One-on-One Review Intervention for Students Struggling in Discrete Mathematics

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ABSTRACT

Helping struggling students succeed can be one of the most time consuming parts of education, but also has a significant impact on students. This is particularly true in introductory courses like discrete math where students can be rusty on prerequisite content and lack intrinsic motivation for the course material. We evaluate an intervention to help struggling students catch up on material and gain confidence in the course. The intervention, called Student Help, involved optional 30 minute one-on-one sessions with a course TA to review content from earlier in the course. The intervention was performed at a large R1 institution in the discrete math course for four academic quarters. We found that while the intervention was time-consuming, there was a notable decrease in DFW-rate for quarters where the intervention was offered, and that students who participated had higher course averages than those who were invited to participate but did not.

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KEYWORDS

tutoring, retention, DFW-rate, discrete mathematics

1 INTRODUCTION

An educator's primary goal is to help their students learn. Understanding why students struggle and how to help them is thus a perennial topic in CS education. We focus here on an intervention adding one-on-one tutoring-style appointments to a discrete mathematics course. Discrete math is a common spot of struggle for students. The content (with minimal programming) is often a surprise for students, and can rely on prerequisite material where students have weaker understanding, a long time gap since they last used it, or just lower confidence. Struggles with prerequisite knowledge and struggles with confidence are an excellent spot for one-on-one or smaller group interventions, rather than interventions done for the whole class. Prerequisite gaps are often unique to the individual, and thus difficult to diagnose or treat at the class-level. Similarly, while educators can try to encourage confidence-building to an entire classroom, direct encouragement from someone who knows you is more viscerally encouraging than a general statement to hundreds of people.

To measure the rate at which students do not adequately complete a course, educators often use the rate at which students get a **D** grade, **F** grade, or **W**ithdraw from the course. The combination of these outcomes, referred to as **DFW-rate**, is a common measure of unsatisfactory student outcomes, as repeatedly lacking satisfactory completion of a course can be a driving factor in students leaving Computer Science altogether.

Researchers have tried a variety of techniques to improve DFW-rates across required courses, including calculus courses, introductory programming courses, and discrete math courses. Interventions such as flipped classrooms, additional peer tutoring support, supplemental instruction, peer-led team learning, and peer-assisted learning communities have shown promise. Common to all these techniques is increased emphasis on peer tutors or teaching assistants providing supplemental small-group or individual support for concepts learned in class [15]. The results of these studies support the hypothesis that this type of additional support helps students succeed by improving DFW-rates.

1.1 Course Context

Our intervention was performed at a large public R1 university. The discrete mathematics course is offered every quarter, with enrollment ranging from 130 to 300. The course comes directly after the one-year introductory programming sequence, and is one of the first courses in the curriculum that is restricted to students accepted to the major. As a result, it is commonly taken by transfer students in their first quarter at the university.

While most students do well in the course, some students do not complete the course satisfactorily. A common cause of student struggle is students falling behind on course material and never being able to catch up. In discrete mathematics, the course concepts build on each other such that it can be difficult or impossible to understand the current content while catching up with previous content. Sometimes students 'fall behind' due to a significant event— a family emergency or major illness, for example. In other instances a student may struggle with a particular concept, but not yet have the study skills to know how to ask for help. Regardless of the cause, once a student is behind, help is less easily available. The focus of the course staff and their classmates is the current material, not the underlying material they still need to work through.

Our intervention aimed to detect when students might be starting to fall behind and intervene earlier–before multiple homeworks were missed, or material had built on itself too much–and support these students directly in catching up.

We designated a few TAs to take on the role of *Student Help Team*. This group was tasked with:

- Checking student homework scores for low scores or drops in scores that indicated a need for extra help
- Emailing these students with an offer of extra help
- Running one-on-one or small group sessions to help students fill gaps in their understanding.

