Instructional Transparency: Just to Be Clear, It's a Good Thing

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ABSTRACT

Background: Instructional transparency makes a course's learning goals, evaluation criteria, and path to success clear to students, with the goal of improving equity in higher education. Increased transparency may improve equity by bolstering students' self-efficacy and sense of belonging in computing, both of which are correlated with persistence in the field. **Purpose**: We aim to understand whether there are group differences in how students perceive and benefit from instructional transparency. We are additionally interested in understanding whether perceiving instructional transparency is positively correlated with students' self-efficacy and sense of belonging and, therefore, can contribute to the persistence of students from historically underrepresented groups in computing. **Methods**: To investigate these relationships, we used linear regressions to analyze survey responses from 11,046 undergraduate students from 203 institutions. **Findings**: We found that there are group differences in students' perception of transparency in their CS courses: students who identify as women, first-generation college students, and/or disabled reported perceiving less instructional transparency than their peers. We also found that perceiving more transparency has a positive correlation with students' self-efficacy and sense of belonging in computing while controlling for important confounding variables, such as prior CS experience. We further demonstrated that this relationship is different for certain groups of students: first, for Black students and first-generation college students, perceiving transparency has a *larger* positive impact on their self-efficacy, and second, for Hispanic students, perceiving transparency has a *smaller* positive impact on their sense of belonging. **Contributions**: Our work constitutes one of the first empirical, multi-institutional investigations of the perceptions and benefits of transparency in CS classrooms that focuses on group differences. Our work also includes a theoretical articulation of the mechanisms through which transparent teaching practices may influence students' self-efficacy and sense of belonging in computing. Taken together, our empirical findings and theoretical argument provide important evidence for the benefits of instructional transparency in CS courses, particularly as it relates to improving equity in computing.

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CCS CONCEPTS

• **Social and professional topics** → **Computing education**; **Computer science education**.

KEYWORDS

instructional transparency; transparent teaching; self-efficacy; sense of belonging; diversity; equity; inclusion; broadening participation in computing

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1 INTRODUCTION

Instructional transparency, or simply *transparency*, makes a course's learning goals, evaluation criteria, and path to success clear to students [58, 60]. Practices to support instructional transparency, known as transparent teaching practices, were developed by Winkelmes et al. [60] with the goal of improving equity by making expectations explicit and providing all students with clear guidelines for success in the course. Using such practices in computer science (CS) courses may also contribute to improving equity by supporting the success of students from historically underrepresented groups: these students are likely to have less exposure to computing coming into college [13] and therefore may benefit most from making the path to success transparent.

Scholars have found that students' perception of transparency may correlate with two important outcomes: students' confidence of succeeding in the course [38, 60], which is related to *self-efficacy*, and students' *sense of belonging* [38, 60]. Self-efficacy, a measure of students' confidence that they can achieve their goals in computing, is itself correlated with students' motivation, performance, and persistence [5, 6, 28]. Sense of belonging, the extent to which students feel that they are legitimate members of a field, has similar relationships with motivation and persistence [26, 30]. Instructional transparency could improve students' self-efficacy and sense of belonging in computing, and, correspondingly, contribute to students' persistence in CS.

By improving student persistence in CS, instructional transparency may play a role in efforts to broaden participation in computing. In the US, people who identify as women, Black/African American, Hispanic/Latina/o/x/e, Native American, Native Alaskan, Native Hawiian, Pacific Islanders, and/or having a disability are underrepresented in computing [16, 27, 33]. We refer to these groups as historically underrepresented groups (HUGs) in computing. Individuals from HUGs are underrepresented in computing at all levels [16, 27, 33], including in the K-12 educational system [13, 14]. Students from HUGs face barriers in accessing computing instruction and resources in K-12 [1, 18, 19, 54] and may, as a result, arrive in college less familiar with strategies for success in computing courses. Transparency in college CS courses aiming to make instructions and expectations clear to all students may, therefore, particularly benefit students from HUGs and encourage their persistence in computing. Because prior experience, knowledge, and background differ between students, it is important to understand whether students vary in their perception of instructional transparency. Consequently, we aim to understand whether there are group differences in how students perceive and benefit from instructional transparency. We are additionally interested in understanding whether perceiving instructional transparency is positively correlated with students' self-efficacy and sense of belonging and, therefore, can contribute to the persistence of students from HUGs in computing.

Although existing evidence suggests a correlation between instructional transparency and both self-efficacy and sense of belonging, there remain gaps in our knowledge that this study aims to fill. First, there has not yet been a theoretical articulation of *how* transparency may contribute to students' self-efficacy and sense of belonging. Second, prior work has not investigated whether group differences exist in either students' perception of transparency or in any benefits that may result from greater instructional transparency. Third, the empirical relationships between transparency and self-efficacy or sense of belonging have not been examined at a large scale, across institutional contexts, while controlling for other variables known to impact self-efficacy and sense of belonging. Our work aims to address these gaps by answering the following research questions:

- RQ0: What are the theoretical mechanisms through which instructional transparency may influence (a) self-efficacy and (b) sense of belonging?
- RQ1: Does the extent to which students perceive instructional transparency in their CS courses differ by their gender, race, ethnicity, disability status, first-generation student status, and prior computing experience?
- RQ2: To what extent is students' computing self-efficacy predicted by their perception of instructional transparency in their CS courses?
- RQ3: To what extent is students' sense of belonging in computing predicted by their perception of instructional transparency in their CS courses?

To address RQ0, we provide a theoretical argument connecting a seminal set of transparent teaching practices, known as the purpose-task-criteria template (described in Section 2), to self-efficacy and sense of belonging in Section 4. To answer RQs 1-3, we conducted linear regressions using data acquired from a multi-institutional survey of undergraduate students enrolled in computing courses. Using 11,046 undergraduate student survey responses from 203 institutions, we created three regression models to answer research questions 1, 2, and 3, respectively.

We found that there are group differences in students' perception of instructional transparency in their CS courses. Students who identify as women, first-generation college students (i.e., their parents or guardians did not attain a college degree), and/or disabled reported perceiving less instructional transparency than their peers. We also found that perceiving more transparency has a positive correlation with students' self-efficacy and sense of belonging in computing while controlling for important confounding variables, such as prior CS experience. We further demonstrated that this relationship is different for certain groups of students: first, for Black students and first-generation college students, transparency has a *larger* positive impact on their self-efficacy, and second, for Hispanic students, transparency has a *smaller* positive impact on their sense of belonging.

Our work constitutes one of the first empirical, multi-institutional investigations of the perceptions and benefits of transparency in CS classrooms that focuses on group differences. Our work also includes a theoretical articulation of the mechanisms through which transparent teaching practices may influence students' self-efficacy and sense of belonging in computing. Taken together, our empirical findings and theoretical argument provide important evidence for the benefits of instructional transparency in CS courses, particularly as it relates to improving equity in computing.

