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Effect of Automated Instantaneous Feedback, Unlimited Submission Attempts, and Optional Exercises on Student Engagement, Performance, and Academic Integrity in an Introductory Computer Programming Course for Engineers

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Effect of automated instantaneous feedback, unlimited submission attempts, and optional exercises on student engagement, performance, and academic integrity in an introductory computer programming course for engineers

Abstract

We explore how automated just-in-time feedback, unlimited submission attempts, and optional no-credit programming assignments impact student engagement, course performance, and academic integrity in an undergraduate introductory computer programming course for engineers. An interactive browser-based coding platform called MATLAB Grader was used to provide customized actionable feedback to students as they develop their solutions to homework, practice, and exam problems. Statistical analysis of students' engagement with the no-credit assignments and their academic performance reveals a positive correlation between students' level of engagement with the optional exercises and their course scores and grade point average. Female students were found significantly more likely to engage with the optional exercises compared to their male peers, despite the GPA distributions of the two groups being very similar. Underrepresented minority (URM) students were found to be significantly less inclined than non-URM students to take advantage of the zero-credit instant-feedback practice opportunities. A significant difference in final exam scores was likewise observed between URM and non-URM students, with the latter group receiving the higher marks. The significance of the differences could not be adequately explained by differences in GPA alone. Analysis of students' survey responses shows that real-time feedback and unlimited submission attempts helped students assess their learning progress and motivated them to continuously improve their solutions. Instant feedback and unlimited submission attempts were regarded by students as likely having positively impacted academic integrity in the course. The effect of automated feedback and optional assignments on students' need to visit office hours is explored. Implications for future pedagogical practice and research are discussed.

Introduction

Timely and effective feedback provided to students on their submitted work has the potential to significantly enhance learning, improve student self-efficacy, reduce drop-out rates, and improve educational outcomes, especially among undergraduates in the early stages of their academic program [1], [2]. In introductory computer programming courses, where inordinately high drop-out rates have been reported [3]–[5], early feedback can play a vital role in supporting student success and retention. Computer systems capable of automatic grading and feedback generation have gained considerable traction over the past two decades. Recent literature on automated feedback and assessment examines key benefits, opportunities, and challenges of the considered practice [6]–[8]. Our study contributes to the existing body of knowledge by examining the effectiveness of optional no-credit programming exercises featuring automated real-time feedback in motivating student engagement with the course material. Whereas previous research focuses primarily on automated feedback on compulsory homework and exams, and its learning impact, our work investigates automated feedback in relation to voluntary assignments as well,

student completion of which has been shown to predict exam scores and academic achievement [9], [10]. Our study thereby expands on the work by Edwards et al. (*ibid*.), who examined the relationship between voluntary coding practice and subsequent exam performance in a CS1 class where an automated drill-and-practice system was used, capable of feedback generation. Their study aimed to measure learning gains afforded by voluntary practice beyond ability level, while our considerations extend past this control variable to include year of study and other variables of interest such as gender and underrepresented minority, transfer, and first-generation status. We also investigate students' beliefs as to whether the provision of instantaneous feedback and unlimited submission attempts potentially improved academic integrity in the course by curbing the tendency of some students to search for online solutions. The effect of automated feedback and optional exercises on students' need to visit office hours is likewise examined.

Related Research

Automated Feedback

The positive impact of quality formative feedback on the learning process has been extensively examined and is well established in the literature. Research shows that effective feedback supports students' willingness to reflect on their understanding, to identify misconceptions and areas of deficiency, and to make adjustments to improve learning and performance [1], [11], [12]. Constructive well-designed feedback has also been shown to improve student motivation and self-efficacy beliefs [13], [14]. Academic integrity research argues that meaningful supportive feedback empowers students, reducing their likelihood to cheat [15]. Educators adopting formative feedback as an instructional intervention too can benefit from the process, as it can offer them valuable insights into students' understanding of the subject material to help inform their pedagogy [16], [17].

While most of the earlier research focused either on feedback to students as a general category, or on feedback in written or oral form provided to learners manually or in face-to-face interaction, considerable effort has more recently been directed to understanding the effect of *automated feedback* on student learning and satisfaction. Research in this area has largely been driven by positive trends in higher education enrollment, the rise of massive open online courses (MOOCs), and broad availability and accessibility of computer systems capable of automatically generating and rendering feedback to learners. Automated assessment and feedback systems can be applied at scale and have been successfully deployed in courses with enrollments over 1000 students, as well as in smaller classes, across various disciplines in the natural and social sciences, engineering, mathematics, and arts [6]–[8], [18]–[20].

Different techniques for automatic assessment and feedback generation have been developed and implemented to meet specific course educational objectives. Foremost among these techniques are cross comparison with a reference solution, the use of dashboards featuring statistics and graphs of task execution and progress, natural language processing (NLP) for the analysis and evaluation of students' written activities, the use of intelligent tutoring systems, and data-driven approaches [6]–[8]. Besides their ability to facilitate feedback delivery in high volume and to significantly lessen the workload on an instructional team, automated assessment systems are

attractive to educators because they are interactive and can offer their students timely, around-the-clock input to guide them in their task-completion and learning efforts [6]–[8]. Educational research confirms that for feedback to be positively impactful it should be relevant and actionable [21]–[25]. Traditional instructor-provided feedback typically has a week-long turnaround. Such feedback students all too often disregard, perceiving it as not immediately relevant to the task at hand. Computer-generated just-in-time feedback, on the other hand, is information students can engage with right away. As such, it is more likely to support students' learning and self-regulation processes in a beneficial way [21], [26].

Much of the research on the effectiveness of automatic feedback in improving student performance and learning outcomes has been performed in the context of computer programming courses. Grading students' code can be particularly tedious if done manually, so automated assessment tools have been developed early on to identify syntax, run-time, and conceptual errors [6]–[8]. Auto-grading platforms capable of evaluating code style and efficiency have likewise been realized to allow for more refined scoring and detailed feedback for students. These systems typically rely on dynamic testing and static analysis of the code with varying degrees of sophistication. Most studies exploring the effectiveness of automated grading and feedback generation in computer programming courses conclude that the two practices significantly support teaching and learning [6]–[8]. With homework graded automatically, instructors and instructional assistants have more time on their hands to interact with students, develop new course materials and activities, and advance their teaching methodology. Learning analytics, typically provided by automated assessment systems, can further help instructional teams better direct their teaching to meet students' learning needs. Instantly generated feedback received by students has similarly been shown to boost overall class performance, improve student course evaluations, and reduce drop-out rates [6]–[8].