We ran this intervention (in various forms and iterations) for four quarters, spread across three academic years. We analyze the effects on student grades and the DFW-rate, as well as practical lessons on how to effectively implement and run a system like this one.

1.2   Organization

In Section 2, we discuss related work on helping struggling students. In Section 3, we go into more depth on the Student Help intervention itself and in Section 4, we present some data on student performance to examine the effect of the Student Help intervention on student outcomes in the class. Finally, in Section 5, we discuss the conclusions we can draw about the intervention and some practical tips we learned on implementing this type of intervention.

2   RELATED WORK

With the student help intervention, we sought to help students who had missed earlier course concepts, and help them catch up. We hoped this would lead to improvement in students successfully completing the course. Extra tutoring is a common strategy for helping students and has been shown to help retention [2, 18], but details of tutoring-style interventions vary significantly by course context.

One thread of additional tutoring in the literature is *Supplemental Instruction* (SI) [14]. SI involves optional student-led practice sessions at scheduled times. These sessions have been shown to help students learn and improve retention broadly across STEM fields [4] and specifically in CS [7, 9, 13, 19]. These sessions are more analogous to TA-led discussion sections in our course structure (as they usually had larger class-sizes and were meant to target the entire classroom). Similarly work on *Peer-Led Team Learning* (PLTL), a strategy involving former-students facilitating groups of 6-8 students working through practice problems, has shown reductions in DFW-rate [5, 20] and improvements in student retention [1].

Still other researchers have looked at the effect of individualized or personalized attention on students and how it affects student performance and retention. Peer tutoring helped to improve student retention in computer science courses [3]. Assessments that allow for one-on-one time with course staff and students is another effective way to improve student performance [6]. Individualized attention can also decrease achievement gaps and increase retention for underrepresented groups in computer science [11, 12, 16].

Prior work has shown generally that students sometimes struggle in introductory computer science courses. Discrete mathematics, where students first work with proofs, is a time when students often struggle [17] and this struggle results in students dropping out of computer science courses and in some cases leaving the major [8, 10].

3   THE INTERVENTION

Before creating the Student Help Team, the course already had multiple layers of support. For all students:

- Weekly discussion sections gave students a chance to practice problems and ask questions in a 25-person classroom with TA(s).
- TA and instructor office hours were available 5-days per week. Most were conducted in-person, but a few virtual hours were available every week.
- The course message board offered a place for Q&A, including the ability to ask questions anonymously to other students and privately (only seen by course staff).

Additionally, we had targeted support for populations who often needed more support:

- a one-credit hour support course, offering extra practice with content (open to anyone in the discrete math course, but intended mainly for those with less preparation)
- seminar courses for transfer students and for students in their first quarter out of high school, focusing on transition to university life and expectations
- staff-advising check-ins after the midterm for students on academic probation or other concern lists.

Nonetheless, students could still fall behind, and, indeed, these support systems are not ideal for supporting students who find themselves behind. Course-wide support, like discussion sections and the optional support course, focus on the most recent material and office hours are often packed with students asking about the current homework—neither allow for easy extended discussion of prior course material. The course messageboard allowed for individualized questions, but does not allow for quick back-and-forth that is helpful for diagnosing misconceptions. And targeted support toward specific populations came outside the context of the course, and thus could not help with technical questions. The Student Help intervention aimed to offer help on technical course matters that could be dedicated to individual students who most needed it.

3.1   Student Help

The primary intervention was offering students the ability to schedule 30-minute one-on-one targeted *review sessions* with a TA in order to review previous course content or prerequisite content. Review sessions are made available to all students in the course, though in practice a small fraction sign up. Additionally, students with low homework scores (or missing homeworks) would be emailed every week to remind them of these help sessions and invite them to contact staff with questions. Because the intervention was viewed as an opportunity for students to review previous material, we explicitly tell students that TAs will not discuss current homework problems during these sessions. Instead, the sessions are intended to review previous course material. As a result, they usually focus on previous homework, lecture, and discussion section problems. If students ask to review current homework problems, the TAs are instructed to explain the purpose of the sessions, and redirect away from the current assignment to content the student may have struggled with. The topic could move to older content,

or to review of recent lectures, but without reference to the current homework itself. Students continued to have access to regular office hours and the messageboard for questions on the current homework assignment.