2 BACKGROUND: TRANSPARENT TEACHING PRACTICES

For our theoretical argument addressing RQ0, we use the *purpose-task-criteria* template, which is a common example of transparent teaching practices (e.g., [21, 38, 39, 60]). The template was created as part of the Transparency in Learning and Teaching in Higher Education (TILT Higher Ed) project by Winkelmes et al. [60][1], which aims to use transparent teaching practices to promote equity in higher education [59]. This template describes three components (the purpose, task, and criteria) that instructors can include in their assignments as well as discuss with students to promote instructional transparency.

Transparency in *purpose* refers to sharing with students how the assignment supports the course learning goals. Specifically, Winkelmes et al. [60] recommend articulating which skills are being developed and what particular knowledge is learned by completing

[1]We note that neither we nor our study are affiliated with the TILT Higher Ed project.

the assignment. Winkelmes [58] argues that sharing the purpose of an assignment before students begin work allows them to better understand how the assignment serves their learning goals and plan their approach.

Transparency of the *task* refers to providing students with clear instructions regarding "what to do" and "how to do it" [60, p. 33]. Winkelmes [58] notes that clear instructions help students to monitor their progress. In addition, Winkelmes [58] contends that because students are told ahead of time what they are supposed to do, they likely spend less time having to understand the task and more time learning.

Finally, providing transparent *criteria* entails giving students a detailed rubric and annotated examples of prior work for each assignment [60]. Winkelmes [58] argues that instructors should discuss the examples of prior work with students to determine how well these examples meet the criteria described in the rubric. According to Winkelmes [58], such a discussion aims to give all students the same starting knowledge to complete the assignment and also demonstrates to them multiple ways of successfully fulfilling the criteria.

Researchers have demonstrated several benefits of implementing these transparent teaching practices, which we describe further in Section 3.1 below.

3 PREVIOUS RESEARCH

3.1 Transparent Teaching Research

The purpose-task-criteria template was developed by Winkelmes et al. [60] as part of a teaching intervention with the goal of improving equity in higher education. In this intervention, faculty at seven institutions used the template to alter assignments given to students in one section of a course [60]. These faculty additionally agreed to discuss the purpose, task, and criteria for each of the altered assignments in class prior to students working on the assignment [60]. Another section of the same course served as a control, where students received unaltered assignments, but Winkelmes et al. [60] noted that the faculty participants "struggled to keep the intervention cleanly out of their control courses" due to its perceived effectiveness. Their analyses reflect this concern: instead of analyzing differences between the control and treatment courses, the authors separated students into those who reported perceiving higher-than-average transparency in their course and those who perceived lower-than-average transparency in their course [60]. When comparing students who perceived high vs. low transparency, the results showed that students reporting high-transparency also reported a higher sense of belonging and higher academic confidence [60]. Winkelmes et al. [60] reported that students who were first-generation college students, not white, and/or from lower socioeconomic backgrounds (i.e., in the lowest quartile for income) additionally benefitted from instructional transparency. However, they did not conduct statistical comparisons *between* student groups in order to investigate whether transparency has a differential impact for students from HUGs. Our work aims to fill this gap by investigating the impact of students' identities on their perception of transparency, self-efficacy, and sense of belonging.

Other scholars have also found evidence that using the purpose-task-criteria template benefits students. For example, Peplow et al. [39] found that using the purpose-task-criteria template led to students asking fewer questions about assignments, reporting less test anxiety, and reporting improved personal organization skills in a variety of courses at their institution. Ou [38] also implemented the purpose-task-criteria template and found an improvement in students' ability to learn independently, their confidence in their success in the field (which is related to self-efficacy), and their sense of belonging. In another study, Howard et al. [21] found that assignments designed using the purpose-task-criteria template can help mitigate typical learning challenges associated with online learning. In particular, they found that learning outcomes for students in online courses that implemented the purpose-task-criteria template were comparable to those of students taking in-person courses with traditional teaching methods [21]. Howard et al. [21] highlight the value of this result for equity efforts, as students from HUGs tend to achieve lower grades in online courses [23, 61, 62].

3.2 Hidden Curriculum

Transparency may also address the need to make visible what scholars have called the *hidden curriculum*. Giroux and Penna [17] defined the hidden curriculum as the "unstated norms, values, and beliefs" that are conveyed to students but are not part of the official curricula. Understanding these norms and values provides "insider knowledge" that may affect students' ability to participate in the "formal" curriculum [42]. Therefore, it is important to make the hidden curriculum transparent to all students [25, 37, 42]; indeed, it has been shown that making expectations explicit and accessible to all students is beneficial to their learning [25, 41].

Students from HUGs may particularly benefit from revealing the hidden curriculum in computing. In K-12 education, students from HUGs experience barriers in accessing computing instruction and resources [1, 18, 19, 54], and so may arrive in college less familiar with the hidden curriculum in computing than their majority peers. Greater instructional transparency may be one way to reveal the hidden curriculum, as transparency, by design, aims to make the path to success in a course equally clear to all students.

3.3 Self-Efficacy

One of the outcomes of interest to this work is students' self-efficacy. *Self-efficacy* is a measure of an individual's belief that they can act in ways that will achieve their goals [2]. According to the original conceptualization of self-efficacy by Bandura [2], an individual's perceived self-efficacy can impact outcomes and behaviors such as the effort they put into a task and their persistence in the face of challenges [2–4]. Computing self-efficacy has been shown to have a positive relationship with student retention and motivation in CS courses [5, 6, 28, 56]. The positive relationships between these outcomes and self-efficacy inspires our investigation into whether perceiving transparency can improve students' self-efficacy.

Prior research has also demonstrated that aspects of students' identities and experiences correlate with computing self-efficacy. In particular, greater prior experience with CS correlates with higher computing self-efficacy [8, 12, 36]. On the other hand, computing self-efficacy is negatively predicted by identifying as a woman [6, 34, 36], non-binary [36], a first-generation college student [6], and/or a member of an underrepresented racial/ethnic group [34, 36]. Previous work also suggests a relationship between self-efficacy and disability status[2]: scholars have found that students with physical [44] and learning disabilities [24] may have different perceptions of their self-efficacy than their peers without disabilities. We include all of the above aspects of students' identities in our models predicting computing self-efficacy, as described in Section 8.2.

3.4 Sense of Belonging

The second outcome of interest to this study is students' sense of belonging in computing. *Sense of belonging* for undergraduate students is defined by Strayhorn [43] as "perceived social support on campus… the experience of mattering or feeling cared about, accepted, respected, valued by, and important to the group" [43, p. 28-29]. Positive correlations between sense of belonging and positive outcomes have been demonstrated in the field of computing. For example, prior work has demonstrated a correlation between belonging and students' perceived CS ability [53], interest in pursuing computing [30], and performance in CS courses [26]. As a result, understanding whether transparency positively correlates with students' sense of belonging in CS may be a valuable insight for promoting student success.

