Using GitHub in the Classroom Predicts Student Learning Outcomes and Classroom Experiences: Findings from a Survey of Students and Teachers

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ABSTRACT

GitHub is a widely-used software development platform that supports version control, collaborative development, and project hosting. Currently, an estimated 18,000 educators use GitHub in programming classrooms. Depending on how GitHub is implemented in the classroom, students may rely on GitHub for activities such as, submitting assignments, collaborating on group projects, and receiving feedback. Despite GitHub's growing presence in programming classrooms, to date, few studies have explored how GitHub and the design of its implementation shape students' learning outcomes and classroom experiences. Building on previous research, we investigated how students in classrooms that used GitHub (GitHub classrooms), as opposed to classrooms that did not use GitHub (non-GitHub classrooms), differed across key variables. We surveyed 7530 students and 300 educators from GitHub and non-GitHub classrooms. Overall, we found that using GitHub in the classroom predicted better learning outcomes and classroom experiences. For example, students felt more prepared for the future, and they felt a greater sense of belonging in the classroom and in the field. Importantly, the design of implementation affected learning outcomes. For example, of the students who used GitHub in the classroom and received instructor feedback, those who received (versus did not receive) feedback via GitHub benefited more from the feedback. We discuss best practices for maximizing benefits to student learning when implementing GitHub in the classroom, study limitations, and future research directions. Our research is a step towards understanding how GitHub, a tool with a growing presence in programming classrooms, impacts students' learning experiences.

KEYWORDS

GitHub; education; learning outcomes

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1. INTRODUCTION

GitHub is a widely-used software development platform that supports version control, collaborative development, and project hosting. With more than 1.8 million businesses and organizations using GitHub [5], it is recognized as an industry standard. In fact, many developers feel that knowing how to use GitHub is an essential part of securing a job [15]. Currently, an estimated 18,000 educators use GitHub in programming classrooms [14]. Depending on how GitHub is implemented in the classroom, students may rely on GitHub for activities such as, submitting assignments, collaborating on group projects, and receiving feedback. Unsurprisingly, the general idea of using GitHub in the classroom has generated interest not only among educators, but also among researchers interested in the implications GitHub has for student learning outcomes. To understand how GitHub can impact the student experience, we will review the general trends uncovered by previous research.

First, using GitHub in the classroom gives students the chance to learn how to use a popular industry tool. Research supports that one of the main motivations instructors have for implementing GitHub in the classroom is to help students develop familiarity with an important industry tool, thus making students more competitive on the job market [3]. Further, students mentioned the importance of publicly presenting their work on GitHub and that it is common for employers to refer to GitHub during the hiring process [3]. Research also supports that industry collaborations may encourage students to take assignments more seriously, invest greater effort, find assignments more meaningful, and be more motivated to perform well on assignments [9].

Next, by encouraging students to use GitHub for collaborative activities, such as peer reviews and group projects, instructors may facilitate students' development of communication, teamwork, and critical analysis skills [2]. Soft skills are important when working in industry, and computer science and software engineering education have begun to adopt a pedagogy that focuses on soft skills in addition to technical skills [3]. In a study where instructors were interviewed, they noted that using

GitHub in their courses effectively introduced students to collaborative practices essential to software development (e.g., cross-team collaboration, peer review) [3]. Further, a survey study found that students preferred the collaborative platform over more traditional individual assignments [8]. One of the key advantages students observed was that GitHub facilitated teamwork and collaboration, allowing students to connect with peers for help outside of the classroom and learn from each other's ideas [8].

In addition, research supports that using GitHub in the classroom boosts student engagement, the overall energy that a student invests in the academic experience [6]. By facilitating student contributions and cross-team collaboration, the use of GitHub enables a participatory culture where students feel their contributions are impactful [3]. Further, in one study, researchers interviewed instructors and found that some instructors use students' contributions on GitHub as materials for discussion in class, thus participation is incentivized because student contributions can direct class discussions [15]. Indeed, past research found that one main motivation instructors have for implementing GitHub in the classroom is to offer students the opportunity to directly influence the course and contribute to course materials (e.g., via pull requests) [3], creating novel ways for students to be involved in the classroom.

