Student-led program to improve equity in Ph.D. oral qualifying exams

Meredith Leigh Hooper, California Institute of Technology

This author was an equal first author contributor to this work. Meredith Hooper is an Aeronautics PhD student studying under Professor Mory Gharib in the Graduate Aerospace Laboratories of the California Institute of Technology (GALCIT). Meredith is a National Science Foundation Graduate Research Fellow, leader within the GALCIT Graduate Student Council, and Co-Director of the Caltech Project for Effective Teaching (CPET). Her PhD research uses a combination of machine learning and experimental techniques to investigate optimal modes of propulsion, spanning interests in both bioinspired propulsion and classical aviation. In her role as Co-Director of CPET, Meredith works at the Center for Teaching, Learning, and Outreach to coordinate and lead a variety of workshops, speakers, discussion groups, and more. These events support a community of graduate students and postdocs passionate about becoming effective educators through an improved understanding of research-based pedagogy.

Jacqueline Rose Tawney, California Institute of Technology

This author was an equal first author contributor to this work. Jacqueline Tawney is a Ph.D. candidate in GALCIT (Graduate Aerospace Laboratories of the California Institute of Technology). Jacque is a National Science Foundation Graduate Research Fellow, a leader within the GALCIT Graduate Student Council, and the founder of Women in GALCIT. In the Kornfield group within Caltech's Chemical Engineering department, Jacque researches associative polymers, their rheological properties, and their potential for agricultural and industrial applications. She is passionate about creating positive change within her communities and being a compassionate scientist and leader.

Dr. Emily Hope Palmer, California Institute of Technology

Emily H. Palmer earned her Ph.D. at the Graduate Aerospace Laboratories of the California Institute of Technology (GALCIT) in 2023. Her current research focuses on the neural mechanisms underlying steady state flight control in Drosophila melanogaster. She has been involved in numerous educational outreach programs throughout her undergraduate and graduate career, and held a leadership position in the GALCIT graduate student council. She earned her M.S. from Caltech in Aeronautics in 2019, and her B.S. in Mechanical Engineering from Johns Hopkins University in 2018.

James Ragan, California Institute of Technology

James Ragan is a Ph.D. Candidate in the Autonomous Robotics and Controls Lab working with Professor Soon-Jo Chung. His research activities include developing algorithms that enable spacecraft to perform autonomous fault detection, including in multi-agent or safety critical settings, using tools such as Monte Carlo Tree Search.

Dr. Morgan Louise Hooper, California Institute of Technology

After completing her PhD at the Graduate Aerospace Laboratories of the California Institute of Technology (GALCIT), Morgan Hooper is now an Assistant Professor (Teaching Stream) at the University of Toronto. There, her teaching focuses on building community within hands-on Engineering Design courses and beyond. She encourages students to engage with multi-faceted, trans-disciplinary engineering projects to learn the complex ways in which engineering, design, and community interact.

Yazmin Gonzalez, California Institute of Technology

Yazmin Gonzalez brings over a decade of experience spearheading targeted equity pipeline and mentorship programs for minoritized groups. She began her journey in higher education at the University of California, Los Angeles (UCLA). There she worked on strategic recruitment and retention initiatives focused on marginalized constituencies including: first-generation, undocumented, nontraditional, foster youth, transfer students of color, among others. She currently serves as the Associate Director at the Caltech Center for Inclusion and Diversity (CCID), where she spearheads programs to increase the retention

and inclusion of identities, histories, experiences and perspectives historically underrepresented in STEM fields.

As an equity-minded strategist, Yazmin is passionate about developing evidence-based programming that delivers authentic and sustainable change. Her approach focuses on coalition-building and mentorship. Trained as a mixed methods researcher, she holds a M.A. and B.A. in Latin American Studies from UCLA.

Student-led Program to Improve Equity in PhD Oral Qualifying Exams

Abstract

In this paper, we present a student-developed and led program implemented in our graduate department to help students begin preparation for oral examinations on more equal footing. Despite the common use of oral qualifying (preliminary) examinations to assess students' ability to succeed and continue in engineering PhD programs, the communication skills needed to be successful in such settings are not always explicitly taught in courses students take to prepare. We give a brief overview of historical and current qualifying exam practices, discuss the benefits and potential inequities of oral qualifying exams specifically, and finally, present one resource educators may use to address the gap in students' preparedness for this particular exam format.