3.2 Logistics

TA time is limited, so we prioritized keeping time focused on actually meeting with students. TAs generally did not take significant time to prepare for these meetings, as they were not intended to be presentations. In practice, students primarily schedule and attend sessions in order to review homework problems on which they had received low scores. The TA then walks through the problem with the student, explaining the correct approach and identifying errors in the student's work. This allows the TA to see what had prevented the student from completing the problem correctly. Then, with the remaining time, the TA helps the student understand the content better by reviewing lecture and discussion section material.

Student Help is advertised on the course website, on the discussion board, and during lectures and discussion sections, to make sure students are aware that these sessions are offered. In order to accommodate students as best as possible, the TAs offer a variety of times throughout the week during which students can schedule sessions.

In most quarters, multiple TAs participated in Student Help by running one-on-one sessions, which allowed us to distribute the work more evenly among course staff and provide a range of times when students could schedule sessions.

3.3 Targeting Struggling Students

Review sessions were open to all students, however the main goal of offering the review sessions was to help students who needed it most. Unfortunately, we cannot always tell who is struggling in the course and why. Our best way to determine which students might need a review session the most is to look at student performance on assignments. In order to reach struggling students, when assignment grades were released, we looked for all students who scored below a threshold of 70% and sent emails inviting them to schedule a review session. Homeworks in the course are primarily formative, with significant collaboration allowed between students. As a result, median grades of 90% or more were common, and 70% often represented significant struggles with the concepts.

Most students who were emailed did not ever respond or schedule a review session (see Section 4.1). Reviewing homework and exam grades each week and emailing students did add to the workload for the TAs running Student Help. However, we thought this was the best way to both target the students who could benefit the most from Student Help and to encourage those students to utilize the intervention. Anecdotally, these emails did prompt some students to engage when they otherwise would not have.

4 RESULTS

In order to begin to understand how effective this intervention was, we examined data from five quarters. We use Winter 2022, the quarter before we implemented Student Help, as a control. We use data from Spring 2022, Winter 2023, Autumn 2023, and Winter 2024 as intervention quarters. These four quarters all had

the Student Help intervention. All five quarters considered had the same instructor of record (the second author). The intervention was also offered in the intervening quarters (Autumn 2022 and Spring 2023), but neither author was involved in the course these quarters so we did not have data to include them in our analysis.

We analyze below whether students came to review sessions, how grades differed for students who attended from those of students who did not attend, and the DFW-rate for the course in the relevant quarters.

All data is anonymized and presented here as averages, without any identifying student information attached. Our Institutional Review Board declared our proposal exempt from review.

We began the intervention without an eye toward analysis of it. As a result, some data is missing. Specifically, we do not have any records of who participated during Winter 24, and a small number of students may have attended review sessions in other quarters without us having a record of these sessions.[1] Anecdotally, we know at least a few such meetings occurred, but we believe the number of such students is small.

4.1 Student Participation in Student Help

We intended Student Help to target the (relatively small) number of students likely to experience significant struggles in the course. The number of students who participated and the number we encouraged to participate, is summarized below. The total number of students enrolled in the course, the number of students each quarter who scored below the threshold on at least one homework assignment and thus were emailed encouraging them to attend Student Help, and the number of students who attended at least one review session each quarter is shown in Table 1. Recall that data from Winter 24 is missing, and data from other quarters may be (slightly) below the true values.

	Total Students	Emailed	Attended
Sp22	210	51	17
Wi23	131	16	18
Au23	305	72	29
Wi24	168	37	-

Table 1: Student enrollment, students emailed, and student participation by quarter. Students who attended at least one session are included in the "Attended" column.