In higher education settings, students' sense of belonging has been shown to be correlated with aspects of their identities, such as gender, race, and disability status, and their prior experiences. Identifying as a woman or as a member of an underrepresented racial/ethnic group is correlated with a lower sense of belonging [9, 40], as is identifying as a first-generation college student [31, 32]. Similar patterns have been found for students with disabilities: Blaser and Ladner [7] found that students with disabilities reported "feeling like an outsider" more than their male peers without disabilities, indicating that disability status may also correlate with sense of belonging. Finally, in the field of computing, scholars have identified that prior experience in CS may contribute to students' sense of belonging in the field: Veilleux et al. [53] found that students' sense of belonging was closely related to their perception of their own ability, which is likely to be tied to their level of experience in computing. We include all of the above aspects of students' identities in our models predicting sense of belonging, described in Section 8.2.

4 RQ0: THEORETICAL FRAMEWORK

In this section, to address RQ0, we use existing theory from educational psychology to argue that transparency, operationalized as the purpose-task-criteria template, may positively influence students' (a) self-efficacy and (b) sense of belonging in computing. Existing work has not focused on providing a theoretical explanation for the benefits of instructional transparency. Thus, an important contribution of our work is an articulation of the mechanisms that connect instructional transparency to students' self-efficacy and sense of belonging.

[2]We note that people with disabilities encompass a wide variety of individual experiences and needs. As such, groups of disabled people should be expected to be heterogeneous. We provide a description of how we categorized students as having a disability in Section 7.2.3.

4.1 Self-Efficacy

As introduced in Section 3.3, *self-efficacy* is a measure of an individual's belief that they can act in ways that will achieve their goals [2]. For students enrolled in CS courses, their goals might include mastering CS concepts or passing their computing courses. Our work aims to investigate whether there is a relationship between students' perception of transparency and their computing self-efficacy; below, we provide a theoretical argument for why this may be the case.

Bandura [2] detailed four possible sources of information individuals draw upon when determining their self-efficacy in a particular domain. One of these sources, "verbal persuasion" from others [2], does not feature in our argument. The first source of self-efficacy information relevant to our work comes from the individual's "performance accomplishments", i.e., succeeding at tasks in the domain of interest [2]. Bandura [2] argued that succeeding at a task increases an individual's expectations of continued success, while failing at tasks lowers their expectations of success in the future. Initial success is especially important as it can build sufficient self-efficacy for later failures to have a diminished negative impact [2]. The second source is "vicarious experience", which is the observation of peers succeeding at tasks in the domain [2]. By observing that others can persevere and be successful, an individual can believe that this success is possible for themself too [2]. The third source of self-efficacy information is described by Bandura [2] as "emotional arousal" and refers to the level of stress and anxiety felt by the individual during the tasks. Negative reactions such as excessive stress and anxiety may lead an individual to avoid the tasks and/or perform worse; on the other hand, Bandura [2] argues, lower stress and anxiety during a task correspond to an increase in self-efficacy.

We argue that a relationship between transparency and self-efficacy is supported by Bandura's theory of self-efficacy. Each element of the purpose-task-criteria template can act as one or more of the above sources of self-efficacy information and, therefore, may bolster self-efficacy. These relationships are pictured in Figure 1.

First, knowing the explicit *purpose* of each assignment may motivate students to put in the effort required to eventually complete the task. In particular, knowing how the task pertains to their overall goals in the course may increase the value students see in it, which may increase their motivation to complete the task. This relationship between perceived value and motivation is known as expectancy-value theory [57]. Increased motivation is likely to result in greater effort and thus a greater likelihood of achieving a "performance accomplishment" [2]. Second, providing detailed instructions on how to complete the *task* may affect self-efficacy by increasing the likelihood that students accomplish the assignment successfully and gain "performance accomplishments" [2], as well as by diminishing the stress and anxiety caused by not knowing what to do. Third, sharing the evaluation *criteria* may contribute to students' self-efficacy in three ways: sharing criteria may clarify to students what the standards are, making it easier for students to achieve them; the ability to use these criteria to self-assess may diminish students' uncertainty and therefore their anxiety; and showing examples of past students' work may act as "vicarious experience" of others' success [2]. In summary, based on the ways

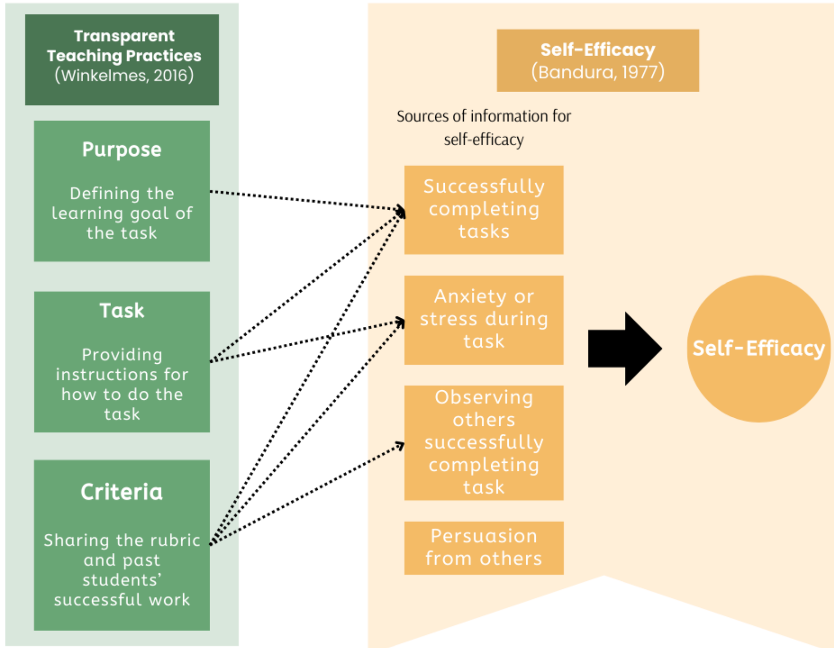

Figure 1: A graphical representation of our theoretical argument connecting the purpose-task-criteria template [60] to self-efficacy [2].

the purpose-task-criteria template contributes to the sources of self-efficacy information described by Bandura [2], we hypothesize that transparency may bolster students' self-efficacy.

4.2 Sense of Belonging

As discussed in Section 3.4, for undergraduate students, *sense of belonging* is defined by Strayhorn [43] as "perceived social support on campus… the experience of mattering or feeling cared about, accepted, respected, valued by, and important to the group" [43, p. 28-29]. Belonging is not only important for students' well-being as a basic human need [43, p. 31], but also because of the role it plays in fostering positive academic outcomes [26, 30, 53]. Therefore, it is valuable to investigate what educators can do to bolster students' sense of belonging in computing, and we provide a theoretical argument below that instructional transparency may do so.