During this department's oral qualifying exams, students entering their second year solve technical problems on the blackboard while professors engage with and evaluate not only their final answer but also their approach and problem-solving process. While in theory evaluating a student's process alongside the final answer can be more equitable, the oral exam format itself may actually amplify inequality via implied expectations that go beyond demonstrating mastery of technical concepts (the nominal goal). Indeed, to succeed in an oral examination, students must also exhibit confident communication and skill working at the board, but these skills are not currently taught, practiced, or assessed during our first-year courses.

We created a progressive qualifying exam preparatory program to bridge the gap between the technical knowledge developed during the first year and the critical communication skills required to effectively demonstrate that knowledge in an oral exam format. Our program, led by graduate student facilitators, consisted of voluntary hour-long weekly sessions with components targeting board work preparation, mental well-being, and study skills. We present details on our pedagogical framework, practical implementation, and lessons learned that highlight the program's main benefits and areas for improvement. This case study is designed to offer one possible method to improve student success, well-being, and overall equity throughout the qualifying exam preparation process.

*Jacqueline Tawney and Meredith Hooper contributed equally to this work.

I Introduction

I.A Background and Motivation

As universities begin to prioritize diversity in training the next generation of technical experts, researchers, and leaders, it is essential to address any institutionalized inequities that may hinder their success. This push for diversity includes enrolling students with increasingly distinct backgrounds, cultures, prior training, learning styles, and goals. However, simply enrolling a more diverse student body does not guarantee a diverse set of graduates [1]. Instead, to provide equitable instruction to all students, universities must not only focus on academic factors to improve achievement gaps, but also socioemotional aspects that will encourage students to persist within their academic track, as posited by the heads-and-hearts hypothesis [2]. In this context, equity is about "ensuring that everyone receives what they need to be successful" [3], where student needs can vary by individual and span from appropriate instruction and practice of technical material to the cultivation of a community with a culture of inclusion.

In this paper, we focus on one traditional milestone towards earning an engineering PhD – the qualifying exam – within a framework of equity. Equity-minded programs, like the model presented in this paper, are a tool to increase the retention of people historically excluded from and underrepresented within higher education. Qualifying exams (i.e., "quals", also referred to as comprehensive or preliminary exams) generally function as an assessment of a student's expertise in the subject matter required for pursuing their PhD and, ideally, assist in their development into an independent researcher. However, inequities in the examination process can arise due to hidden expectations and examiner biases. Despite their ubiquity across American universities, the true purpose of quals is subjective and can vary between faculty even within the same department [4] [5]. We will therefore briefly discuss some of the equity pitfalls associated with qualifying examinations before describing one simple and effective student-led strategy, grounded in pedagogical theory, for improving equity in the examination process, in the hopes that readers may use this work as a starting point for re-imagining examinations at their own institutions.

The National Science Foundation (NSF) Inclusive Graduate Education Network's (IGEN) brief on doctoral exams identifies that while faculty may perceive the purpose of qualifying exams differently, there is a commonly held belief that the exams should serve to gatekeep who is allowed to proceed to the dissertation stage [6]. However, this gatekeeping function can act as a barrier to equity if certain populations of students struggle disproportionately at the 'gate.' Indeed, the researchers acknowledge that "it is not that the exams do not test important subject matter. The problem is that the design and implementation of exams may carry cultural baggage that creates disproportionate barriers for minoritized students" [6]. This 'cultural baggage' stems from academic traditions built with a predominantly white and masculine perspective in mind; one that prioritizes "individual prowess, stoicism in the face of adversity, dominance in competition, and personal self-sacrifice" [7]. Whether or not these qualities are truly suitable for determining the potential for academic and personal advancement warrants a critical and comprehensive evaluation beyond the scope of the current study (for an in-depth treatment, see [4] ,[5], [8]). Instead, we focus on the potential for inequities perpetuated by this cultural tradition within the commonly utilized oral exam format and discuss opportunities for improvement.