About 20% of students enrolled in the course received at least one email encouraging them to schedule a Student Help meeting, though this number varied substantially by quarter. About 10% of students attended at least one review session. As these sessions were available to all students in the course, it is possible for students who were never emailed to sign up for a session (hence Winter 23 having more students attended than emailed).

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[1]We generally had students fill out a form (which asked for their name and email—these form results are the source of our data), and in response we sent a calendar which would allow students to schedule. This calendar link could be forwarded from student-to-student, or given directly by a TA, without the form being filled out. Any students who got a calendar link without the form would be absent from our records.

4.2 DFW-Rates

DFW-rate is a common method of determining the fraction of students who are succeeding in a course. DFW data for the study period is shown in Table 2.

Our institution uses a decile grading scale, where instructors award grades at 0.1 increments between 0.0 and 4.0 (e.g., grades of 3.8, 3.9, and 4.0 can all be assigned at the end of the course). For computing our DFW-rate, we used the following conventions:

- Grades between 2.0 and 2.4 were considered "D" grades.
- Grades below 2.0 were considered "F" grades.

While this convention does not match our registrar's grade definitions of 'D' and 'F', it accurately reflects our grading practices and the students we were targeting with this intervention. Computer Science program policy requires a student receiving a grade below 2.0 to retake the course. The program also requires a major GPA of 2.5 (averaged across all CSE courses) to graduate.

For computing the withdraw rate, we count only withdrawals that happen after the end of the second week of courses (which is the first drop deadline for students[2]). As the intervention did not start until after the second week of classes, we would not anticipate affecting rates until well after this point.

The DFW-rate varies between approximately 4% and 10% by quarter. The highest DFW-rate is the control quarter (Winter 2022).

4.3 Student Grades and Student Help

If review sessions help individual students, we would also expect to see improvements in those students grades.

For context, we begin by showing the average course grade percentage for **all** students in the course (see Table 3). Homework assignments, exams, and some course policies changed from quarter to quarter. These changes, along with changes in the student population, would lead to slightly different grades—across our dataset, all quarters have average grade percentages in a 5-percentage-point range.

As sessions were only held for about 10% of students, we would not anticipate a large change in the average course grade—indeed, we include the table as evidence that other changes in the course had a relatively minor effect and so it makes sense to compare grades from quarter-to-quarter.

We now look to see if the sessions made a difference in grades for the students who attended. The average course grade across all students in a quarter, average grade for students who were emailed about student help (because they had at least one homework assignment grade fall below the threshold of 70%), and average grade for students who attended at least one review session are compared in Table 4.

The grades of those who attended at least one session tended to be much higher (10-or-more percentage points higher than the average for all who were emailed). These scores show a correlation between attending a session and success in the course, though there are many possible confounding factors (see Section 5.2).

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5 DISCUSSION

Ultimately, the goal of any intervention in education is to improve student outcomes in the class and hopefully improve student learning as a result. With the Student Help intervention, we hoped to address an issue with student learning that we observed: students in the course were struggling with homework assignments because they did not understand the material from previous weeks, not just because they were confused about the current content being assessed by the assignment.

5.1 Conclusions

While data is limited, there are promising signs that the intervention might have helped students improve.

The Student Help intervention was intended to improve student outcomes, but it was specifically aimed at students who were struggling with course content because they had an incomplete understanding of previous course content. When we look at students who were emailed about the Student Help intervention, their average grade percentage was noticeably lower than the overall average student grade percentage each quarter. This is to be expected, as the trigger for emailing students was a grade below 70% on any one homework assignment. However, when we look at the average grade percentage for students who attended at least one review session, it is much higher than that of the students who received Student Help emails.

In each quarter we have data for, we see that students who attended the Student Help intervention ended up with a higher grade percentage than the average of all the students who were invited via email to sign up for a review session. While this is not enough to prove that the Student Help intervention improved the grades of those students, it certainly shows a correlation between higher grades and Student Help attendance.