Lastly, although past research has not directly addressed this specific idea, using GitHub in the classroom may strengthen the sense of belonging students feel within the classroom because it allows students to collaborate and contribute to each other's learning process. Research finds that, more collaborative projects, where students work closely with peers, can foster a stronger sense of belonging [7]. Importantly, students' sense of belonging can positively predict variables tied to academic success, such as intrinsic motivation and academic self-efficacy [4]. Self-efficacy, the degree to which individuals feel capable of accomplishing a task, is essential to student success because it can protect students' confidence and help them persist when they encounter setbacks [11]. In addition, GitHub supports interactions with individuals in industry [3] and may promote a sense of belonging to the field. For instance, in a past study, an instructor reported that unregistered students and other GitHub users visited and "starred" their class's public repositories, establishing a connection between students and others in the field [15]. Research suggests that improving students' sense of belonging can have a protective effect on retention and increase achievement motivation [13, 10].

Building on previous research, we investigated how students in classrooms that used GitHub, as opposed to classrooms that did not use GitHub, differed across key variables. Our research deviated from previous studies in several ways. Notably, to date, studies on the use of GitHub in the classroom have relied on data from qualitative studies that mostly focus on instructors' perceptions of student learning. Although these approaches have highlighted important issues, trends, and ideas, we aim to build a deeper understanding of students' experiences and also draw comparisons between the students' and instructors' perceptions. Lastly, we hope to extend our understanding of how GitHub shapes student learning outcomes and experiences by measuring additional relevant outcome variables.

2. RESEARCH

This section describes the research methodology: the research questions, the survey used to collect data, and the participants.

2.1 Research Questions

R1: Does using (versus not using) GitHub in the classroom predict students' learning outcomes? Past research suggests that using GitHub in the classroom may boost student engagement [6], and encourage class participation [15]. In the survey, we asked students to rate how much they learned about teamwork and collaboration, popular tools, and project management from 1(very little) to 5 (very much). We also asked instructors to rate their students using the same survey items and scale. We hypothesized that, based on student and teacher responses, using (versus not using) GitHub in the classroom predicts learning more about collaboration, popular tools, and project management.

R2: Does using (versus not using) GitHub in the classroom predict students' feelings of preparation for the future? Research suggests that collaborative activities, such as peer reviews and group projects facilitated by GitHub, may strengthen students' development of skills important when working in industry in the future [2]. In the survey, students rated how much 1(very little) to 5 (very much) their course has prepared them for a future internship or career, being a part of the developer community, developing a portfolio of their work, and taking more advanced courses. We hypothesized that, based on student and teacher responses, using (versus not using) GitHub in the classroom predicts feeling more prepared for all measured domains.

R3: How is the implementation of GitHub in the classroom associated with students' classroom experiences? Using GitHub in the classroom may strengthen the sense of belonging students feel within the classroom. Research finds that, more collaborative projects, where students work closely with peers, can foster a stronger sense of belonging [7]. In addition, GitHub supports interactions with individuals in the broader developer community and may promote a students' sense of belonging to the field. We predicted that, using (versus not using) GitHub in the classroom predicts a greater sense of belonging both in the classroom and in the field.

To assess students' sense of belonging in the classroom and in the field, students were asked to rate the following items using a scale of 1(strongly disagree) to 7(strongly agree), and we created a composite score by averaging ratings across each set of three items. Items were adapted from a previous study [12].

Belonging in the classroom

1. My contributions in my course are valued.
2. I feel comfortable in my course.
3. People in my course accept me.

Belonging in the field

1. I see myself as part of the developer community.
2. I feel that I am a member of the developer community.
3. I feel a sense of belonging to the developer community.