In theory, oral exams have the potential to be more equitable than written exams because students are evaluated on their process in addition to the final answer, and professors are there to provide guidance to overcome minor gaps in knowledge. In practice, however, oral exams may amplify inequity through hidden expectations and examiner bias. Hidden expectations are qualities or skills examiners expect students to exhibit when demonstrating expertise, which are not necessarily stated in a clear, identifiable way. For instance, many oral qualifying exams including the ones held by the department considered in this study have the stated purpose of demonstrating mastery of foundational technical material. However, what is often left open to interpretation is precisely *how* one should demonstrate this: what does mastery look like in the context of this exam, and who is more likely to already behave in the anticipated manner? This type of criteria is far more subjective than the technical material supposedly at the core of the assessment, and the ambiguity creates room for bias by distorting evaluations of a person's ability to succeed. Correll et. al. states that while meritocracy is the American ideal, "research finds that assessments of individual performance are biased by gender, race, and other characteristics. These biases, in turn, lead women and people of color to be rated as less hirable or promotable than similarly qualified men and white people" [9]. Additionally, hidden expectations can have disproportionate effects on minoritized students, who may already question their belonging in a graduate program in STEM; for example, Chen et. al. states that "[s]tudents from all backgrounds may find the experience [of an unexpectedly poor academic performance] threatening to their competence, but students from minority groups must also contend with anxiety that this performance 'confirms' negative academic stereotypes attributed to their group memberships"[10].

Often, these biases and stereotypes reflect an automatic judgment without an awareness of individuals' specific abilities or experiences [11] [12]. Thus, the format of assessment, rather than the rigor, quality, or intended learning can have undue effect on educational outcomes. For example, IGEN performed a case study on a top-ranked physics program which noticed its "passage rate [for a qualifying exam] had been marked by a stubborn gender gap that was related to how women were experiencing the exam" [6]. To address this, the department replaced the qualifying exam with an incoming diagnostic exam, so students who pass the diagnostic move straight to research, and those who do not must pass the core courses within two years. The change "effectively reduced the core problems of gender inequity and mental health crises that induced reform" [6]. In another case study performed by IGEN, a middle-rank chemistry program that had traditionally relied on qualifying exams to signal the rigor of their program replaced their qualifying exam with a mock National Science Foundation (NSF) or National Health Institute (NIH) grant proposal, which they consider equally rigorous and aligned with developmental goals. They also added a scientific writing course to support students as they prepare for this assessment, which transformed "a one-time, individual performance of expertise into a collective capacity building process" [6].

This 'collective capacity building process' presented in the second IGEN case study highlights the role of constructive alignment in meaningful and equitable assessment. Though in principle constructive alignment of teaching and learning activities[†] supports the use of 'performance assessments' such as oral qualifying exams or the preparation of a realistic grant proposal to measure student knowledge [13], this relies on transparency in the alignment between the learning process students participate in leading up to assessment, and the assessment process itself. For example, if the learning objective for a qualifying exam is for students to confidently communicate mastery of technical material, and the mode of assessment is an oral exam at a

[†]Constructive alignment can be briefly stated as the idea that activities students undertake during an educational experience (their learning process) should align with the way they are assessed (their course outcome) and promote their active involvement to achieve "deep, transformational learning as opposed to a surface involvement with facts and information" [13]. This latter factor also has connections to students' development as lifelong learners, especially when assessment methods support students self-assessing progress [14].

blackboard in front of their professors, alignment in the learning process leading up to the point of assessment could mean providing students the opportunity for oral assessment and professor feedback within courses students take to prepare for the exam and an active discussion of the way(s) in which such oral exams are indicative of situations the students may encounter beyond the classroom.

This study aims to address a gap in this alignment for a particular department in which core courses traditionally include only written assessment, whereas, during oral qualifying exams, students are expected to exhibit confident communication with the examiners and strong skills working at the board. These skills are not currently taught, practiced, or assessed during first-year courses. Moreover, these expectations are not always explicitly communicated, compounding the effects of hidden expectations mentioned previously. We present our efforts to create a new resource to better support student preparation: a preparatory program, grounded in pedagogical theory, that promotes essential skill development and emotional well-being. While our preparatory program is student-driven and can be implemented regardless of faculty participation, faculty could certainly implement a similar program with few administrative barriers and much to gain. Our goal in sharing the development and results of our program is two-fold. First, we hope to encourage other students to support each other's success and well-being by providing simple yet effective ways for senior graduate students to support junior students during the challenging quals preparatory period. Second, we provide this case study as a starting point for our department and others to reflect on the true goals and best practices for qualifying exams.

I.B Our Department's Quals

This section focuses on how qualifying exams were formatted for students during the two years in which this program has so far been implemented. Details of the exam format can vary year-to-year, but the fundamental aspects such as the number and duration of the exams are constant. We intend to provide an understanding of the exam context motivating the program as well as illuminate gaps which the program was intended to fill.