Optional Assignments

Though homework does not in general ensure improved learning outcomes and achievement among students who do it, meaningful, well-designed assignments with feedback have been shown to contribute to students' scholastic attainment across disciplines [27]–[29]. Optional or extra credit assignments have similarly been found to support students' learning and academic success in many situations, though not unconditionally [9], [10], [30]–[33].

Non-compulsory assignments are typically intended by educators to offer students supplementary learning opportunities, promote subject mastery, reduce test anxiety, and, in the case of extra-credit assignments, allow students to earn additional points toward a higher grade [9], [30], [33]. Interestingly, students with stronger existing academic standing have been observed to engage with voluntary assignments at often a significantly higher frequency than students who are in greater need of supplementary practice and extra-credit opportunities [31], [32]. It has been argued that this is because high-achieving students are intrinsically more motivated, hence derive greater satisfaction from being additionally challenged, whereas low-performing students may be discouraged by past failings from engaging in activities that could further their feelings of low self-efficacy (*ibid*.). It has been likewise observed that female students engage with optional and extra-credit assignments more readily than their male

classmates, which is thought to be in part due to a possible disparity in the level of motivation toward scholastic achievement favoring the former sex [31], [34]. Finally, optional assignments have been found to be more appealing to students in larger classes than in smaller ones [31]. This is likely because students in large-enrollment classes have typically less opportunities to interact with the instructor, and more peer competition, and hence a reduced sense of preparedness, which they may recognize as something they can improve by engaging with optional practice exercises (*ibid.*).

Research Questions

The present study attempts to address the following research questions in the context of an introductory computer programming course:

RQ1. Are students who engage with no-credit instant-feedback practice problems more likely to receive higher scores on homework or exams?

RQ2. Are certain demographic groups more or less likely to engage with optional no-credit instant-feedback assignments?

RQ3. Do students' feel that the provision of instant feedback and unlimited submission attempts motivates them to engage with optional no-credit assignments?

RQ4. Do students feel that the provision of instant feedback, together with multiple submission attempts on assignments, improves academic integrity in the class?

Context and Methods

The benefits to student learning and performance associated with compulsory homework have been reported to outweigh those of optional assignments in many circumstances [10], [30], [35], [36]. Notwithstanding, students do by and large value the availability of ancillary, optional practice opportunities, as evidenced in prior work [10], [37]. Voluntary assignments have been found by many studies to foster deeper learning, increased academic engagement with course content, and improved scholastic performance as measured by exam scores and course grades [9], [37], [38]. Motivated by these reasons, in our offering of an introductory computer programming course, we have introduced optional practice sets to supplement each required homework assignment. Moreover, considering the many reported benefits of timely actionable feedback on student learning and success, we have adopted an interactive online browser-based platform called MATLAB Grader, offering instant customized feedback to students as they code their solutions to homework problems, optional exercises, and exams.

Our study focuses on the impact of immediate automated feedback and optional no-credit coding assignments on students' engagement with course content, performance, and academic integrity in three offerings of a MATLAB programming course offered by an engineering department at a large public research university. The course was offered remotely in the winter 2021 and in hyflex modality [39] in the winter quarter of 2022. These offerings coincided with the COVID-19 pandemic, when many university campuses, including our own, were shut down or operating under restrictions for health and safety reasons.

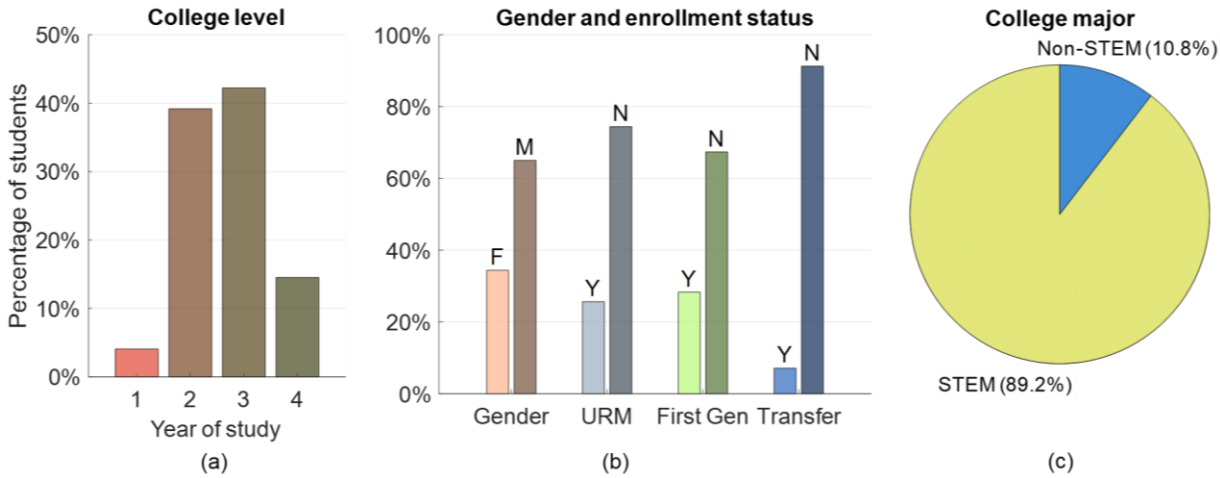

Figure 1. Distribution of structures across (a) college level, (b) gender (M = male, F = female) and URM, first-generation, and transfer status (Y = yes, N = no), and (c) major category (STEM and non-STEM).

The learner population in both course sections was comparable with respect to demographic characteristics and academic standing, and we shall only report on aggregate statistics. Of all 296 undergraduate enrollees, 4.1% were freshmen, 39.2% sophomores, 42.2% juniors, and 14.5% seniors. About 90% of them were STEM majors (mechanical, aerospace, structural, and bioengineering, physics, chemistry, biology, and mathematics), with just over 10% being majoring in cognitive science, psychology, economics, and other non-STEM fields. The population was also diverse culturally, socioeconomically, racially, and in other ways. Figure 1 summarizes the composition of the two classes combined.

Adding further to the academic diversity in the course was the variation in prior programming experience among students. Such a variation is regularly observed in college-level introductory computer programming courses due to differing high school curricula and variability in students' level of preparation at enrollment. Students from underserved communities, where access to computers and programming coursework opportunities may be limited, may enter the class with less coding experience than their peers. For this reason, additional practice and learning opportunities for such students can be essential in ensuring they succeed in the course and advance in their academic studies.