The strongest evidence of impact is in the DFW-rate, which was lower than the control in every quarter that Student Help was offered and in total was almost 40% lower on average than the control quarter. Of the three components, the decreased rate of 'D' grades was the main factor in the decreased overall rate (decreasing from about 5.6% to 1.9%). A χ^2-test (comparing intervention total to control, and using 'C or better', 'D','F', and 'W', as categories), gives a test statistic of 7.01 for a p-value of approximately 0.072. While the results are not statistically significant, we still believe it is strong evidence of impact.

One possible interpretation of the decreased number of 'D's is that the review sessions are working as intended: students who otherwise might have misconceptions snowball are able to get help they need to have a stronger finish to the course. Though with only numerical data, other interpretations are possible.

5.2 Possible Confounding Factors

While this data is very promising, a few confounding factors should be considered.

Other Policy Changes. Various course policies changed over the two years for which we have data, including: the exams given in each quarter, the weights associated with each assessment in the course grade, awarding credit for attending discussion sections, and the

Quarter	Total Students	C or better	D grade	F grade	Withdraw	DFW %
Spring 22	206	192	2	4	8	6.80%
Winter 23	131	122	5	0	4	4.22%
Autumn 23	305	291	4	3	7	6.87%
Winter 24	166	159	4	3	0	4.59%
Intervention Total	808	764	15	10	19	5.45%
Winter 22 (control)	126	114	7	1	4	9.52%

Table 2: DFW rates for Winter 2022 - Spring 2023

	Wi22	Sp22	Wi23	Au23	Wi24
Avg. Grade	87.37%	84.89%	88.71%	86.52%	89.60%
Total	87.37%	87.08%			

Table 3: Average Student Grade Percentage by Quarter. Winter 22 (the control) has a mean course average very close to the mean across all intervention quarters.

	All Students %	Contacted %	Attended %
Wi22	87.37%	N/A	N/A
Sp22	84.89%	63.18%	73.39%
Wi23	88.71%	54.45%	81.94%
Au23	86.52%	70.55%	81.62%
Wi24	89.60%	73.97%	-

Table 4: Average Student Grade Percentage by Intervention Participation by Quarter. Students who attended at least one session are included in the "Attended" column.

addition of formative post-lecture quizzes. Any of these could have impacted the DFW-rate as well.

Changing Student Population. The set of students in the course can vary significantly from quarter-to-quarter. For example, in Autumn quarters many students are new to the university (transferring from community college, or from high school with enough programming experience to skip the introductory programming sequence), similarly Spring quarters have a large transfer cohort. While in Winters the course has only about half-as-many students and no one new to the university. Given the relatively small number of students who struggle in the course, cohort effects like these can have large effects on DFW-rate and other success measures.

Remote Start in Winter 2022. Due to a spike in COVID cases, all courses at our university began remotely in Winter 2022. In-person instruction resumed a few weeks into the quarter. While this may have impacted the DFW-rate, that quarter is still our best comparison: all other quarters with the same instructor of record were fully remote.

5.3 Lessons Learned

Over the course of the quarters of running the Student Help intervention, we learned some lessons on the practicalities of running the intervention, which we summarize in this section.

Gentle and Clear Invitation. Sending a targeted invitation to come for a one-on-one session was a key part of the intervention, and a delicate one. We quickly realized that emails each week needed to come from a TA, as opposed to the course instructor of record. Emails from the instructor were perceived as a requirement or a reason for a student to panic (particularly in such a large course where direct interaction with the instructor is uncommon).

Another concern was that students may feel discomfort or pressure and might avoid Student Help because of it. By having the invitation come from a near-peer teaching assistant, we hoped to put students at ease.