In our department, qualifying exams cover the content of the first-year curriculum in three areas, chosen from solids, fluids, controls, and math, matching the student's course of study. The exams themselves consist of three separate hour-long oral exams, one on each chosen subject. All students are required to take the math curriculum and qualifying exam. Each exam is scheduled on a separate day during a week-long period. Students are examined by two examiners; usually, at least one examiner in each subject is a professor who taught one term of the three-term (year-long) class.

Many students spend 4-6 weeks of full-time study to prepare for quals, but there are students who have utilized up to 10 weeks of full-time study. The amount of time given away from research over the summer to study for quals is dependent on one's advisor; students may have to advocate for the amount of time they estimate they will need. After reviewing material individually for several weeks, students generally transition to studying in pairs or groups, using a compendium of past problems to mock-examine each other. During the two weeks immediately preceding quals, senior graduate students self-organize to offer mock exams as well.

When students arrive at their exam, they are provided with the exam questions, and allowed up to ten minutes of silent time to peruse them. Students may use this time to plan their response without verbal communication or use of the blackboard. Although the examiners are intended to leave the room during this time, some do not. In addition, the examiners may allow students to begin the exam, if they wish, before the allotted reading time is over, allowing those who read faster (or plan less) more working time on the exam. Students may select which problem of the exam they would like to begin with. During the exam time, the examiners provide varying levels of interaction with the student while the student speaks through their thought process and writes their work to solve each problem on the chalkboard. The examiners provide hints, guidance, and questions additional to what is printed on the exam sheet at their discretion.

No results are given immediately following each exam. The examiners collect the exam sheet from the student and erase the board for the following student. Students are informed of their results within a week of their exam date. The results available for each exam are “Pass”, “Conditional Pass”, or “Fail”. Students who have conditionally passed an exam may be required to retake the exam, serve as a teaching assistant for that course, take an additional course in that content area, and/or perhaps even retake the original course, as determined by their advisor and the examiners. Students who have failed an exam do not proceed on to the PhD. This is, however, a rare outcome in our department.

II Methods

We created an annual preparatory program designed to bridge the gap between the technical knowledge taught in the first year and the hidden communication requirements of the qualifying exam. This program was designed and implemented by senior graduate student volunteers and organically modified to fit students’ needs over the course of its first two years of implementation. In the next two subsections, we present the current version of the program followed by a brief discussion of the changes we made between the initial pilot year and the second, more formalized, year of the program.

During the development and implementation of the program, data collection regarding student experiences in the program was collected in the form of surveys administered to students after completion of the program, and again after they had completed their qualifying exams. More details about the data collection process is discussed in the survey procedures subsection below.

The development and implementation of this program was made possible by our department’s strong history of senior graduate students helping prepare junior students via mock exams. The program was voluntary and occurred during the summer term, so there were no changes necessary to the required first-year curriculum. In addition, it was also completely free, since it was developed and run by student volunteers. Because of this, no faculty or administrative involvement was needed; however, this also meant that the program could only address student preparation for quals. Changes to the exams or first-year curriculum themselves were not considered due to the administrative burden they posed. Instead, we chose to focus on addressing inequities deriving from the hidden communication requirements of the exam process.

II.A Program Objectives and Format

In this subsection, we present the current iteration of our preparation program which has been refined using survey feedback and formalized with a syllabus and concrete learning objectives. A syllabus is distributed to the first-year students prior to collaboratively scheduling the preparatory program sessions. This syllabus aims to communicate and expand upon the four learning objectives that were synthesized from the pilot year of the program. Selecting learning objectives and communicating them to students "guide[s] efforts to make instruction more effective and engaging" [15], and learning objectives are so prevalent in higher education as to even be used as a criteria for accreditation of engineering programs [16]. The learning objectives we determined to guide this program are:

> By the end of this course, students will be able to:
>
> 1. Confidently and clearly communicate their thought process via use of a blackboard.
> 2. Incorporate on-the-spot feedback and questions into their verbal presentations in a collaborative, not combative, fashion.
> 3. Create and execute a 4-8 week plan of study that incorporates research-based study techniques.
> 4. Approach the mountainous goal of preparing for quals armed with strategies to maintain their mental well-being.