The potential of automated feedback systems and optional computer programming exercises to induce student engagement with course content is gauged by tracking and analyzing students' coding activities and work patterns over time with the help of learner analytics within the MATLAB Grader browser-based coding environment used by students to develop and submit their solutions to homework assignments, optional practice sets, and exam problems. The feedback provided to students by the automated grading system is diagnostic in nature, serving to inform the students of syntax and run-time errors, as well as failures of their code to produce correct results and meet problem specification criteria. Students are given unlimited submission attempts on each assignment and exam (up to the submission deadline) so that they may revise and improve their solutions based on the feedback received. A representative example of feedback offered on a submitted solution which does not meet all criteria is shown in Fig. 2.

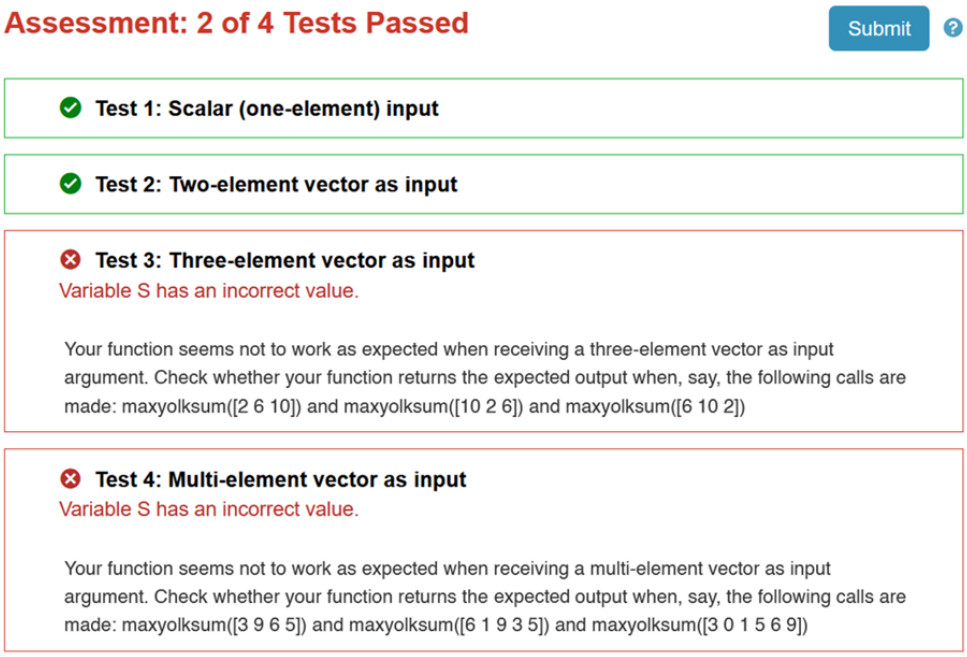

Figure 2. Snapshot of customized feedback provided by MATLAB Grader to a student's partially correct submission to a problem. The problem asked for a function called maxyolksum to be written that receives a one-dimensional array (vector) of real numbers and returns the maximum yolk sum (yolk sum = sum of two adjacent elements) if the vector length is greater than one, and NaN if the vector length is one. The student's submission succeeds in producing the expected solution when the input is a one-element and two-element vector, but fails otherwise, as detected by Test 3 and Test 4.

By carrying out statistical analysis, including the independent-samples t-test, ANOVA, and correlation analysis, we investigate the relationships between students' engagement, performance on voluntary and required assessments, and demographic variables of interest (academic level, gender, GPA, etc.). Students' surveyed perceptions about automated feedback as it relates to engagement, self-regulated learning, need to visit office hours, and academic integrity, are also examined.

Results

Class engagement with optional exercises

A student's engagement with each optional no-credit coding assignment was measured as the percent of problems on the given assignment which the student attempted and submitted a solution for, irrespective of its level of correctness. A measure of the student's overall engagement with no-credit practice exercises in the course was calculated as the average level of engagement over all exercise sets, of which there were seven (six) in the winter 2021 (2022) offering of the course. Each set consisted of 4-8 coding problems, similarly as the credit-bearing homework assignments which they accompanied. The bar chart in Fig. 3a shows the distribution of student engagement with the optional practice exercises in the two classes combined.

The mean and median engagement with the optional assignments were 33.1% and 23.6%, respectively. That engagement would be skewed toward the lower end of the scale was expected,

as many students who enroll either come in with strong programming skills, and likely do not feel they need practice beyond homework to do well in the course, or find it insufficiently rewarding, or see it not as a priority, to work on zero-credit assignments. A little under 20% of the students (58 out of 297) did not attempt the optional exercises at all, and just under a third (93 out of 297) had a level of engagement below 10%. The opposite end of the scale shows a sizable portion of students (13.5% or 40 out of 297) who engaged above the 90% level, most of whom (26 out of 40) attempted all problems on all practice sets (100% engagement). The levels of engagement of the remaining roughly half of the class (54.9% students) fall in between the two extremes, i.e., within the interval 10-90%. For sake of comparison, the mean and median levels of engagement on homework assignments were 92.9% and 99.4%, respectively, with just above three quarters of the students engaging at a level above 90%. Such a discrepancy is understandable, given that homework was mandatory and worth 20% (25%) of the overall course grade in the winter 2021 (2022) section. Nevertheless, the results summarized in Fig. 3a corroborate the findings of earlier studies, that optional exercises, even when not for credit, have the potential to support the learning efforts of a substantial portion of the class [9], [37], [38].

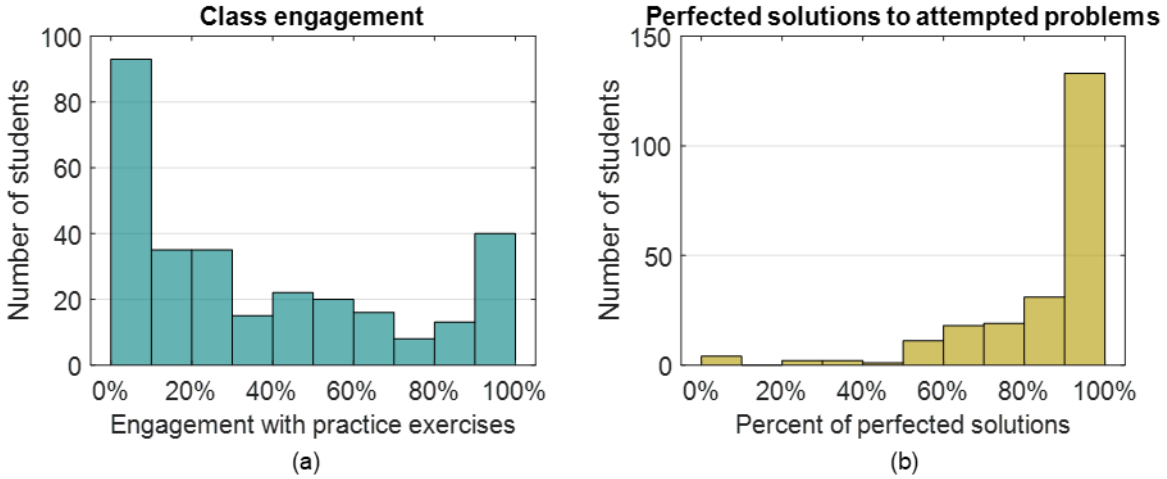

Figure 3. Distribution of (a) level of student engagement with optional no-credit practice assignments, and (b) percentage of perfected solutions to attempted no-credit optional practice problems.