Likewise, the wording of the email was important. We wanted the emails to be consistent and gentle so students would not feel put off from wanting to participate in Student Help. We also wanted to make it clear that while the students might have struggled on an assignment or with a concept, there were opportunities for them to address the difficulty with the help of course staff, and doing so would hopefully help them struggle less in the future. We decided to come up with a simple template to use for the emails so that the wording was consistent and positive. This template was tweaked somewhat from quarter to quarter, but the basic structure stayed the same (see Figure 1).

Clear Ground Rules. One of the most important parts of Student Help that we learned early on was to be firm with students that we would not treat these sessions as a private 30 minute office hour so students could get help with the current assignment. One of the main motivations for the intervention was that our standard-scheduled office hours were consistently very busy with students stuck on the current homework (making it difficult for students to get detailed help on any other questions, particularly older content). A few times every quarter, students will come to Student Help and vaguely ask for help with a topic, and suggest that perhaps a problem from the current homework assignment is the best example to help them understand the concept.

In this case, it is important for TAs to be firm that we do not help with current homework in Student Help, and instead help the student find a topic that would be beneficial to review. Often, just looking at the student's performance on previous assignments can reveal a problem they solved incorrectly, and that can provide a good topic for review during the 30 minute session.

Group Sessions. Some students would find the sessions helpful, and decide to schedule additional sessions. We limited students to one session per week to ensure TAs could have enough sessions for other students who might want to schedule. In quarters where multiple students tried to schedule regularly, a TA would encourage

Hi (name),

We noticed some misconceptions on your HW# submission while grading, and we thought you might benefit from a chance to review important concepts.

We run a few by-appointment office hours most weeks (including this week!). We're reaching out to give you an opportunity to schedule one of these extra 1-on-1 office hours specifically to review important concepts. (course number) builds up from small building blocks to big ideas very quickly, so ironing out misconceptions early tends to make a big difference.

To attend one of these hours, please fill out this form to schedule an appointment.
(link)

If you have any questions or concerns, please feel free to respond to this email or ask on (the discussion board)! We look forward to working with you one-on-one!
– The CSE 311 Staff :)

Figure 1: The basic email structure from the Winter 2023 offering.

these students to meet with a TA as a group. Group meetings would still allow discussion of difficult concepts while preserving slots for other students, and encouraging the students to work with each other.

Logistics. Another key insight learned through multiple quarters of offering Student Help was to streamline the reservation process as much as possible. In the first quarter, TAs spent significant time emailing back and forth with students trying to find times when both they and the TAs were available to meet. Much of the total hours spent on Student Help were spent communicating with students and then finally scheduling them, and it ultimately was not a very productive use of time. In later quarters, once we had switched to using Google Calendar to have TAs create available slots which students could book through Google Calendar's interface, much less time overall was spent on all that administrivia, which meant TAs had more time to devote to actually helping students.

5.4 Limitations and Future Work

Future work could try to measure more precisely whether review sessions make a significant numerical difference in student success. Qualitative data could also be very helpful; given the relatively small number of students affected, qualitative responses (both from students who participated in the intervention and students who did not) could help understand how to better reach out to students who need more help, and what type of help would be most effective. Qualitative data could also shed light on whether one-on-one contact with a TA would lead to more of a sense of belonging in the course or degree program.

6 CONCLUSION

Students in discrete math sometimes struggle with the course material. Some of their struggle is due to the inherent difficulty of the course content. However, a number of students seem to struggle with later homework in part because they do not have a solid understanding of concepts taught earlier in the course.

We offered all students the ability to schedule (optional) 30 minute one-on-one review sessions with a TA, and emailed all

students after receiving a low score on a homework assignment to encourage them to sign up for a review session.

Overall, the data suggests that the intervention was effective. Course grades were higher for students who attended sessions than those who were contacted but did not attend; the DFW-rate also fell during quarters that we offered the intervention. Future work could include qualitative feedback from students on the effects of the intervention, as well as more careful experimental design to more thoroughly understand the effectiveness of the intervention.

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