The program itself is a five-week series of hour-long informal sessions, set up by senior graduate students and designed to give students experience with working at the board. The spectrum of activities selected for each week of this program is best encompassed by Theobald et al.'s "heads-and-hearts hypothesis", wherein both deliberate practice (heads) and a culture of inclusion (hearts) "are required to... reduce, eliminate, or reverse achievement gaps" [2]. The sessions are collaboratively scheduled to fit the availability of all students and can be made available in a hybrid virtual format to ensure that all students who wish to attend are able.

The following sections describe student activities during each week of the program.

Week 1: Connections with Senior Graduate Students

We kick off the program with a panel discussion with senior graduate students to answer any questions about qualifying exams. This session is intended to allow senior students to both share their experiences preparing for and taking the qualifying exams, and to also act as an unofficial resource for information about the exam process. It is also an opportunity to set expectations for the preparation program and the qualifying exam process. Furthermore, first-year students now have connections with senior graduate students to reach out to for support while preparing. By introducing the first-year students to a support network of senior graduate students who believe in them and wish to see them succeed, this first session aims to fulfill the latter half of Theobald et al.'s "heads-and-hearts hypothesis" [2].

Week 2: Foundations in Active Communication

The second week of the program consists of a mini-workshop on active communication run by our university's Project for Effective Teaching (a graduate student organization under the auspices of the Center for Teaching, Learning, and Outreach) followed by students answering 'speed prompts' at the board. The mini-workshop on active communication is intended to highlight specific, actionable means of building communication skills, and to spark ideas for how students can best practice these during the sessions and their own study time. After priming students to think about their communication with the mini-workshop, this session transitions to hands-on practice with speed prompts. This is students' first opportunity to work at the board in the program, and the speed prompts are designed as a low-stakes introduction to speaking and writing on the board at the same time. For example, one student was asked to "draw a rough map of your hometown" and another student was asked "are team sports or individual sports better?" A full list of prompts used, categorized by week, are provided in the Appendix.

All prompts are nontechnical in nature and deliberately open ended or subjective, intended to be answered with minimal stress and without needing to find a "correct" answer. In addition, each answer's duration is capped at four minutes to provide a bite-sized introduction to boardwork. Students are asked to choose a prompt at random. They are allowed to peruse this prompt while the student prior to them presents. This is to mimic how our qualifying exams function; students are allowed time to read the problem and plan their response without use of the board. While the student is responding to the prompt at the board, senior graduate student facilitators ask questions designed to mimic examiner interaction. Finally, students are given informal feedback on their performance from the senior graduate students as well as their peers. If time permits, more than one round of prompts may be given. All weeks in which students were asked to respond to prompts or problems follow this format.

Week 3: Incorporating Technical Content

The third week begins to incorporate on-the-spot technical thinking. The students randomly draw from a bank of high-school level math problems which do not require any prior knowledge beyond mathematical skills that students should already have from high school. For example, one student was asked "A coin of radius 1 cm is tossed onto a plane surface that has been tesselated by right triangles whose sides are 8 cm, 15 cm, and 17 cm long. What is the probability that the coin lands within one of the triangles?" Thus, while the process of solving the problems requires on-the-spot thinking, students should be equipped with all the information required to successfully solve the problem at hand. For this week each student is given 8 minutes per question, and draws a random prompt 2 minutes before the previous student finishes.

This week represents a step up in technical complexity from Week 2, since the problems considered do have a 'correct answer' for students to determine; however, they allow students to practice technical communication and board-writing in a lower stakes technical environment, where the level of questions asked is not meant to challenge their knowledge of the subject material.

Week 4: Increasing Technical Complexity

In the fourth week, students move on to problems requiring logic and estimation. A critical qualifying exam skill we identified is being able to begin and continue a problem when one is missing pieces of information, whether because of a gap in one's own technical knowledge or a gap in the problem statement. Thus, these prompts are designed to not only require on-the-spot technical thinking, as in the week prior, but also require information that students would not know a priori. For example, one student was asked "About how large is a mole of moles (the small mammals) in radius?" [17]. As students identify the information they have and the knowledge they are missing, they are encouraged to first outline how they would solve the problem, then estimate the missing pieces. During this process, senior graduate students prompt the students with hints or suggestions and eventually any missing values, mimicking how examiners may help students recall details during qualifying exams.