Vaccaro and colleagues have developed a theoretical framework that identifies four factors that contribute to students' sense of belonging [46–51]. Two of the factors in their model, the campus environment and students' community involvement [48], are not directly relevant to our study; we describe the relevant factors below. The first factor relevant to our work is described by Vaccaro and Newman [48] as "academic success and/or mastery of the student role". This factor was described by students as including earning good grades as well as being treated as a "legitimate student" and "blending in", rather than being treated as different from their peers [48]. The second factor relevant to our work is the relationships students have with their peers and educators, which includes receiving "task-related" and affective support [48]. Vaccaro and Newman [48] noted that it is particularly valuable for students from HUGs to be able to build relationships that felt authentic and supportive.

We use the theoretical framework developed by Vaccaro and Newman [48] to argue that instructional transparency may influence students' sense of belonging. Specifically, we contend that instruction using the purpose-task-criteria template impacts two of the sources of sense of belonging discussed above: students' perceived mastery of the student role and their relationship with peers and educators. We illustrate these arguments in Figure 2.

Firstly, by explicitly stating the *purpose* of each assignment in a course, instructors are providing students with clarity and an understanding of why the course is designed the way it is, potentially improving students' relationships with and trust in their instructors (i.e., educators). Secondly, detailed *task* instructions may make it easier for students to successfully complete the task, contributing to their "academic success and/or mastery of the student role". These instructions may also be considered "task-related" support, which Vaccaro and Newman [48] describe as a component of students' relationships with their educators. Thirdly, providing the assignment's *criteria* and examples of past work may increase the likelihood of students succeeding at the task, contributing to their "academic success" [48]. In addition, sharing the evaluation criteria may also enhance students' belief that their instructors are preparing them for success, contributing to a better relationship with their educators. Based upon these relationships between the purpose-task-criteria template and the sources of sense of belonging theorized by Vaccaro and Newman [48], we hypothesize that

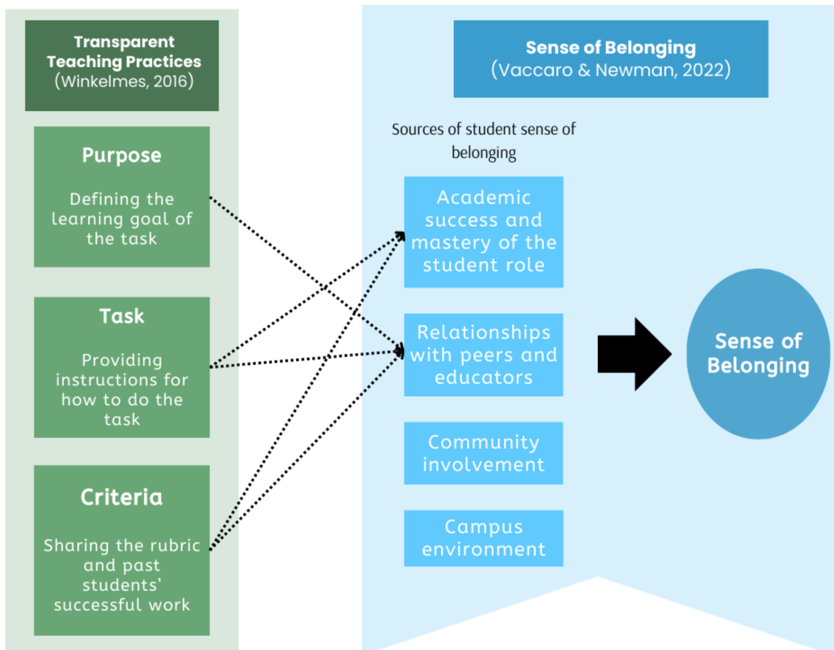

Figure 2: A graphical representation of our theoretical argument connecting the purpose-task-criteria template [60] to sense of belonging [48].

increased perception of instructional transparency will correspond with an increase in students' sense of belonging.

5 RESEARCH QUESTIONS AND HYPOTHESES

Building upon our theoretical argument above in response to RQ0, we address the following remaining research questions:

RQ1: Does the extent to which students **perceive instructional transparency in their CS courses** differ by their gender, race, ethnicity, disability status, first-generation student status, and prior computing experience?

RQ2: To what extent is students' **computing self-efficacy** predicted by their perception of instructional transparency in their CS courses?

RQ3: To what extent is students' **sense of belonging in computing** predicted by their perception of instructional transparency in their CS courses?

Our first research question aims to explore whether any of the listed factors correlate with perceptions of instructional transparency. We hypothesize that prior computing experience may lead to students perceiving greater transparency in their CS courses, because familiarity with computing concepts may lead them to readily perceive learning goals and task requirements that their less experienced peers do not.

For our second and third research questions, we hypothesize a positive correlation between perception of instructional transparency and each outcome variable investigated, i.e., self-efficacy and sense of belonging in computing. We also hypothesize that students' identities will moderate the relationships between their perception of transparency and self-efficacy or sense of belonging; that is to say, that students from HUGs will have an additionally positive correlation between their perception of transparency and their self-efficacy or sense of belonging in computing. This hypothesis stems from the documented barriers students from HUGs encounter in participating in computing [1, 13, 18, 19, 54]: we hypothesize that students from HUGs will have had fewer opportunities to learn the hidden curriculum in computing and will, as a result, benefit more from instructional transparency.

Our research questions, hypotheses, and the methods discussed below were pre-registered [35].

6 DATA

The data used in this study was provided by the Computing Research Association from their Computing Education Research Pipeline's undergraduate Data Buddies survey [10]. The survey is provided to computing departments in the US and Canada, who share the survey with students in their computing courses. The response rate to the survey is below 20% at most participating institutions [10]. Data for this study is drawn from the surveys administered in the academic years ending in 2021 and 2022, encompassing 11,046 student respondents from 203 institutions. Because not all students responded to all relevant survey items, our models for self-efficacy and sense of belonging use different subsets of the data used in the larger model for instructional transparency. Specifically, our model for self-efficacy uses data from 10,973 students, and our model for sense of belonging uses data from 10,982 students. While some students may have responded to the survey in both years, our data does not permit tracking individual students.

7 MEASURES

7.1 Perception of Instructional Transparency, Self-Efficacy, and Sense of Belonging

We used the procedure described below to create three measures, one for each of our three student outcomes of interest: perception of transparency, self-efficacy, and sense of belonging. Each measure was constructed using the relevant survey items, provided below in Sections 7.1.1, 7.1.2, and 7.1.3.