R4: How does the design of implementation predict outcomes related to classroom learning? Lastly, because GitHub is a tool with diverse features and can be implemented

flexibly in the classroom, we wanted to examine whether the design of implementation can predict outcomes related to classroom learning. First, we assessed how the number of features students used in the classroom is associated with positive learning outcomes and feelings of preparation for the future. We expected that using more GitHub features in the classroom is associated with greater positive learning outcomes and feelings of preparation for the future. In addition, we investigated how using GitHub as a tool to deliver feedback may predict the perceived effectiveness of feedback.

GitHub allows students to receive line-specific feedback from their instructors or peers via pull requests. Because detailed informational feedback tends to increase student self-efficacy and learning strategies [1], relying on GitHub may make students better learners who use feedback effectively. We measured students' perceptions of instructor and peer feedback by asking them to rate the following items from 1(strongly disagree) to 7(strongly agree)

Instructor feedback:

1. I understand the instructor's feedback.
2. I pay attention to the instructor's feedback.
3. I use the instructor's feedback effectively.
4. I find the instructor's feedback helpful.
5. The instructor understands my needs as a student.

Peer feedback:

1. I understand feedback from peers.
2. I pay attention to feedback from peers.
3. I use feedback from peers effectively.
4. I find feedback from peers helpful.

We hypothesized that, based on student and teacher responses, using (versus not using) GitHub to deliver feedback generally predicts greater effectiveness of peer and instructor feedback. However, we did not have specific predictions for how using (versus not using) GitHub to deliver feedback predicts the extent to which students pay attention to instructor and peer feedback, because it is unclear how the manner in which feedback is delivered would shape students' motivation to attend to feedback.

2.2 Methodology

Two surveys were designed to collect student and instructor responses. The student survey assessed students' perceptions and experiences in the classroom, and the instructor survey asked instructors to report on their impressions of students' learning experiences.

We invited 459,558 students (9.9% high school; 69.4% college; 3.3% non-traditional; 17.4% other) and 17,806 instructors (15.3% high school; 62.6% college; 2.0% non-traditional; 20.1% other) to participate in our study. Recipients had verified student or instructor status through GitHub and received a link to the online survey via email. In addition, to be eligible for the survey, the recipient must have either taken or taught a class with a programming component in the past semester. 7530 students and 300 instructors who either used or did not use GitHub in the classroom during the most recent semester completed our survey. The response rate of student recipients was 1.6% and the completion rate was 82.1%, and the response rate of instructor recipients was 1.7% and the completion rate was 85.0%. Tables 1 and 2 provide more information on the student and instructor participants' demographic information.

Table 1: Student and instructor respondents' use of GitHub in the classroom

	Students	Instructors
Used GitHub in the classroom	37.2%	67.0%
Did not use GitHub in the classroom	62.8%	33.0%

Table 2: Student and instructor respondents' gender

	Students	Instructors
Female	8.5%	6.9%
Male	90.0%	91.5%
Non-binary	1.0%	0.8%
Prefer to self-describe	0.5%	0.8%

3. RESULTS

Next, we present the results of our survey research.

3.1 Learning outcomes

To examine how implementing GitHub in the classroom predicts students' learning outcomes, we compared self-reported responses from students who used and students who did not use GitHub in the classroom during the previous semester. We also compared responses about students' experiences from teachers who implemented and from teachers who did not implement GitHub in the classroom. First, we examined how much students felt they learned about, and how much instructors felt their students learned about teamwork and collaboration, popular industry tool(s), and project management through their programming course. Separate analyses were conducted to examine teacher perceptions of students' learning outcomes. We used the Welch's t-test, accounting for unequal variance and unequal sample sizes.

In line with our hypothesis, we found that students who used GitHub in the classroom (M = 3.65, SD = 1.30) felt they learned more about teamwork and collaboration than students who did not use GitHub in the classroom (M = 2.78, SD = 1.47; $t(5743)$ = 25.60, $p < 0.01$). Instructors who used GitHub in the classroom (M = 3.12, SD = 1.44) also felt their students learned more about teamwork and collaboration than students who did not use GitHub in the classroom (M = 2.51, SD = 1.31; $t(277)$ = 3.44, $p < 0.01$). Results suggest that students who used GitHub in the classroom may have developed more skills necessary for collaborative work.