This represents a further increase in both technical and communication complexity from Week 4, as it asks students to engage with questions which may not have a completely satisfying 'correct answer', while challenging them to communicate a technical process with a mock examiner. By incorporating interaction with graduate student examiners, students are also able to practice responding to questions, and accepting suggestions from observers in a collaborative and constructive way.

Week 5: Plan of Study, Personal Wellbeing, & Qualifying Exam Demonstration

The last week of the program diverges from the structure of the previous four weeks, consisting of a workshop run by our university's occupational therapy and wellness staff and a demonstration practice qualifying exam by a senior graduate student.

The process of studying full-time for between one and two months, culminating in three separate oral exams, is a new and complex task for many students. The occupational therapy and wellness workshop covers strategies for both studying and maintaining one's mental well-being during this stressful time.

The demonstration practice qualifying exam is intended to offer an example both of how a student might work through a real exam problem, but also how an examiner might prompt a student through the problem. Traditionally in our department, a significant portion of students' study is devoted to working through past exam problems passed down from year to year in a collaborative document. These problems are usually worked out on the chalkboard by one student, while another student fills the role of the examiner by offering prompts and questions. This demonstration is intended to model this study style to students, and demonstrate the role an examiner might fill during the real exam.

The Role of Active Learning in Program Development

The three middle weeks of the program deliberately incorporate evidence-based active learning strategies, in alignment with the former half of the "heads-and-hearts hypothesis"[2].

Theobald et al. note four specific items of deliberate practice: "1) extensive and highly focused efforts geared toward improving performance—meaning that students work hard on relevant tasks, 2) scaffolded exercises designed to address specific deficits in understanding or skills, 3) immediate feedback, and 4) repetition" [2]. All boardwork prompts were designed with the original learning objectives in mind, ensuring that all tasks were relevant. The tasks increased in complexity throughout the weeks; in the second week, the only new skill to learn was speaking while writing at the board. In the third week, speaking at the board was paired with on-the-spot technical thinking, and finally in the fourth week these two skills are joined by logic and estimation skills, as well as real-time interaction with observers. This progression in complexity of skills learned, called scaffolding, has been shown to effectively increase students' performance on multi-component skills [18],[19],[20]. Furthermore, students received informal feedback from senior graduate students and peers immediately upon completion of the task, allowing them to reflect and implement improvements when the task was either repeated in the same week or repeated with greater complexity in the following week.

II.B Changes from the Pilot Year

The pilot year of the program was similar to the current version presented above, but we incorporated several changes into the curriculum based on the experience and feedback gained after running the program for the first time. In particular, the following aspects were modified based on student feedback from the pilot year:

1. **Increased time for interaction with senior graduate students.**

   During the pilot year, both the senior graduate student panel and speed prompts took place during the first session. Due to the quantity of students' questions about qualifying exams, this first session extended unexpectedly to an hour and a half. To better respect students' time and scheduling constraints, we decided to dedicate an entire session (one hour) to the senior graduate student panel in future years and move the speed prompts to their own session.

2. **Addition of the active communication workshop.**

   The active communication workshop was added to the beginning of the second session such that the students could learn actionable strategies for improving communication, before engaging in deliberate practice during the remaining sessions.

3. **Addition of the demonstration practice exam.**

   The demonstration practice exam by a senior graduate student was an addition motivated by specific feedback we received from the pilot year. While students said they found our pilot program to be helpful in getting board work experience, they felt they were lacking a model for what a successful exam looked like, both from the student and the examiner perspective.

4. **Adjustment of program timing.**

   Another piece of specific feedback implemented was to shift the program one week earlier in the summer, to avoid conflicting with the average duration of full-time study for quals.

II.C Survey Procedures

Surveys to receive student feedback on the program were given in both the pilot year and second year of the program. These surveys were optional and hosted anonymously over Google Forms. In the pilot year of the program, only one survey was given after students had taken their qualifying exams. In the second year of the program, to access any temporal component of the data, a survey was given immediately after the program, and another was administered after students had completed their qualifying exams.

Since the original purpose of these surveys was to obtain information on how to improve the program for the following year (purely for instructional/educational improvement), no IRB approvals were granted at the time the program was held. Upon the decision to write a paper using this data, our IRB was contacted and guided us through the process of gaining approval to publish this data. Our data is thus published under our institution's IRB Protocol Number IR22-1270.