To verify that each set of items measured a related construct, we conducted Exploratory Factor Analyses. Based on a low factor loading, we excluded one of the items under perception of instructional transparency, "My instructors provide students with annotated examples of past students' work". All other items had factor loadings above 0.4 in their respective measure, which is a typical cutoff point for inclusion in a factor [20], and were therefore included in calculating that particular measure. Cronbach's alpha for each set of the resulting items was above 0.7, which is considered acceptable reliability [52].

Students were excluded from a model if they did not respond to all of the items used in that particular model. Each student's value for each measure was then calculated by taking an average of a student's rating (i.e., a value from 1 to 5) to all the items pertaining to that factor. For ease of interpreting results, the values were then standardized to have a mean of 0 and a standard deviation of 1.

7.1.1 Perception of Instructional Transparency. To calculate students' perception of instructional transparency, we used the following question: *Think about the computing courses you are taking. Please assess the following statements and indicate how many of your computing courses they apply to.* For each item under this question, students could select one of the following options: (1) None of my courses; (2) Less than half of my courses; (3) About half of my courses; (4) More than half of my courses; (5) All of my courses. The items were:

- In these courses, I know the purpose of each assignment.
- My instructors identify a specific learning goal for each assignment.
- Each assignment includes a detailed set of instructions for completing it.
- I know how my work would be evaluated.

Prior to standardization, students' mean perception of transparency was 4.1 out of 5 with a standard deviation of 0.83. Cronbach's alpha for these items was 0.71.

7.1.2 Computing Self-Efficacy. Students' computing self-efficacy was measured using their agreement with the three items given below. Students could indicate one of the following Likert scale options: (1) Strongly disagree; (2) Somewhat disagree; (3) Neither disagree nor agree; (4) Somewhat agree; (5) Strongly agree.

- I am confident that I can learn the foundations and concepts of computing.
- I am confident that I can quickly learn a new programming language on my own.
- I am confident that I can pass my computing courses.

Students' mean computing self-efficacy prior to standardization was 4.2 out of 5 with a standard deviation of 0.79. These items had a Cronbach's alpha of 0.77.

7.1.3 Sense of Belonging in Computing. To measure students' sense of belonging in computing, we used their agreement to to the following items on the same 1-5 Likert scale as for the self-efficacy items:

- I feel like I belong in computing.
- I feel like an outsider in computing. *(Reverse-coded)*
- I feel welcomed in computing.

Prior to standardization, students' mean sense of belonging was 3.6 out of 5 with a standard deviation of 0.94. Cronbach's alpha for this measure was 0.79.

7.2 Student Demographics

For details regarding how student responses were categorized for each category below, please refer to our pre-registration [35]. We provide details of how many students identified with each of these groups in Table 1.

7.2.1 Gender. For each student, the survey data included a binary variable indicating whether the respondent identified as either a man or a woman, and an additional variable indicating whether they identified as gender non-binary. Unfortunately, our participant pool included few non-binary students ($n = 68$); since our analysis would be underpowered, we did not include students who indicated only a non-binary gender identity in our models.

7.2.2 Race and Ethnicity. The data provided to us indicated each student identifying as one or more of the following racial/ethnic identities: Asian, Black, Native, Pacific Islander, Hispanic, Arab/ Middle Eastern, and white. Due to low numbers, we combined students who identified as Native and those who identified as Pacific Islanders into one group, "Native". In accordance with the US Census [55], we combined students who identified as Arab/Middle Eastern with those who identified as white. Each participant may be represented in multiple of the above groups.

7.2.3 Disability Status. Our dataset included a variable where the respondent could indicate identifying as having one of 14 disabilities, more than one disability, or no disability. The 14 options included, for example, cognitive disorders (e.g., attention deficit disorder), learning disabilities, and sensory impairments (e.g., visual disability). Because we did not have specific hypotheses related to the kind of disability students indicated having, we grouped all students who indicated having one or more disabilities as disabled.

7.2.4 First-generation Status. The dataset also included a variable indicating whether students identified as the first generation in their family to attain a college degree.

7.3 CS Experience & Major

In response to the question *Which of the following experiences did you have prior to entering an undergraduate program? Select all that apply*, respondents were able to indicate having participated in computing experiences prior to college. Based on the activities they

Table 1: Descriptive statistics of participants in our dataset.

	Number of students	Percent
Women	3,963	36%
Men	7,083	64%
First-generation	2,842	26%
Disabled	2,206	20%
Black	892	8%
Native	194	2%
Hispanic	1,293	12%
Asian	4,585	42%
White	5,663	51%
CS majors	10,029	91%
Intro CS completed	9,057	82%
Within 2 years of graduation	6,068	55%
Substantial HS CS experience	7,463	68%
Some HS CS experience	608	6%
All participants	11,046	100%

Note: These numbers represent participants included in our largest model, Model 1. The participants included in the other models are subsets of this group.

selected, our research team categorized students as having *substantial* prior computing experience, *some* prior computing experience, or *no* prior computing experience in high school (HS). Experiences that were categorized as substantial experience included taking an AP CS course and learning a programming language. Some experience included participating in computing-related student groups. For a complete list of possible responses and how they were categorized, see our pre-registration [35].

Students indicated their major(s) from a list of options. We categorized each of these options as either a CS major, a non-CS STEM major, or a non-STEM major. For a complete list of possible major options and their categorization, please see our pre-registration [35].

Descriptive statistics of students' CS experience categorization and their majors are provided in Table 1.

8 METHODS

We answered each of our research questions using linear regression models.

8.1 RQ1: Predictors of Perception of Instructional Transparency

RQ1 aimed to examine whether students' perception of instructional transparency in their CS courses is predicted by their identity or prior experience. To this end, the equation for Model 1 was as follows:

$$\begin{aligned} transparency_s = \ & \beta_0 + \beta_1 woman_s + \beta_2 firstGen_s \\ + \ & \beta_3 disabled_s + \beta_4 black_s + \beta_5 native_s \\ + \ & \beta_6 hispanic_s + \beta_7 asian_s \\ + \ & \beta_8 substantialExp_s + \beta_9 someExp_s \\ + \ & \gamma_y + \mu + \iota_s + \epsilon_s \end{aligned}$$

Equation 1: The linear regression for Model 1, in response to RQ1.

In this model, $transparency_s$ is the measure of a student's perception of instructional transparency in their CS courses. $woman_s$ indicates whether a student identifies as a woman, with students who identify as men being the reference group. $firstGen_s$ represents whether the student indicated being a first-generation college student (compared to continuing-generation students), and $disabled_s$ represents whether they indicated having a disability (compared to those who indicated not having a disability). $black_s$, $native_s$, $hispanic_s$, and $asian_s$ capture whether the student identifies with each of those racial and ethnic identities. Students who identify as white are the reference group. As students may identify with multiple racial and ethnic identities, each student may be represented in multiple of the categories above. $substantialExp_s$ and $someExp_s$ represent how much experience the student had with computing prior to college, as described in Section 7.3; students with no experience prior to college are the reference group. We used fixed effects to control for the differences between students completing the survey in each year (γ_y), students pursuing different categories of major (μ; as defined in Section 7.3), and students attending different institutions[3] (ι_s). ϵ_s represents the error term per student.

