option to stay with their group or choose a different group for the second half of the semester. Students were awarded participation points for completing the group activities with their group, but were not required to attend class. Students also frequently worked with their groups on larger, weekly lab assignments outside of class, although it was not required for these groups to be the same.

3.2 Numerical Methods

Numerical methods is a 3-credit hour required course for CS majors, but also fulfills requirements for the CS minor as well as a variety of other STEM majors. The course is typically taken by second- and third-year undergraduate students. The course met twice a week for 1.25 hours each, but students worked in groups only once a week. The instructor usually did not give a brief lecture. Students in the in-person section were required to attend class (i.e., TAs scanned student IDs to verify attendance). Students in the online section could meet during class using the course's Zoom link or at a time and place of their choosing. The collaborative learning activity took place in a shared Jupyter notebook and consisted of sub-problems (i.e., short programming prompts) that built up to an application of the ideas presented in the pre-class activity. For example, the pre-class activity on rounding covered the basics of floating point representation, followed by the associated collaborative learning activity where students implemented different rounding schemes to compare the impact on precision of bank account transactions.

Students who did not sign up with a group were pseudo-randomly assigned a group by a graduate research assistant. Groups were assigned such that students who self-identified as women or non-binary were not in the minority within groups. In Spring 2022 groups needed to have at least one student with prior linear algebra experience. Students worked with the same group for the first half of the semester, then they were offered the option to stay with their group or choose a different group for the second half of the semester, except for Fall 2022. Students were allowed to discuss, but not work together, on other assignments with other students.

3.3 Database Systems

Database systems is an elective 3-credit hour course for CS majors, and an elective 4-credit hour course for graduate students. It is typically taken by fourth-year undergraduate students, Master's students, and early-stage doctoral students. The course met twice a week for 1.25 hours each with students working collaboratively in both class sessions. The instructor typically started each class by answering student questions submitted via a form included in the pre-class activity and solving a few sample problems. Students were required to attend class (i.e., TAs scanned student IDs to verify attendance). The collaborative learning activities were usually more complex versions of the pre-class activity. Question types included short prompt database programming, diagram design, and short answer questions. For example, the pre-class activity on basic SQL queries had students identify which query would give the desired outcome, followed by the associated collaborative learning activity where students wrote queries for more complex outcomes.

For the Spring 2022 and Fall 2022 semesters, students who did not choose a group were randomly assigned by a TA with no constraints. In the Spring 2023 semester, all students were assigned groups using a group formation tool CATME [45]. The instructor set CATME to form groups where women were not in the minority and to match students with similar availability for meetings. Additionally, the instructor set CATME to form groups where members were dissimilar across other demographic categories (e.g., race/ethnicity, international status), academic background (e.g., field of study, incoming GPA), and skill sets (e.g., prior web development experience, leadership preferences). Students worked with the same group for both collaborative learning activities and a semester-long project.

4 METHODS

4.1 Statement of Positionality

Our analysis uses data from the three courses that the last three authors taught. All three instructors believe in the value of collaborative learning in improving student outcomes and created a community of practice during COVID-19 to share ideas and improve their respective courses. Analysis was therefore led by the first two authors who were not instructors of the courses. The first author joined the research team based on their prior research on collaborative learning. The second author joined the research team based on their expertise in statistical methods.

4.2 Participants

All research protocols were reviewed and approved by our Institutional Review Board-approved protocol (#21412). All students in all three courses were recruited to participate in the research study. We exclude students in honors sections of the courses since they are a self-selected group taught with a small class size. At the start of the semester, a graduate research assistant, who was not affiliated with any of the courses, collected consent.

4.3 Data Collection

We collected students' sense of belonging in a pre- and post-course survey based on the survey by Hoffman et al. [19]. In the pre-course survey, students were also asked to self-identify their gender and race/ethnicity. Students were able to identify as woman, man, or non-binary (we exclude students who identify as non-binary due to small numbers). Students were allowed to select multiple race/ethnicity options (we exclude race/ethnicity from the model due to lack of statistical power).

4.4 Measuring Sense of Belonging

Sense of belonging survey items were taken from a subset of questions by Hoffman et al. [19]. Questions focused on students' course-based experiences and are listed below:

- I feel comfortable volunteering ideas or opinions in class
- I feel that an instructor would take the time to talk to me if I needed help
- I know very few people in class *(reverse coded)*
- I feel comfortable asking an instructor for help if I do not understand course-related material
- Other students are helpful in reminding me when assignments are due or when tests are approaching
- I feel comfortable seeking help from a instructor before or after class
- I feel comfortable asking a question in class
- It is difficult to meet other students in class *(reverse coded)*
- I feel that my instructors care for my personal success in the class
- I have made friends in lecture/discussion section/lab who I can turn to for help with course material

A total of 10 items were used in the surveys. Questions were presented on a 5-point Likert scale using the following options and numeric values: "Strongly disagree" (1), "Disagree" (2), "Neither agree nor disagree" (3), "Agree" (4), "Strongly agree" (5). Negatively phrased questions (e.g., "It is difficult to meet other students in class") were reverse coded.