Figure 3b provides further insight into student engagement with optional practice exercises. The ratio of perfected to attempted solutions, averaged over all practice sets for each student was computed and converted to a percentage. By perfected solutions we mean submitted solutions that pass all our implemented automated tests and are thus regarded as fully correct by the MATLAB Grader application. The distribution shown in Fig. 3b, being highly skewed to the high-percent end, suggests that instant provision of feedback in the context of unlimited submission attempts may have provided additional drive to the students to perfect their solutions. Further evidence in support of such a view is obtained from the distribution of students' homework scores, which exhibit the ceiling effect, with 76.4% of students obtaining an average above 95%. The ceiling effect implies high persistence among students to develop correct solutions to homework problems, to which the interactive feedback-enriched developing environment likely contributed, as suggested elsewhere [40].

Relationship between engagement on optional exercises and academic performance

Linear correlation analysis was performed to inspect the relationships between students' engagement with optional no-credit assignments and their course scores and incoming academic standing. Table I shows a significant positive correlation (Pearson's r) at the 5% significance level ($p < 0.05$) between engagement on practice exercises and all considered academic performance metrics: homework and exam scores, total course score, and GPA at course enrollment. The finding echoes that of previous studies which show that high-performing students are more inclined to take advantage of supplemental practice opportunities, even though such are typically intended for students who need extra preparation or catching up in order to succeed in the course [31], [32], [37].

Table I. Engagement with optional no-credit assignments versus academic performance

	Engagement with optional exercises			
	Pearson's r	p-value	$r_{.\mathrm{GPA}}$	p-value
Homework score	0.35	< 0.0001	0.05	0.49
Quiz/Midterm score	0.25	< 0.0001	–0.04	0.59
Final exam score	0.19	< 0.0001	-0.04	0.61
Total course score	0.28	< 0.0001	-0.04	0.55
GPA	0.46	< 0.0001	-	-

To better understand the interactions between students' engagement with optional exercises and their course scores, partial correlation coefficients ($r_{.\mathrm{GPA}}$) were computed between the matched variables in Table I, with GPA used as the control variable. In all cases, when controlling for the effect of incoming academic standing (GPA), no relationship is observed between course performance and engagement with optional exercises. Such a finding does not preclude the possibility that supplemental practice enhanced course performance among those who engaged with the optional problem sets.

Demographic group analysis

Students at an earlier stage in their undergraduate education are at an increased risk to fail in a course or drop out of an academic program and are therefore considered more likely to benefit from supplemental support structures and learning opportunities [41]. To determine whether freshmen and sophomore students took advantage of supplemental practice opportunities more often than their senior classmates, we investigate student engagement with optional feedback-enriched coding exercises across college level.

Figure 4a shows the inverse-cumulative engagement with practice exercises across college level. For example, the figure shows that about 40% of students of all four college levels engaged with practice exercises above the 35% engagement level. Overall, no significant difference is observed in engagement between students at different college levels (Fig. 4b). ANOVA confirms no statistically significant difference in the means of engagement between freshmen, sophomores, juniors, and seniors, at the 5% significance level.

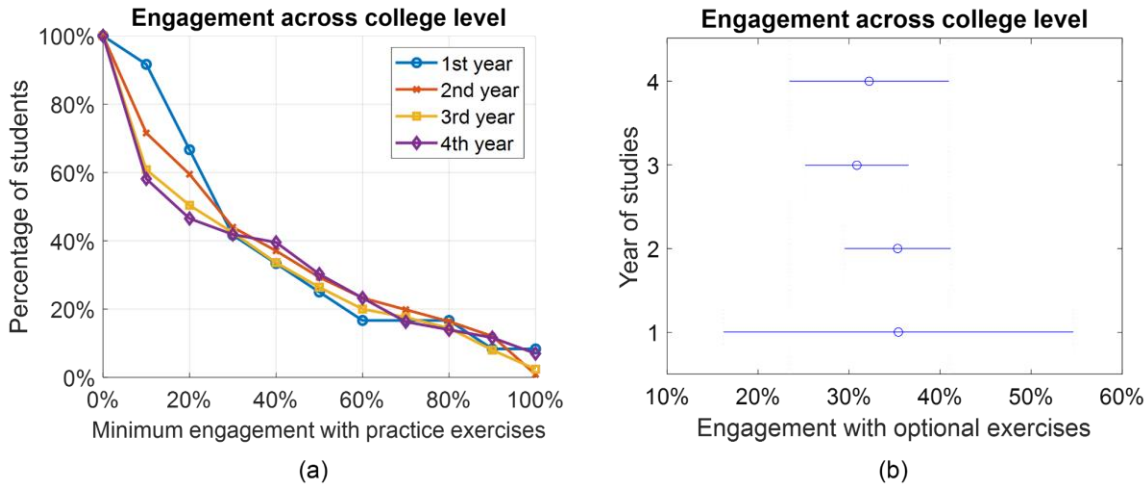

Figure 4. (a) Inverse-cumulative engagement with optional practice assignments across college level. (b) Comparison of mean engagement with optional practice assignments between first, second, third, and fourth year students at the 5% significance level. The circular plot symbols represent the mean values, while the linear segments define the confidence intervals.

Independent samples t-tests are performed to evaluate the significance of differences in engagement between students of different gender and underrepresented minority (URM[1]), transfer, and first-generation status. We report on results of tests run for Winter 2021 and Winter 2022 course sections separately, as well as for the aggregated data (both sections combined), as certain differences were found statistically significant in one section and not the other. Results indicate non-URM students tended to engage with voluntary exercises significantly more than URM students in the Winter 2021 section (t = 3.21, df = 190, SE = 29.90, p = 0.0016), though not in the Winter 2022 section (t = 0.7575, df = 103, SE = 35.27, p = 0.4505), as illustrated in Fig. 5a,b. The difference in engagement levels between URM and non-URM students is found to be statistically significant for the aggregate population, as well (t = 2.98, df = 295, SE = 31.97, p = 0.0032; Fig. 5e). Further, in both the Winter 2021 and Winter 2022 classes, female students were seen to be more inclined toward supplemental practice than their male peers (Fig. 5a,c), and, though the difference was not statistically significant at the 5% level in either section, it was for the two classes combined (t = 2.34, df = 293, SE = 32.19, p = 0.0198; Fig. 5e).