8.2 RQ2: Predictors of Self-Efficacy and RQ3: Predictors of Sense of Belonging

To answer RQ2 and RQ3, we created four linear regression models. Two of these models, which we called "a" models (Models 2a and 3a), included only the main effects we were investigating, while in the "b" models (Models 2b and 3b), we added variables representing possible moderating effects. The equation for the "b" models is given below; the equation for the "a" models differs in that it does

[3]Due to an oversight, we omitted including the institution the student attends as a fixed effect in our pre-registration [35]. We include it in our analysis regardless due to the importance of controlling for differences in the perception of instructional transparency between students at different institutions.

not include any of the moderation effects (i.e., interaction terms that include transparency).

$$
\begin{aligned}
outcome_s = \quad & \beta_0 + \beta_1 transparency_s \\
+ \quad & \beta_2 woman_s + \beta_3 firstGen_s + \beta_4 disabled_s \\
+ \quad & \beta_5 black_s + \beta_6 native_s + \beta_7 hispanic_s + \beta_8 asian_s \\
+ \quad & \beta_9 substantialExp_s + \beta_{10} someExp_s \\
+ \quad & \beta_{11}(transparency_s \times woman_s) \\
+ \quad & \beta_{12}(transparency_s \times firstGen_s) \\
+ \quad & \beta_{13}(transparency_s \times disabled_s) \\
+ \quad & \beta_{14}(transparency_s \times black_s) \\
+ \quad & \beta_{15}(transparency_s \times native_s) \\
+ \quad & \beta_{16}(transparency_s \times hispanic_s) \\
+ \quad & \gamma_y + \mu + \iota_s + \epsilon_s
\end{aligned}
$$

Equation 2: The linear regression for Models 2b (in response to RQ2) and 3b (in response to RQ3).

In each model in the form of the above equation, $outcome_s$ represents each of the student outcome variables we are interested in predicting:

Model 2: self-efficacy in CS ($selfEfficacy_s$), and
Model 3: sense of belonging in computing ($belonging_s$).

The following variables, representing the same constructs as in Equation 1, were included in the model due to their previously documented relationship with computing self-efficacy and sense of belonging: $woman_s$, $firstGen_s$, $disabled_s$, $black_s$, $native_s$, $hispanic_s$, $asian_s$, $substantialExp_s$, and $someExp_s$.

We also anticipated the possibility of moderation effects between perceptions of transparency and students' identities. In particular, Winkelmes et al. [60] noted a *greater* effect of instructional transparency on self-efficacy and sense of belonging for students who identified as first-generation college students, of lower socioeconomic backgrounds, or not white, although the authors did not conduct between-group comparisons. Given the data we have available, we tested for whether identifying as a member of a HUG moderates the effect of perceiving transparency by including moderating effects between perception of transparency and students' identities as Black, Native, Hispanic, and/or a first generation college student. We further included moderating effects for women and for students with disabilities, as these groups are underrepresented in CS [16]. These moderation effects investigate whether perception of transparency has a differential impact on self-efficacy and sense of belonging for different groups.

9 LIMITATIONS

Our work constitutes a large-scale investigation of the relationships between students' perception of instructional transparency and their self-efficacy and sense of belonging, as well as of group differences in these relationships. However, our study and its implications have a number of limitations.

First, we do not know what, if any, transparent teaching practices were intentionally implemented in the courses students were enrolled in. The survey questions we use in our measure for transparency are specifically about students' *perception* of instructional transparency in their CS courses. Therefore, our claims are limited to concerning how students' perception of instructional transparency correlates with their self-efficacy and sense of belonging, rather than the actual practices implemented in their courses.

Second, our methods indicate correlations, but do not demonstrate whether our hypothesized relationships are causal. We mitigate this concern by providing a theoretical argument for the mechanisms by which transparent teaching may affect self-efficacy and sense of belonging in Section 4. Future work may seek to implement classroom interventions to further investigate the impact of instructional transparency.

Third, we could not control for all factors we believe may be relevant. In particular, students' self-efficacy and sense of belonging in computing may be affected by factors that we did not have data for, such as students' current performance in the CS course(s) they are enrolled in. There may also be self-selection in the students who agree to take the survey. Different students may also interpret and/or respond to the questions differently; for example, prior work suggests that women may report lower self-efficacy even when earning the same grades as men [22].

10 RESULTS

10.1 RQ1: Predictors of Perception of Instructional Transparency

In RQ1, we investigated whether students' gender, race, ethnicity, disability status, first-generation status, and prior CS experience predicted students' perception of instructional transparency in their CS courses. We hypothesized that prior computing experience may lead to students perceiving greater transparency in their CS courses. The regression table for Model 1 is shown in Table 2.

Our findings show that identifying as a woman, a first-generation college student, or disabled all predict a lower perception of instructional transparency. That is to say, compared to students who identify as men, continuing-generation, and not disabled, respectively, these students express lower agreement that their CS courses had instructional transparency. In addition, we confirm our hypothesis that a student's reporting of more CS experience prior to college predicts greater perception of transparency in their courses.

We note that the coefficient associated with students with disabilities had a magnitude almost three times as large as the other statistically significant relationships. Recall that this coefficient represents a difference in students' perception of transparency, as defined in Section 7.1.1, a distribution that was standardized to have a mean of 0 and standard deviation of 1. The coefficient for disabled students, -0.20, means that compared to students without disabilities, students with disabilities reported a lower perception of transparency by 0.20 standard deviations. Our definition of disabled students included those who identified with one or more of 14 disabilities, including but not limited to cognitive disorders, learning disabilities, and sensory impairments.

We also note that Model 1 has a relatively low adjusted R-squared, which is a measure of how much of the variation in our dependent variable, perception of transparency, can be explained by our independent variables. A low adjusted R-squared is not surprising, as we expect that most of the variation in students' perception of instructional transparency will be due to the many different CS

Table 2: Regression Model 1 predicting perception of instructional transparency.