In addition, in line with our predictions, students who used GitHub in the classroom (M = 3.72, SD = 1.14) felt they learned more about popular industry tool(s) than students who did not use GitHub in the classroom (M = 2.86, SD = 1.38; $t(6032)$ = 28.01,

$p < 0.01$). Similarly, instructors who used GitHub in the classroom ($M = 3.78$, $SD = 1.04$) felt their students learned more about popular industry tool(s) than students who did not use GitHub in the classroom ($M = 3.24$, $SD = 1.20$; $t(161) = 3.66$, $p < 0.01$). Thus, using GitHub in the classroom may lead students to feel better prepared for working in industry.

Lastly, students who used GitHub in the classroom ($M = 3.53$, $SD = 1.23$) felt they learned more about project management than students who did not use GitHub in the classroom ($M = 2.68$, $SD = 1.38$; $t(5697) = 26.54$, $p < 0.01$). In line these results, instructors who used GitHub in the classroom ($M = 2.95$, $SD = 1.15$) felt their students learned more about project management than students who did not use GitHub in the classroom ($M = 2.41$, $SD = 1.24$; $t(276) = 3.62$, $p < 0.01$). These findings suggest using GitHub in the classroom may help students build skills important for tackling project objectives.

3.2 Preparation for the future

To examine how implementing GitHub in the classroom predicts students' feelings of preparation for the future, we compared self-reported responses about their own experiences from students who used and students who did not use GitHub in the classroom during the most recent semester. Again, we also compared responses about students' experiences from teachers who implemented and from teachers who did not implement GitHub in the classroom. We examined how much students felt their course prepared them, and how much instructors felt their course prepared their students for a future internship or career, being a part of the developer community, developing a portfolio of their work, and taking more advanced courses. Again, separate analyses were conducted to examine teacher perceptions of students' learning outcomes.

Consistent with our hypothesis, we found that students who used GitHub in the classroom ($M = 3.84$, $SD = 1.12$) felt more prepared for a future internship or career than students who did not use GitHub in the classroom ($M = 3.25$, $SD = 1.30$; $t(5826) = 19.77$, $p < 0.01$). However, when we compared instructors who used ($M = 3.83$, $SD = 1.01$) versus did not use GitHub in the classroom ($M = 3.67$, $SD = 1.02$), we found no difference in their ratings of students' preparation for a future internship or career, $t(276) = 1.23$, $p = .22$. This suggests, although instructors saw a connection between their course and students' future career regardless of using GitHub, students who used GitHub in the classroom found their courses more valuable to their future.

In addition, as predicted, we found that students who used GitHub in the classroom ($M = 3.68$, $SD = 1.22$) felt more prepared for being a part of the developer community than students who did not use GitHub in the classroom ($M = 2.82$, $SD = 1.38$; $t(5717) = 27.09$, $p < 0.01$). Similarly, instructors who used GitHub in the classroom ($M = 3.37$, $SD = 1.22$) felt their students were more prepared for being a part of the developer community than those who did not use GitHub in the classroom ($M = 2.75$, $SD = 1.20$; $t(276) = 3.99$, $p < 0.01$). Results suggest that students may feel more fit to contribute to the developer community after a semester of using GitHub in the classroom.

Supporting our predictions, we also found that students who used GitHub in the classroom ($M = 3.58$, $SD = 1.30$) felt more prepared for developing a portfolio of their work than students who did not use GitHub in the classroom ($M = 2.85$, $SD = 1.40$; $t(5516) = 21.66$, $p < 0.01$). In line with these results, instructors who used GitHub in the classroom ($M = 3.37$, $SD = 1.23$) also felt their students were more prepared for developing a portfolio of their work than students who did not use GitHub in the classroom ($M = 2.77$, $SD = 1.11$; $t(276) = 3.96$, $p < 0.01$).