To better appreciate these outcomes, we compare the mean GPAs between the two groups in each considered demographic category (Fig. 5b,d,f). The GPA means and 95% confidence intervals across the different demographic groups are very similar for the two sections (Fig. 5b,d). Referring to the results for the aggregated data (Fig. 5e,f), we first observe that female students tended to be engaged with voluntary exercises at a significantly higher level than males, despite the rather similar distribution of GPAs between the two genders, as inferred from Fig. 5f. This is notable, given the previously established strong positive correlation between engagement level and GPA (Table I). Findings of other studies similarly point to female students being more

[1] URM students are defined in this study as students identifying as American Indian/Alaskan Native, Black/Afro-American (not Hispanic), Filipino/Pilipino, Latin American/Latino/Latinx, Mexican/Mexican American/Chicano, Native Hawaiian/Other Pacific Islander, or Other Spanish/Spanish American.

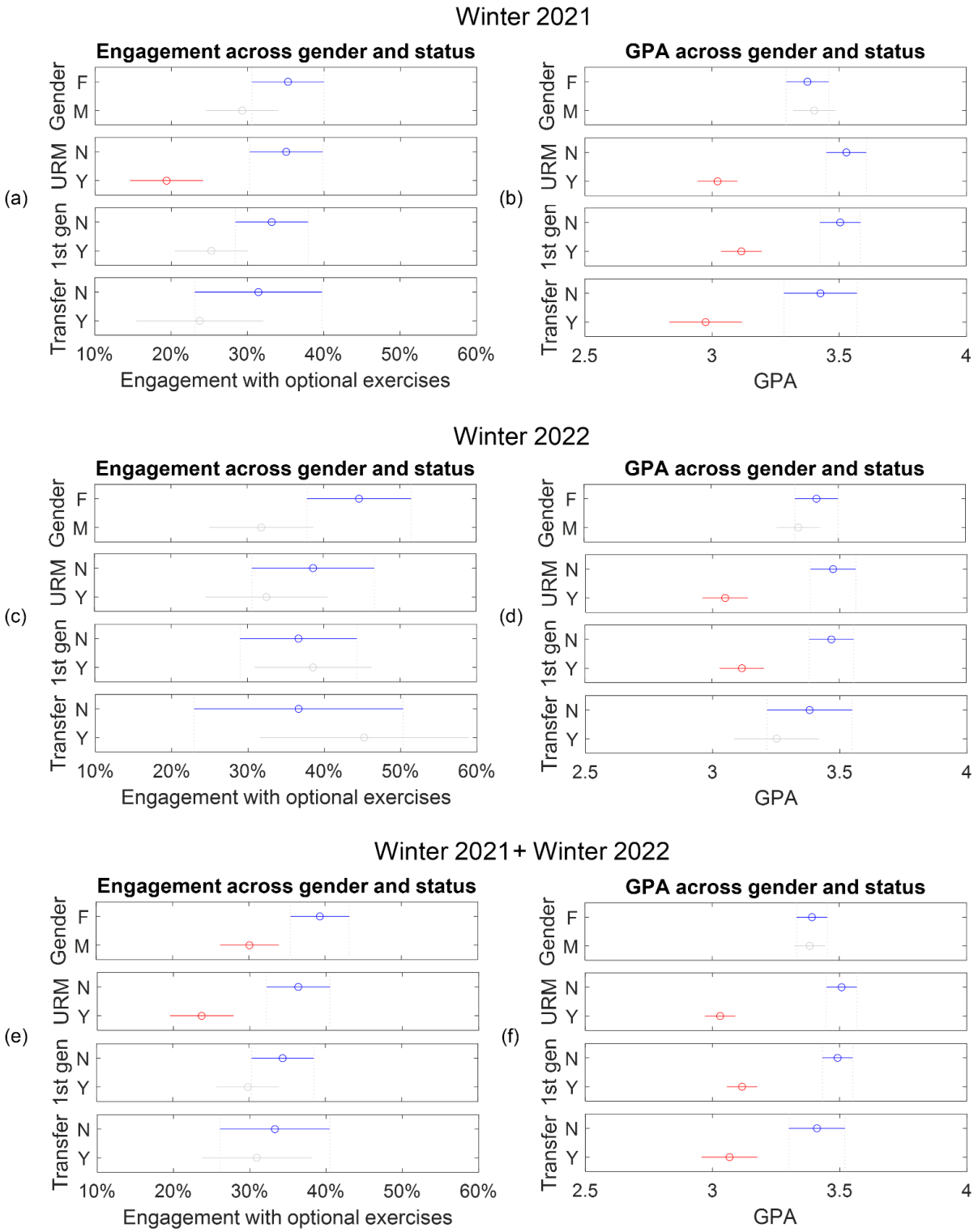

Figure 5. Comparison of mean (a) engagement with optional practice assignments and (b) mean GPA between students of different gender, URM, transfer, and first-generation status at the 5% significance level. The circular plot symbols represent the mean values, while the linear segments define the confidence intervals.

inclined than males to engage with discretionary practice exercises and extra-credit assignments and opportunities [31].

Secondly, looking at Fig. 5f, we observe that non-URM students on average had higher incoming GPAs than their URM classmates (t = 7.84, df = 295, SE = 0.46, p < 0.0001), as similarly did non-first-generation students in comparison to first-generation students (t = 6.15, df = 295, SE = 0.47, p < 0.0001), and as did non-transfer students in comparison to transfer students (t = 3.06, df = 295, SE = 0.50, p < 0.0024); yet, URM students emerged as the most critical group in that voluntary practice was least common among them (Fig. 5e), despite their GPA being, on the whole, comparable to that of the first-generation and transfer students (Fig. 5f).

Further insights are gained by conducting analysis of covariance (ANCOVA) with GPA as the control variable. GPA is found to account for the significant difference in engagement observed between URM and non-URM students in the Winter 2022 section (F(1,103) = 0.30, p = 0.5860) and the aggregate population (F(1,295) = 1.29, p = 0.2568), but not in the Winter 2021 section (F(1,190) = 3.92, p = 0.0491). This suggests the possibility that differences in situational factors between the two course offerings may have occasioned dissimilar behavior of URM students in the two sections. The most salient difference between the Winter 2021 and Winter 2022 courses was that the former was delivered entirely remotely, while the later was offered in hyflex modality, with most students having returned to the physical classroom or the campus premises. Arguably, campus closures during the COVID-19 pandemic disproportionately disadvantaged URM students, who may as a result have had less time on their hands for study and optional zero-credit assignments [42], [43].