Predictor of instructional transparency perception	Model 1
Woman	-0.08^{***} (0.02)
First-generation	-0.07^{**} (0.02)
Disabled	-0.20^{***} (0.02)
Black	-0.06 (0.04)
Native	0.07 (0.07)
Hispanic	-0.05 (0.03)
Asian	0.01 (0.02)
Substantial experience	0.05^{*} (0.02)
Some experience	0.05 (0.04)
Major (fixed effect)	x
Data collection year (fixed effect)	x
Institution (fixed effect)	x
Number of respondents	11,046
Adjusted R-squared	0.04

Note: Standard errors are given in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. An x indicates that the variable was included as a fixed effect. Each coefficient represents a change in perception of instructional transparency along a distribution with mean 0 and standard deviation 1.

courses they are enrolled in and the extent to which those courses implement transparent teaching practices. As our work does not aim to predict an individual student's perception of transparency, but rather to find statistically significant patterns in students' perceptions more broadly, we do not believe this R-squared value is a cause for concern.

10.2 RQ2: Predictors of Self-Efficacy

RQ2 sought to investigate the extent to which students' perception of transparency predicts their computing self-efficacy, while controlling for factors known to correlate with self-efficacy. To answer RQ2, we created two models, Model 2a and Model 2b. Model 2a included only main effects, while Model 2b included moderating effects of underrepresented identities. We hypothesized that perceiving more transparency will predict higher computing self-efficacy, and that this effect will be stronger for students from HUGs, i.e., underrepresented identities will positively moderate the relationship between perception of transparency and self-efficacy. The results of the regression analysis are shown in Table 3.

Findings from Models 2a and 2b indicated that perception of instructional transparency has a significant, positive relationship with computing self-efficacy, as hypothesized. Specifically, Model 2b predicts that students whose reported perception of transparency in their CS courses was one standard deviation above the mean reported a higher computing self-efficacy by 0.22 standard deviations. We additionally found two significant moderating effects, demonstrating that for Black students and for first-generation college students, instructional transparency has a larger positive impact on their self-efficacy. These significant moderating effects partially confirm our hypotheses that perceiving greater transparency is additionally beneficial for students from HUGs, as we demonstrate the differential benefit only for Black and first-generation students, and not for all students from HUGs.

The variables representing students' gender, race, ethnicity, disability, and first-generation status confirm prior work in having a negative relationship with self-efficacy. Having substantial prior CS experience correlated with higher computing self-efficacy, also confirming prior work.

10.3 RQ3: Predictors of Sense of Belonging

In RQ3, we examined the extent to which students' perception of instructional transparency predicted their sense of belonging in computing, controlling for known factors relating to sense of belonging. As with Model 2, we created Model 3a with only main effects, while Model 3b included moderating effects of underrepresented identities. We hypothesized a positive relationship between perception of transparency and sense of belonging, with positive moderation effects of underrepresented identities. The regression table for these models is shown in Table 4.

We found that students' perception of transparency is significantly positively correlated with their sense of belonging in computing. Our model indicates that greater perception of instructional transparency by one standard deviation above the mean predicts a greater reported sense of belonging by 0.24 standard deviations above the mean. We found evidence for one significant moderating effect: identifying as Hispanic *negatively* moderated the relationship between perceiving transparency and sense of belonging. This negative moderation is contrary to our hypotheses that perceiving greater transparency would additionally benefit students from HUGs.

Other variables included in Model 3 confirmed results from prior work in their relationship to sense of belonging. We note, however, that even having *some* prior CS experience predicted an increase in sense of belonging, unlike self-efficacy, where only *substantial* prior experience was a statistically significant predictor.

Table 3: Regression Models 2a (main effects only) and 2b (with moderating effects) predicting computing self-efficacy.

Predictor of self-efficacy	Model 2a	Model 2b
Transparency perception	0.24*** (0.01)	0.22*** (0.01)
Woman	−0.21*** (0.02)	−0.21*** (0.02)
First-generation	−0.14*** (0.02)	−0.14*** (0.02)
Disabled	−0.12*** (0.02)	−0.12*** (0.02)
Black	−0.20*** (0.03)	−0.20*** (0.03)
Native	−0.15* (0.06)	−0.13* (0.06)
Hispanic	−0.06* (0.03)	−0.05 (0.03)
Asian	−0.23*** (0.02)	−0.23*** (0.02)
Substantial experience	0.29*** (0.02)	0.29*** (0.02)
Some experience	0.06 (0.04)	0.06 (0.04)
Transparency perception × Woman		−0.02 (0.02)
Transparency perception × First-generation		0.05* (0.02)
Transparency perception × Disabled		0.01 (0.02)
Transparency perception × Black		0.11*** (0.03)
Transparency perception × Native		0.10 (0.06)
Transparency perception × Hispanic		0.02 (0.03)
Major (fixed effect)	x	x
Data collection year (fixed effect)	x	x
Institution (fixed effect)	x	x
Number of respondents	10,973	10,973
Adjusted R-squared	0.16	0.16

Note: Standard errors are given in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. An x indicates that the variable was included as a fixed effect. Each coefficient represents a change in self-efficacy along a distribution with mean 0 and standard deviation 1.

Table 4: Regression Models 3a (main effects only) and 3b (with moderating effects) predicting sense of belonging in computing.

Predictor of sense of belonging	Model 3a	Model 3b
Transparency perception	0.24*** (0.01)	0.24*** (0.01)
Woman	−0.47*** (0.02)	−0.47*** (0.02)
First-generation	−0.06** (0.02)	−0.06** (0.02)
Disabled	−0.17*** (0.02)	−0.17*** (0.02)
Black	−0.15*** (0.03)	−0.15*** (0.03)
Native	−0.10 (0.07)	−0.10 (0.07)
Hispanic	−0.05 (0.03)	−0.06* (0.03)
Asian	−0.12*** (0.02)	−0.12*** (0.02)
Substantial experience	0.31*** (0.02)	0.31*** (0.02)
Some experience	0.15*** (0.04)	0.15*** (0.04)
Transparency perception × Woman		−0.01 (0.02)
Transparency perception × First-generation		0.01 (0.02)
Transparency perception × Disabled		0.03 (0.02)
Transparency perception × Black		0.02 (0.03)
Transparency perception × Native		−0.02 (0.06)
Transparency perception × Hispanic		−0.06* (0.03)
Major (fixed effect)	x	x
Data collection year (fixed effect)	x	x
Institution (fixed effect)	x	x
Number of respondents	10,982	10,982
Adjusted R-squared	0.19	0.19

Note: Standard errors are given in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. An x indicates that the variable was included as a fixed effect. Each coefficient represents a change in sense of belonging along a distribution with mean 0 and standard deviation 1.

11 DISCUSSION

11.1 RQ1: Predictors of Perception of Instructional Transparency

Our results for RQ1 indicate that, compared to their peers, women, first-generation college students, and students with disabilities perceive less transparency in their CS courses. As far as we are aware, these are the first findings to illustrate group differences in students' perception of instructional transparency in their CS courses. We note that because we controlled for the institution students attend using fixed effects in Model 1, this pattern cannot be explained by people from different demographic groups attending institutions that employ more or less transparency in their CS courses. However, it could be the case that within an institution students from different demographic groups tend to select CS courses that employ more or less transparency.