Lastly, we found that students who used GitHub in the classroom ($M = 3.88$, $SD = 1.14$) felt more prepared for taking more advanced courses than students who did not use GitHub in the classroom ($M = 3.70$, $SD = 1.24$; $t(5529) = 5.97$, $p < 0.01$). However, instructors who did (M = 3.84, SD = 1.07) versus did not ($M = 4.05$, $SD = 0.91$) implement GitHub in the classroom showed no significant difference in ratings of students' preparedness for taking more advanced courses, $t(275) = 1.67$, $p = 0.10$. This suggests, although instructors may see a connection between their course and more advanced courses regardless of using GitHub in the classroom, perhaps using GitHub in the classroom helps highlight that connection for students.

3.3 Classroom experiences

Next, to investigate how implementing GitHub in the classroom predicts students' classroom experiences, we compared responses from students who used and students who did not use GitHub in the classroom. Specifically, we focused on students' sense of belonging in the class and in the field. We also examined students' likelihood to recommend their course to others, and to take a similar course in the future. Because these questions centered on students' personal feelings and perceptions to which instructors may have less insight, we did not assess instructors' perceptions of how students felt.

Consistent with our hypothesis, we found that students who used GitHub in the classroom ($M = 5.78$, $SD = 0.99$) felt a greater sense of belonging in the classroom than students who did not use GitHub in the classroom ($M = 5.49$, $SD = 1.12$; $t(5620.04) = 11.23$, $p < 0.01$). In addition, students who used GitHub in the classroom ($M = 5.49$, $SD = 1.26$) also felt a greater sense of belonging in the field than students who did not use GitHub in the classroom ($M = 5.05$, $SD = 1.52$; $t(5883) = 12.90$, $p < 0.01$). Findings suggest that using GitHub in the classroom may help students feel like they are a part of a larger community of people, and that their contributions are valued.

In addition, as predicted, students who used GitHub in the classroom ($M = 5.90$, $SD = 1.30$) were more likely to recommend their course to others than students who did not use GitHub in the classroom ($M = 5.50$, $SD = 1.58$; $F(1,34) = 3.55$, $p < 0.01$). Students who used GitHub in the classroom ($M = 5.78$, $SD = 1.43$) also felt they were more likely to take a similar course in the future than students who did not use GitHub in the classroom ($M = 5.43$, $SD = 1.70$; $t(5939) = 9.09$, $p < 0.01$). These results suggest students may enjoy and value their courses when they use GitHub in the classroom.

3.4 Design of implementation

Lastly, to explore how the design of implementation affects classroom learning, we conducted analyses focused on the way

GitHub was used in the classroom. Running separate regression analyses, we found that the number of GitHub features used in the classroom predicted various student learning outcomes and feelings of preparation for the future. Specifically, using more GitHub features in the classroom predicted students learning more about teamwork and collaboration (b = .17, $t(2505)$ = 15.74, p < 0.01), popular industry tools (b = .11, $t(2504)$ = 10.95, p = < 0.01), and project management (b = .16, $t(2505)$ = 15.34, p < 0.01). In addition, using more GitHub features in the classroom also predicted students feeling more prepared for a future internship and career (b = .11, $t(2501)$ = 11.40, p < 0.01), being a part of the developer community (b = .15, $t(2500)$ = 14.78, p < 0.01), developing a portfolio of their work (b = .15, $t(2499)$ = 13.65, p < 0.01), and taking more advanced courses (b = .09, $t(2488)$ = 9.26, p < 0.01). Consistent with our predictions, results suggest that it may not simply be the implementation of GitHub in the classroom that matters, but how GitHub is used in the classroom may be a key predictor of positive learning outcomes and experiences.