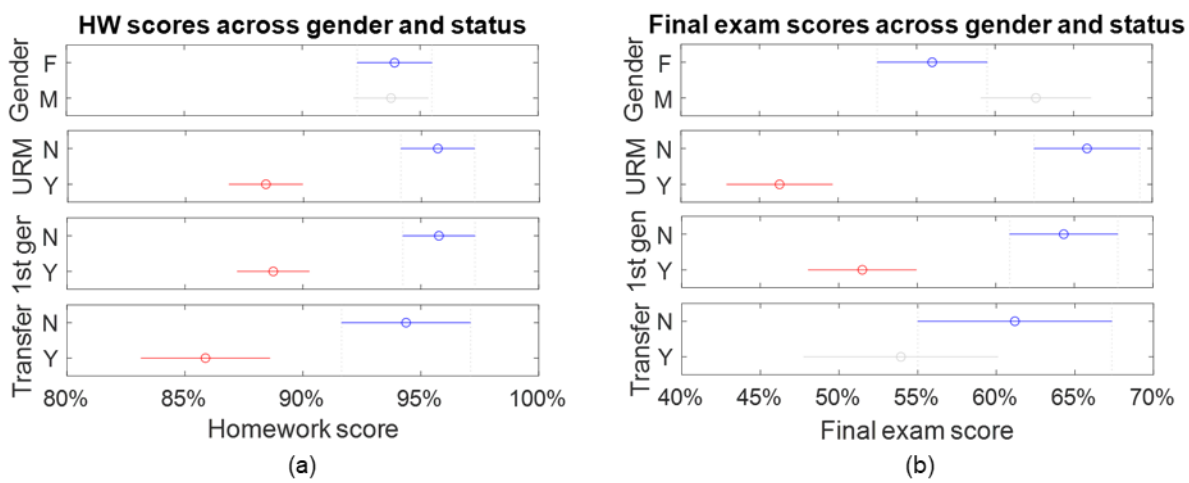

Figure 6. Comparison of (a) homework and (b) final exam scores between students of different gender and URM, transfer, and first-generation status at the 5% confidence level.

Another perspective on demographic group differences is offered in Fig. 6, showing homework and final exam scores across gender and enrollment status for both sections combined. Only results for the aggregate population are presented, as differences between course scores in any demographic category were similar for the two course sections. The shown differences in homework scores (Fig. 6a) follow the pattern eof differences in GPAs, illustrated in Fig. 5f. Conversely, the differences in final exam scores fall out of pattern with the differences in GPA.

In particular, a disproportionately large difference is observed in final exam scores between URM and non-URM students. ANCOVA reveals that while final exam score differences between first-generation and non-first-generation students are far from significant at the 5% level when controlling for GPA ($F(1,295) = 0.6$, $p = 0.4403$), the same cannot be said for the corresponding differences between URM and non-URM students, which are borderline significant ($F(1,295) = 3.79$, $p = 0.0526$). In summary, demographic group analysis indicates that the URM students were a performance and engagement sensitive group, having lower GPA and final exam scores overall, and exhibiting significantly reduced tendency to engage with optional no-credit assignments, which is unpredicted by their GPAs alone. The results further indicate that transfer students, despite having had significantly lower incoming GPAs in comparison to their remaining classmates, demonstrated a level of engagement with optional exercises and received scores on the final exam that are not significantly lower than those of the non-transfer students. Finally, a statistically significant difference in levels of engagement with optional exercises, unaccounted for by GPAs, is found between females and males, with the former group being more inclined toward the supplemental practice.

Student perception analysis

To gain further insights into how instant feedback and unlimited submission attempts implemented within the MATLAB Grader application influenced students' learning and course experience, a survey instrument was developed following the winter 2021 offering of the course and used to probe the perceptions of students enrolled in the winter 2022 section. The survey instrument was a questionnaire consisting of several Likert-scale questions with the multiple-choice response options: Strongly Disagree, Disagree, Neither Agree nor Disagree, Agree, Strongly Agree. At the end of the academic term, an invitation was sent to the class to anonymously take the survey, which was administered using Google Forms. The survey response rate was 32 out of 105 students, or 30.5%.

Table II. Student perception survey.

Question:	The immediate feedback and unlimited submission attempts provided by MATLAB Grader:	μ	σ
1	helped me identify gaps in my knowledge	4.31	0.93
2	helped me assess my learning progress	4.53	0.67
3	motivated me to continue to improve my solutions	4.34	1.00
4	led me to solve problems by guess-and-check rather than with true understanding	2.88	1.31
5	reduced my need to visit office hour	3.87	1.20
6	prompted me to visit office hours more frequently	2.91	1.41
7	motivated me to attempt the optional practice exercises	3.78	1.21
8	likely reduced the temptation of some students to search for solutions online	4.16	0.81

Response options and their quantification: Strongly Disagree = 1, Disagree = 2, Neither Agree nor Disagree = 3, Agree = 4, Strongly Agree = 5.

For the purposes of summarizing the survey results concisely, we adopt a quantification scheme whereby Strongly Disagree = 1, Disagree = 2, …, Strongly Agree = 5. Table II lists the questions

Q1-Q8 which students were asked on the survey and shows the means (μ) and standard deviations (σ) providing indication of the respondents' average sentiments and spread in opinion. We remind that automated instant-feedback and unlimited submission attempts were offered to students not only on optional no-credit assignments, but also on homework and exams (up to the submission deadline).

As Table II shows, respondents overwhelmingly agreed that immediate feedback and unlimited submission attempts helped them identify areas of improvement (Q1: μ = 4.31, σ = 0.93) and assess their learning progress (Q2: μ = 4.53, σ = 0.67). Likewise, the sentiment was strong among respondents that instant provision of feedback and unlimited attempts on problems motivated them to work toward perfecting their solutions (Q3: μ = 4.34, σ = 1.00). Figure 7 offers a more resolved look into the distribution of responses for select survey questions, including Q2.