The effect size corresponding to disabled students indicated a larger effect than the other statistically significant relationships. That is to say, students with disabilities report perceiving *less* transparency in their CS courses than their peers with no disabilities. This finding may signal that transparent teaching practices that "work" for non-disabled students are less effective for disabled students. For instance, one of the survey items asked whether students agree that they were provided a "detailed set of instructions" for an assignment (see Section 7.1.1); it is possible that what students without disabilities considered "detailed instructions" are less clear for those with particular disabilities. Prior work has documented the many challenges disabled students face regarding accommodations in higher education [29, 45]; disabled students being denied accommodations may make it more challenging for them to benefit from instructional transparency.

Our findings also suggest that instructional transparency may not be as apparent to students who identify as first-generation college students, i.e., students whose parents or guardians did not attain a college degree. A possible explanation may be that first-generation college students are less likely to be familiar with the "insider knowledge" that is part of the hidden curriculum at academic institutions [42] and may, therefore, need additional or different forms of transparency than their continuing-generation peers. We note that this finding cannot be explained by first-generation students tending to attend particular institutions that have high transparency in their CS courses, because our model controlled for students' institutions.

Women also reported perceiving less transparency in their CS courses. A possible explanation for this pattern may also relate to the hidden curriculum in computing: prior work has noted the implicit masculine culture, values, and norms in computing [11, 15, 30], which may lead to women perceiving the same instruction as less transparent than their peers who are men.

Consistent with our expectations, having substantial prior CS experience positively predicted students' perception of instructional transparency. This result suggests that prior familiarity with computing concepts helps students more readily perceive learning goals and instructions. Therefore, students with *less* prior CS experience may not perceive instruction as transparent even when their more experienced peers do. Students from HUGs are less likely to have had prior exposure to computing in their K-12 education [1, 18, 19, 54]; therefore, this patterns *compounds* the disadvantages students from HUGs face in accessing computing instruction.

11.2 RQ2: Predictors of Self-Efficacy

The regression model for RQ2 demonstrated that students who perceive greater instructional transparency in their CS course also report higher computing self-efficacy, as hypothesized. Our findings in this regard are a notable contribution to the evidence for the benefits of instructional transparency, as we are able to demonstrate this relationship across institutional contexts and while controlling for confounding variables.

The results from these models also demonstrate that transparency has a differential positive impact on the computing self-efficacy of Black students and first-generation college students. The significant moderating effects indicate that although transparency alone has a positive relationship with self-efficacy, there is an even stronger relationship for Black students and first-generation college students in our participant pool. Winkelmes et al. [60] noted greater effects of transparency for students who were first-generation and for students who did not identify as white, but did not conduct comparisons between groups; therefore, we are able to fill this gap and demonstrate that instructional transparency may indeed have a greater impact on self-efficacy for Black students and for first-generation college students. However, we cannot confirm this relationship for students from other underrepresented racial/ethnic groups among our participants. An open question for researchers to consider is why instructional transparency may be particularly effective for Black students' and first-generation students' computing self-efficacy.

It is possible that students' overall attitude towards computing may positively influence both their self-efficacy and their perceived transparency, explaining the positive correlation between the two found in our model. However, we note that attitude towards computing is unlikely to affect the survey items used in our measure for perception of transparency, as these were specific to practices seen in students' courses, such as "each assignment includ[ing] a detailed set of instructions for completing it".

We note that the lack of other significant moderators may simply indicate that instructional transparency is equally useful for all other groups of students. Our results indicate that students who identify as women, Native, Hispanic, and/or having a disability do not *differentially* benefit from transparency, but for all students, perception of transparency was still positively correlated with self-efficacy.

11.3 RQ3: Predictors of Sense of Belonging

In response to RQ3, we found that students' perception of instructional transparency predicted their sense of belonging, confirming our hypothesis. These statistically significant results provide empirical evidence regarding the benefits of instructional transparency across institutions while accounting for confounding variables.

Our regression models further demonstrated one significant moderating effect, but not in the direction we hypothesized: identifying as Hispanic *negatively* moderated the relationship between perception of transparency and sense of belonging. This means that for Hispanic students, the positive relationship between perceiving transparency and sense of belonging has a smaller effect size than for other students[4]. This result is inconsistent with claims from prior work regarding the additional benefits of instructional transparency for students from HUGs [60]. We encourage future research to investigate other factors that may affect Hispanic students' sense of belonging in computing.

A notable result is the significant correlation we found between having *some* prior CS experience in high school and college students' sense of belonging in computing. (We note that *some* prior HS CS experience was defined as engaging in software/hardware projects, attending a computing workshop, or being part of a computing student group.) In our models for self-efficacy, we found that only *substantial* experience correlated positively with self-efficacy, in line with prior work [36]. This suggests that while *some* prior experience may be insufficient to predict self-efficacy, it can be beneficial for students' sense of belonging in computing. Finding that even limited exposure to computing can correlate with sense of belonging is a promising result, as sense of belonging is itself correlated with positive outcomes such as perceived ability, interest, and performance [26, 30, 53].

12 CONCLUSION

This study aimed to investigate whether there are group differences in students' perception of transparency in their CS courses, and whether instructional transparency correlates with students' self-efficacy and sense of belonging in computing. Self-efficacy and sense of belonging are important outcomes for equity in computing: both constructs are correlated with persistence in computing and can, therefore, support efforts to retain students from HUGs in computing. Using undergraduate students' responses to a large, multi-institutional survey, we conducted linear regression to examine whether perception of transparency correlates with self-efficacy and sense of belonging. Our work constitutes one of the first empirical, multi-institutional investigations of the perceptions and benefits of transparency in CS classrooms that focuses on group differences.

We found that there are group differences in students' perception of transparency in their CS courses. Students who identify as women, first-generation college students, and/or disabled reported perceiving less instructional transparency than their peers. We also found that perceiving more transparency has a positive correlation with students' self-efficacy and sense of belonging in computing while controlling for important confounding variables, such as prior CS experience. We further demonstrated that this relationship is different for certain groups of students: first, for Black students and first-generation college students, perceiving transparency has a *larger* positive impact on their self-efficacy, and second, for Hispanic students, perceiving transparency has a *smaller* positive impact on their sense of belonging. Finally, our work also includes a theoretical articulation of the mechanisms through which transparent teaching practices may influence students' self-efficacy and sense of belonging in computing. Taken together, our empirical findings and theoretical argument provide important evidence for the benefits of instructional transparency in CS courses, particularly as it relates to improving equity in computing.

[4]The effect size of the main effect between perception of transparency and sense of belonging is 0.24, while the effect size for the moderating effect for Hispanic students is -0.06. Therefore, for Hispanic students, the overall effect remains positive, but is smaller than for other students.

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