Individual question scores were averaged together to get a student's individual sense of belonging score between 1 and 5. Cronbach's α was 0.77 for the pre-course surveys and 0.85 for the post-course surveys, which indicates good internal reliability [38]. See Table 2 for summary statistics.

Table 2: Counts of respondents and average sense of belonging score by gender. Semesters with a cross symbol (+) indicate terms where an online section was available for students. Response rates are based on the number of students included in the sample.

Course Title	Semester	Response Rate	# Women	# Men	Pre-course $\mu(\sigma)$		Post-course $\mu(\sigma)$	
					Women	Men	Women	Men
Computer Architecture	SP22	67%	39	115	3.36(0.49)	3.54(0.52)	4.01(0.53)	3.95(0.60)
	FA22	72%	47	105	3.56(0.54)	3.52(0.51)	3.93(0.57)	3.88(0.57)
	SP23	72%	64	130	3.45(0.52)	3.57(0.53)	3.93(0.53)	3.91(0.64)
Numerical Methods	SP22+	82%	55	171	3.21(0.55)	3.47(0.51)	3.49(0.57)	3.61(0.67)
	FA22+	71%	73	170	3.29(0.50)	3.25(0.54)	3.61(0.57)	3.41(0.61)
	SP23+	60%	59	131	3.39(0.56)	3.35(0.59)	3.52(0.66)	3.52(0.72)
Database Systems	SP22	71%	57	93	3.36(0.48)	3.52(0.56)	3.83(0.60)	3.80(0.65)
	FA22	80%	117	285	3.38(0.52)	3.46(0.53)	3.86(0.62)	3.75(0.57)
	SP23	74%	78	151	3.46(0.51)	3.51(0.54)	3.77(0.61)	3.68(0.66)

To measure the improvement in students' sense of belonging from pre- to post-course, we calculated the percent improvement in an individual student's sense of belonging score using the following equation:

$$\%\ \text{Improvement} = (\text{Post-Course} - \text{Pre-Course})/\text{Pre-Course}$$

4.5 Linear Regression

To answer our research question, we use survey data from all courses across three semesters, yielding 1,940 data points across 9 course observations, to build a linear regression model. We use five explanatory variables: gender, semester, group formation, course, and modality.

Using the lm package [25] in R [39], we generate the following linear regression model using man as gender reference group, random as formation reference group, the Fall 2022 semester as semester reference group, Computer Architecture as reference course, and in-person as reference modality:

$$\%Improvement_i = \beta_0 + \beta_1 Gender_i + \beta_2 Semester_i + \beta_3 GroupFormation_i + \beta_4 Course_i + \beta_5 Modality_i,$$

where i indexes the student, $Gender_i$ represents self-identified gender (0 = man, 1 = woman), $Semester_i$ represents the semester that the student took the course (0 = Fall 2022, 1 = Spring 2022, 2 = Spring 2023), $GroupFormation_i$ represents how the student's group was formed (0 = Random, 1 = Pre-Form, 2 = Re-form), $Course_i$ represents different courses (0 = Computer Architecture, 1 = Numerical Methods, 2 = Database Systems), and $Modality_i$ represents official course section location (0 = in-person, 1 = online).

4.6 Limitations

We cannot definitively claim that collaborative learning improved students' sense of belonging or that it disproportionately helped women. However, our results provide a way to critically challenge claims made by past related research.

While these results may be in part due to all three instructors' deep commitment to teaching and learning (indeed, 4/10 questions in our survey were related to the instructor) [5], students spent more time interacting with peers than with their instructors. Anecdotally, many students complain that the instructors don't "teach enough," leading them to believe that the instructors have little influence or say on course content, even though the opposite is true. These factors lead us to believe that interactions with peers likely substantially influence students' self-reported sense of belonging.

All courses' policies allowed for some flexibility in groups that students worked with to accommodate absences, so students may not have worked with their assigned groups in one-off occasions.

Due to a mistake in the Spring 2022 post-survey for Numerical Methods and Database Systems, sense of belonging questions used the pre-course wording (i.e., asked students about past CS courses). Despite this wording issue, the use of the same survey across courses provides evidence that the question wording may not have greatly impacted students' interpretations of the questions.

5 RESULTS

Results from the linear regression model described in Section 4.5 are shown in Table 3. Each of the coefficients in the table indicates an additive percent improvement. Consider two examples: 1) men in a randomly formed group taking Computer Architecture in Fall 2022 (Constant) reported 10.75% improvement in sense of belonging on average, and 2) women in a randomly formed group taking Numerical Methods online in Spring 2022 reported 11.13% improvement in sense of belonging on average (Constant + Woman + Spring '22 + Numerical Methods Online).

The analysis indicates that, on average, all students in all semesters across courses reported an improvement in their sense of belonging. Women's sense of belonging increased by 15% (Constant + Woman) compared to 10% for men (Constant).