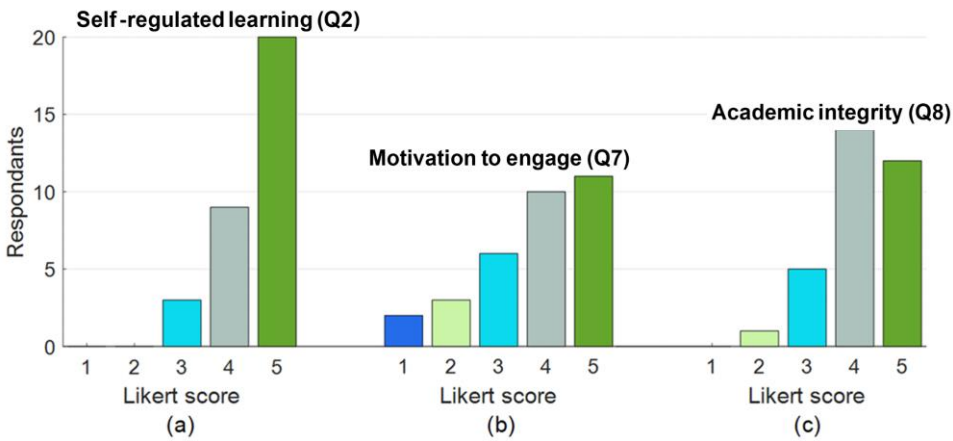

Figure 7. Distribution of students' responses to questions (a) Q2, (b) Q6, and (c) Q7 of the student perception survey (Table II).

We were also interested whether unlimited submission attempts provided a recourse to students to solve problems by guess-and-check rather than with true understanding. On average, students neither agreed nor disagreed with this statement (Q4: μ = 2.88, σ = 1.31). A portion of the students indicated that the feedback-enriched coding environment and limitless submission attempts reduced their need to visit office hours (Q5: μ = 3.87, σ = 1.20). Survey responses to the converse question as to whether the environment prompted them to go to office hours more frequently were mixed however (Q6: μ = 2.91, σ = 1.41).

Many respondents felt that immediate feedback and inexhaustible chances to improve their solutions motivated them to engage with the optional practice exercises (Q7: μ = 3.78, σ = 1.21). Survey responses indicate that most students agreed that the provision of real-time feedback and countless submission attempts on homework, optional exercises, and exams likely reduced the temptation of some students to cheat in the course by searching for online solutions (Q8: μ = 4.16, σ = 0.81). The distribution of responses for questions Q7 and Q8 are given in Fig. 7b,c.

Since the browser based code-development environment MATLAB Grader does not offer all the same code-developing and debugging capabilities as the MATLAB desktop application, the

questionnaire also asked students, using the same five-point scale, whether they agree with the statement: “When I didn’t get the right answers in MATLAB Grader, I turned to the MATLAB desktop environment to debug, troubleshoot, and resolve issues.” Of all respondents, 18.8% strongly agreed, 56.3% agreed, 18.8% neither agreed or disagreed, 3.05% disagreed and 3.05% strongly disagreed with the statement. This suggests that the use of MATLAB Grader did not significantly detract students from use of advanced capabilities of the MATLAB application, such as debugging in debug mode, plotting, and I/O.

Conclusions

Learner analytics provided by MATLAB Grader shows a broad variation of engagement levels across students enrolled. It is found that over 80% of the students engaged at least once with the optional exercises. The level of engagement averaged over all students and over all exercise sets was 36.5%, with 13.5% of the class engaging at a level above 90%. These findings are evidence that in the context of the present study involving a mixed-level large-enrollment programming course for engineers, no-credit optional exercises and instant automated feedback with unlimited submission attempts have the potential to promote practice and support the learning efforts of a sizable fraction of the class. Such a conclusion fits the narrative of previous studies focused on the impact of voluntary practice assignments on students’ learning in diverse environments [9], [37], [38].

Statistical analysis indicates that the level of student engagement with optional feedback-enriched practice assignments correlates strongly against students’ performance on homework ($r = 0.35$, $p < 0.0001$), quizzes/midterms ($r = 0.25$, $p < 0.0001$), final exams ($r = 0.19$, $p < 0.0001$), and total course scores ($r = 0.28$, $p < 0.0001$). We therefore answer our first research question RQ1:

> *Students who engage with no-credit instant-feedback practice problems are significantly more likely to receive higher scores on homework and exams.*

Correlation analysis also shows a strong relationship between the level of student engagement with optional exercises and students’ incoming GPAs ($r = 0.46$, $p < 0.0001$). This together with the previous finding mirrors that of earlier studies [31], [32], [37] and suggests that optional practice and supplemental learning opportunities may advantage high achievers more than struggling students for whom such opportunities are ordinarily intended. Simply offering additional practice exercises, even when enriched with actionable and timely feedback, may thus be insufficient to academically stimulate students in the class who need support the most.

Demographic group comparisons were carried out to investigate differences in engagement with optional instant-feedback exercises and academic performance between male and female students, and students of differing URM, transfer, and first-generation status. The difference in engagement level between males and females were found to be statistically significant at the 5% level ($t = 2.34$, $df = 293$, $SE = 32.19$, $p = 0.0198$), even though the means and the variances of the GPA distributions of the two groups were comparable. This finding complements earlier reports that likewise find, in their respective instructional contexts, female students to be more inclined toward optional practice assignments, extra-credit activities, and supplemental learning

opportunities than their male classmates [31], [32]. Higher motivation for academic achievement, better time-management skills, and more advanced self-regulation strategies among female students, in comparison to males, as have been observed in different educational settings, may help explain the above outcomes [34].

Our demographic group analysis further reveals that URM students were significantly less likely to engage with optional feedback-enriched practice than non-URM students ($t = 2.98$, $df = 295$, $SE = 31.97$, $p = 0.0032$). The differences in GPAs, on the other hand, were observed to be significant at the 5% level not only between URM and non-URM students ($t = 7.84$, $df = 295$, $SE = 0.46$, $p < 0.0001$), but also transfer and non-transfer students ($t = 3.06$, $df = 295$, $SE = 0.50$, $p < 0.0024$), and first-generation and non-first-generation students ($t = 6.15$, $df = 295$, $SE = 0.47$, $p < 0.0001$), with the students of "non-" status having higher GPAs on average. Analysis of covariance indicates that GPA alone does not account for the significance of the difference in levels of engagement with optional practice assignments between URM and non-URM students in the Winter 2021 section of the course ($F(1,190) = 3.92$, $p = 0.0491$), but does for the Winter 2022 section ($F(1,103) = 0.30$, $p = 0.5860$) and the aggregate population ($F(1,295) = 1.29$, $p = 0.2568$). Differences in situational factors between the Winter 2021 and Winter 2022 courses may have influenced results, as the former course was fully remote during the midst of the pandemic, which arguably disproportionately disadvantaged URM students, while the later course was offered in hyflex modality with most students already back on campus. Our answer to research question RQ2, in two parts, thus reads:

> *Male students are significantly less likely to engage with optional no-credit instant-feedback assignments than female students, despite the similar GPA distributions between the two groups.*
>
> *URM students tend to engage significantly less with optional feedback-enriched exercises compared to the remainder of the class. Moreover, such an outcome is not always predicted by differences in GPA alone.*

Students' responses to questions on the student perception survey indicate that 21 of 32 respondents agreed (10) or strongly agreed (11) with the statement that immediate feedback and unlimited submission attempts provided by MATLAB Grader motivated them to attempt the optional practice exercises. Conversely, only five respondents disagreed (3) or strongly disagreed (2). Assuming the survey responses are representative of the overall class sentiment, we formulate the answer to our research question RQ3 as follows:

> *Most students feel that the provision of instant feedback and unlimited submission attempts motivates them to engage with optional no-credit assignments*.