To further assess how the design of implementation affects classroom learning, we explored how feedback is perceived by students when it is delivered via GitHub. One way in which instructors use GitHub in the classroom is as a tool for feedback communication, and we examined students' perceptions of feedback effectiveness when feedback is delivered via GitHub versus not via GitHub. Of the students who used GitHub in the classroom and received instructor feedback, students who received feedback via GitHub (M = 6.01, SD = 1.07) (versus not via GitHub (M = 5.72, SD = 1.34)) perceived feedback as more helpful, $t(790)$ = 4.43, p < 0.01. Compared to students who did not receive feedback via GitHub (M = 5.58, SD = 1.40), students who did receive feedback via GitHub (M = 5.90, SD = 1.18) also felt their needs were better understood by their instructor, $t(733)$ = 4.48, p < 0.01. Lastly, students who received feedback via GitHub (M = 5.99, SD = 1.13) felt they used the instructor's feedback more effectively than students who did not receive feedback via GitHub (M = 5.81, SD = 1.18, $t(666)$ = 2.67, p = .008). However, there was no difference in students' understanding of instructor feedback ($t(1659)$ = 0.38, p = 0.70) and the extent to which they pay attention to instructor feedback ($t(1668)$ = 1.04, p = 0.30) when it was delivered via GitHub versus not via GitHub. In contrast, instructors reported no difference in feedback effectiveness across items when feedback is delivered via GitHub versus not via GitHub. Results suggest that student and teacher perceptions may not be in line with each other. Interestingly, delivering instructor feedback via GitHub seemed to impact students' perceptions that involved use or application of feedback, but not necessarily how much students paid attention to or understood feedback. One potential explanation is that the manner in which feedback is delivered may not shape students' willingness to attend to feedback or their ability to comprehend the feedback. However, how feedback is communicated may influence its perceived value and thus impact the extent to which students feel understood by their instructors.

We also assessed students' perceptions of peer feedback effectiveness when feedback is delivered via GitHub versus not via GitHub. Of the students who used GitHub in the classroom and received peer feedback, students who received feedback via GitHub (M = 5.96, SD = 1.10) (versus not via GitHub (M = 5.76, SD = 1.25)) perceived feedback as more helpful, $t(682)$ = 2.50, p < 0.01. Compared to students who did not receive peer feedback via GitHub (M = 5.68, SD = 1.17), students who received peer feedback via GitHub (M = 5.99, SD = 1.03) also felt they used the feedback more effectively, $t(687)$ = 4.14, p < 0.01. However, there was no difference in students' understanding of peer feedback ($t(980)$ = 1.74, p = 0.08), or in the extent to which students paid attention to peer feedback ($t(988)$ = 1.24, p = 0.22). when it was delivered via GitHub versus not via GitHub. In contrast, instructors reported no difference in peer feedback effectiveness across items when feedback is delivered via GitHub versus not via GitHub.

4. DISCUSSION

Overall, we found that students who used GitHub in the classroom tended to have better student learning outcomes, feel more prepared for the future, and report more positive classroom experiences. In addition, we learned that although using GitHub in the classroom is an important predictor of learning outcomes, the design of implementation mattered. Thus, it is important to consider how students will interact with GitHub when implementing it in the classroom.

We found that students who used (versus did not use) GitHub in the classroom felt they learned more about teamwork and collaboration, popular industry tool(s), and project management via their programming course. These findings suggest students can build skills necessary for working with others in industry by using GitHub in the classroom. Collaborative experiences between students may make them more effective developers in industry, and it is likely that other platforms that facilitate similar experiences can also generate such benefits.

Next, we found that students who used GitHub in the classroom felt more prepared for their future career, being part of the developer community, developing a portfolio of their work, and taking more advanced courses. Research supports that one of the main motivations instructors have for implementing GitHub in the classroom is to help make students more competitive on the job market [3]. Based on our findings, students do perceive benefits in line with instructors' motivations to implement GitHub in the classroom. However, instructor and student findings were not completely in line with each other. Specifically, instructors reported no difference in student preparation for taking more advanced courses and for a future internship or career. One possible explanation is that students and teachers consider different sets of skills when evaluating student preparedness across domains, but further research is necessary to understand the discrepancies in responses.