The significant increase in students' sense of belonging was robust across in-person courses. Students in Numerical Methods' online section reported a significantly smaller increase in sense of belonging compared to in-person students in all three courses (Constant + Numerical Methods Online); however, students in this section still reported positive improvements (5.88%).

The way students' groups were formed or whether students chose to re-form their groups mid-semester did not have a statistically significant impact on students' sense of belonging.

Table 3: Linear regression model uses man as gender reference group, Fall 2022 as semester reference group, random as formation reference group, in-person as modality reference group, and Computer Architecture as course reference group. A cross symbol ($^+$) indicates courses where an online section was available for students. An asterisk (*) denotes $p < 0.05$, which is statistically significant given $\alpha = 0.05$.

Fixed Effects	Coeff.	S.E.	t value	Pr(> $\|t\|$)
Constant	10.75	1.67	6.45	0.00*
Gender: Woman	4.63	0.95	4.90	0.00*
Semester: SP22	0.62	1.12	0.55	0.58
Semester: SP23	-1.62	1.18	-1.38	0.17
Formation: Pre-Form	1.61	1.25	1.29	0.20
Formation: Re-form	-2.25	2.27	-0.99	0.32
Course: Num. Methods	-2.84	1.48	-1.92	0.05
Course: Num. Methods$^+$	-4.87	1.54	-3.17	0.00*
Course: Data. Sys.	-2.66	1.14	-2.34	0.02*

6 DISCUSSION

As stated in the introduction, we sought to interrogate the generalizability of past research by studying the relationship between collaborative learning and sense of belonging across multiple courses and multiple semesters. Our results show that regardless of the course or semester, students' mean sense of belonging increased. While there were some differences between in-person courses on how much students' sense of belonging increased, these differences were generally small. Even the online offerings of a course were still associated with an increase in students' sense of belonging (Constant + Numerical Methods Online). We have no evidence to challenge the generalizability of past findings that infer a causal connection between collaborative learning and improved sense of belonging. This in turn makes it plausible to believe that past results were not just the result of extra effort put into changing a course to use collaborative learning for the first time or something that works only for specific types of courses.

Our work also complements these past studies by specifically looking at how students of different genders report changes in their sense of belonging in these courses. In aggregate, women reported a greater increase in their sense of belonging relative to men. Because lower sense of belonging is associated with students leaving their field of study [19], this disproportionate increase is particularly encouraging for efforts to improve diversity and representation in CS. While our study was not designed to make causal claims, these findings do suggest that it will be fruitful to more robustly explore whether collaborative learning is a better learning paradigm for retaining women in CS. It seems likely that a causal link may exist, given how prior work has demonstrated that women tend to pursue fields of study where they experience more communal-oriented learning goals and environments [21].

Additionally, our work further interrogates differences across variations of collaborative learning implementations. Across courses, students reported smaller increases in sense of belonging in the online section of the Numerical Methods course (5.88%) and in the in-person sections of the Database Systems course (8.09%) on average. For the online section of Numerical Methods, this may speak to the differences between in-person and online **opportunities to belong** in hybrid formats moving forward (i.e., where students choose online options over in-person options). Anecdotally in our context, students who met online typically only communicated through audio even though video was available, thus features of in-person communication such as facial expressions may contribute to lower levels of social presence [16]. For Database Systems, this may speak to the different (and larger) population it serves; Computer Architecture and Numerical Methods are required courses for CS undergraduates whereas Database Systems is also frequently taken by non-CS majors and graduate students. In a recent follow-on study, we explore the relationship between course modality (online vs. in-person) and group consistency with students' reported sense of belonging and satisfaction [7].

Perhaps more encouragingly, our results provide evidence that students' sense of belonging is still malleable beyond the first year. While prior work has tended to focus on introductory-level courses (e.g., [35, 41, 46], our findings suggest pedagogical changes to later courses in the curriculum still hold promise in improving students' affective outcomes.

7 CONCLUSION

Our analysis shows statistically significant and robust increases in sense of belonging for all students (10.75%), and increases in sense of belonging were significantly greater for women (15.38%). Students enrolled in Database Systems and online sections of the Numerical Methods course reported smaller improvements compared to students enrolled in in-person sections of Computer Architecture and Numerical Methods. Combined with past work, our results provide more evidence that collaborative learning may be a promising pedagogy for promoting equity in CS courses beyond the introductory level. Future work could compare these findings with changes in students' reported sense of belonging in comparable courses being taught differently to further interrogate the potential benefit.

ACKNOWLEDGMENTS

We thank the Computers and Education research group at the University of Illinois, Urbana-Champaign for their helpful feedback on earlier drafts of this paper. This material is based upon work supported by the National Science Foundation under Grant No. DUE 21-21412 and Graduate Research Fellowship Program. This work is also supported by the Strategic Instructional Innovations Program in the Grainger College of Engineering at the University of Illinois, Urbana-Champaign.

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