Given the established positive correlations between engagement with optional exercises and academic performance indicate that the students most motivated to engage with practice assignments are high-achieving students, it could be that automatically generated feedback and countless submission attempts contributed most to the motivation of these students, who tend to be more eager to take on additional challenges and put their knowledge to test. However,

additional research would be needed to resolve the impact of on-the-spot feedback and limitless submission attempts on motivation across different student groups.

Respondents also expressed a high level of agreement as to whether the provision of instant feedback and limitless submission attempts on homework, optional exercises, and assessments likely reduced the tendency of some students to search for online solutions. Of the 32 respondents, 26 either agreed (14) or strongly agreed (12), whereas only one disagreed and none strongly disagreed that this was the case. Accordingly, we formulate the response to our research question RQ4:

> *Most students feel that the provision of instant feedback together with unlimited submission attempts likely contributed to improving the academic integrity of the class*.

Literature on academic integrity explains that the temptation to cheat commonly arises out of feelings of distress resulting from lack of academic support, social disconnection, repeating low scores, and failure to self-regulate learning. It has been argued that one of the more effective and beneficial ways of dealing with the problem of cheating is by implementing organizational changes that quell the need to cheat among students who typically find themselves struggling in a course. Interventions which improve motivation, increase engagement, support learning, and allow students to build knowledge and hone their skills in a self-regulated way are regarded as preferable in combating academic misconduct over those interventions whose main aim is to deter cheating by technical impediments or policing, which can have detrimental effects on student learning and formation [44]–[46]. From this viewpoint it may be reasoned that the respondents found there to be ample opportunities to progress and succeed in the course owing to the affordance of immediate feedback and unlimited submission attempts, and thus felt that fewer students would be tempted to resort to questionable or unethical conduct for the sake of passing the course or obtaining a satisfactory grade. Further investigation will be needed into students' perceptions to confirm or disprove this conjecture.

Responses were varied as to whether instant feedback and unlimited submission attempts factored into how frequently students visited office hours. Some students expressed that it reduced their need to visit office hours. This is understandable, given the diagnostic input and assessment of correctness provided by MATLAB Grader automatically. Yet a fraction of respondents indicated that automatically generated feedback and unlimited submission attempts prompted them to visit office hours more frequently. This could be because they felt motivated to seek help from the instructor or teaching assistants when persistently failing to pass all the tests to a homework or practice problem implemented in MATLAB Grader. Were automated feedback not offered, the students might not have known a solution to be incorrect, and thus might not have felt the need to visit office hours.

Summary

We have studied how optional no-credit exercises and required homework and assessments, primed with instant actionable feedback, may incentivize additional practice, support learning, and promote academic integrity among a diverse student population in a beginner-level computer programming course. To facilitate our study, we have offered our students, in addition to

regularly assigned homework, optional zero-credit exercise problems over the interactive online coding platform MATLAB Grader. The auto-grading platform has been customized by the course instructional team to provide actionable on-the-spot feedback and unlimited submission attempts to students as they develop their code.

Disregarding demographic group belonging, students who engaged with no-credit feedback-enriched practice problems were found to be significantly more likely to receive higher scores in the course. A student's GPA was found to be a strong determinant of their engagement level. This finding suggests optional practice and learning opportunities foremost benefit high achievers, and to a lesser extent struggling students who may need supplemental practice the most, as previous work shows [31], [32], [37].

Demographic group analysis revealed a statistically significant difference between the levels of engagement with zero-credit feedback-enriched optional exercises between female students and their male peers, with the latter group less readily taking advantage of the supplemental practice opportunity. The significant difference in engagement levels is unaccounted for by GPAs, as GPA distributions of male and female students did not differ appreciably. Similar observations regarding male and female preferences toward supplementary practice and extra-credit assignments were described in prior research [31], [32], and may reflect gender differences in task valuation and academic motivation, which, in turn, influence students' approaches to learning, study strategies, and academic motivation, as discussed elsewhere [34].

It was also found that URM students were significantly less likely to engage with optional assignments compared to non-URM students. The statistical significance of the differences in engagement between URM and non-URM students was explained by the differences in GPAs between the two groups in the Winter 2022 section, as well as in the aggregate population, but could not be explained by GPA differences in the Winter 2021 section alone. While our study does not investigate the reasons for this, we do point to the possibility of differences in situational factors between the two course sections having influenced the observed outcomes: specifically, the Winter 2021 course was delivered entirely remotely during the midst of the COVID-19 pandemic, while the Winter 2022 course was offered in hyflex modality, with most students having returned to campus. It has been argued that URM students have been more adversely affected by the COVID-19 crisis, and that, in particular, their time for schoolwork has been disproportionately diminished. It is understandable then that zero-credit assignments may not have been high on the priority list of students most impacted by the crises. We further observed final exam scores of URM students were significantly lower than those of non-URM students. The difference was found to be borderline significant at the 5% level when controlling for GPA. This may be further evidence that the pandemic impacted the education of URM students more negatively than non-URM students.

In light of these results, engagement levels on optional exercises may serve to instructors as convenient additional information based on which they could assess student risk of weak performance in the course and accordingly develop early interventions to support struggling students to succeed. Moreover, supplementary practice assignments with automatically generated feedback may particularly cater to female students, who, according to prior research, particularly

value study-aid and self-testing opportunities across academic settings [34]. Catering to the learning needs and styles of female students in engineering and computer science is especially important for closing the persisting gender gap affecting these academic and professional domains and advancing gender equality more broadly [47]–[49].

Our student perception surveys revealed that most respondents felt the provision of instant feedback and unlimited submission attempts motivated them to engage with optional no-credit assignments. It is likely that high-achieving students were particularly motivated by the supplemental opportunities to put their knowledge to the test, given the high levels of engagement with optional exercises within this group. The survey respondents further widely agreed that the provision of instant feedback together with unlimited submission attempts likely contributed to the academic integrity of the class. We argue that affording students multiple opportunities to fail without penalty before succeeding and supporting their self-assessment of learning through actionable just-in-time feedback, as offered in the two sections of the course, reduces the probability that students will breach academic integrity out of perceived necessity. Students may have reasoned similarly.

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