In addition, our data supported that students who used GitHub in the classroom felt a greater sense of belonging in the classroom. One potential explanation is that using GitHub in the classroom allows students to collaborate and contribute to each other's learning process. Research finds that, more collaborative projects, where students work closely with peers, can foster a stronger sense of belonging [7]. Importantly, students' sense of belonging can positively predict variables tied to academic

success, such as intrinsic motivation and academic self-efficacy [4]. We also found that using GitHub in the classroom may promote a greater sense of belonging in the field more generally. One potential explanation is that GitHub supports interactions with individuals in industry. For instance, in a previous study, the researchers reported that unregistered students and other GitHub users visited and "starred" their public repositories, establishing a connection between students and others in the field [15].

Lastly, we learned that the design of implementation may impact student's learning outcomes and preparation for the future. For instance, using more features within GitHub may predict greater student learning outcomes. Because GitHub can be flexibly used in the classroom for tasks ranging from distributing classroom content to providing line-by-line feedback via pull requests, it is unsurprising that engaging more deeply with GitHub may boost benefits associated with using it. Further, we uncovered that receiving instructor and peer feedback via GitHub may have boosted students' perceptions of the feedback's value. In particular, using GitHub in the classroom predicted students' effective use of feedback and perception of feedback as helpful, but not students' attention towards or understanding of feedback. Importantly, students who received instructor feedback via GitHub felt better understood by their instructor. These findings highlight future avenues for research. For example, from this survey, we did not learn how students are actually applying instructor feedback when it is delivered via GitHub or via other means. It may be the case that receiving feedback via GitHub improved students' perceptions of the feedback but did not impact how students actually applied the feedback. However, it may also be the case that students are better able to apply feedback when it is delivered via GitHub versus via other means. Developing a deeper understanding of how students perceive and apply feedback delivered via different means will help instructors leverage tools that enhance their teaching. Lastly, it is unclear why instructors' responses were not in line with that of students'. One possibility is that instructors lack insight to students' more private experiences that meaningfully shift relative to the use of GitHub in the classroom to deliver feedback.

4.1 Limitations

Our research is a step towards understanding the impact associated with using GitHub in the classroom. However, there are a few notable limitations of the research that should be considered. First, our student and instructor participants may have been more experienced with using GitHub than the average user of GitHub because we only recruited participants who had verified student or instructor status through GitHub. It is possible that the average student would benefit even more from using GitHub in the classroom than our participants because they were learning a valuable industry tool with which they were less familiar. On the other hand, it is possible that the average student would benefit less from using GitHub in the classroom than our participants because they may be less committed to learning GitHub. To improve the generalizability of our findings, future research should attempt to replicate our pattern of results using a sample more representative of the average student using GitHub in the classroom.

In addition, the replication of findings is especially important because our effects are small. Although it may be the case that the benefits associated with using GitHub are small, another reason could be that we recruited a diverse sample of participants who used GitHub in various types of classrooms. Thus, it is possible that examining the effect of using GitHub in a more controlled classroom study would produce larger effects. Although we cannot be fully confident in these results without replication and further research, the pattern of results was mostly consistent across variables. Overall, our findings support that using GitHub in the classroom is associated with positive student learning outcomes and experiences.

Lastly, our study design did not allow us to draw conclusions regarding causality. Although we could determine how students who used (versus did not use) GitHub in the classroom differed, our correlational data did not reveal how using GitHub in the classroom caused change in students' learning outcomes and experiences. So, although we could examine the relationship between key variables and make inferences about causality, we did not collect data that directly examined causality. Future research may use the experimental method to explore whether implementing GitHub in the classroom causes change in students' learning outcomes and experiences. For example, researchers may randomly assign classes to either implement or not implement GitHub in the classroom, and observe how the two conditions differ on key variables.

5. CONCLUSION

Our research provides preliminary evidence illustrating how using GitHub in the classroom may benefit student learning and classroom experiences. Results highlight the potential impact of using GitHub in the classroom on student learning outcomes, and suggests using GitHub in the classroom positively predicts learning outcome variables. Importantly, the design of GitHub implementation matters and our results support that how students use GitHub in the classroom may impact learning outcomes. Combined with further research, our findings may be used to inform best practices for implementing GitHub in the classroom.

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