III Results

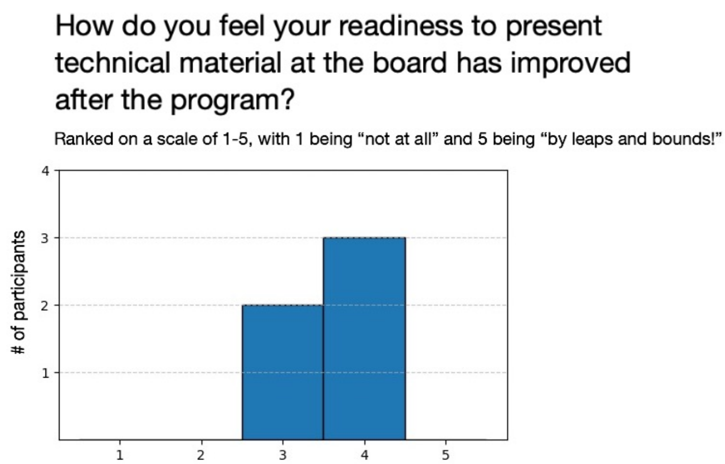
III.A Respondents

In this section, data from the second year of the program is presented. Data from the first year aligns with the data drawn from the second year and is therefore omitted in this section. The cohort taking quals in the second year of our program consisted of eight students. Five to six students attended our program each week, with most students attending all sessions. Five students responded to the survey given pre-quals, and four students responded to the survey given post-quals. While the majority of students who attended the program also took the survey, it should be noted that, due to the size of our department, our sample size is very small. This limits both generalizability and strength of our conclusions; nonetheless, we believe it provides an interesting case study for discussion.

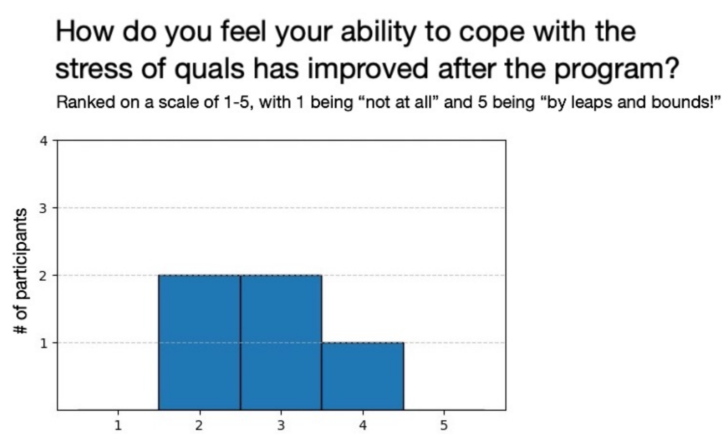
III.B Survey Data

In the survey given immediately after the program, students were asked how they felt they had improved in two general areas: one being "readiness to present technical material at the board", and the other being "ability to cope with the stress of quals". These outcomes are directly related to the learning outcomes for the preparatory program. Students rated their improvement on a scale of 1-5, with 1 labeled "Not at all." and 5 labeled "By leaps and bounds!" As seen in Figure 1a, all students felt that their readiness to present at the board had improved, with most students rating their improvement a 4 out of 5. Students also felt that their coping abilities improved, but not as significantly as their readiness to present at the board, as shown in Figure 1b. Most students rated their improvement in this area as either a 2 or 3 out of 5.

Both immediately after the program as well as after taking their qualifying exams, students were asked to rate how well they felt that the program had achieved its learning objectives. They rated each objective on a scale from 1-5, with 1 being "Did not achieve", 3 being "Achieved passably", and 5 being "Achieved very well". In both surveys, most respondents felt that the program had achieved its learning objectives at, or above, passably, with only one student rating one objective



(a) Students' perceptions of the level to which their readiness to present technical material at the board has improved after the program. Five responses were received in total immediately following the program but before the actual qualifying exams.



(b) Students' perceptions of the level to which their ability to cope with the stress of quals has improved after the program. Five responses were received in total immediately following the program but before the actual qualifying exams.

below passable (Figure 2). These learning objectives can be divided into the two general content areas described above, with the first two falling under readiness to present at the board and the latter two falling under coping abilities. Interestingly, while in the first survey students felt that their coping abilities had improved less than their readiness to present at the board, their rating of the associated learning objectives in the same survey did not show the same clear trend (Figure 2). In fact, learning objective #3 ("create and execute a 4-8 week plan of study that incorporates research-based techniques") obtained more ratings of 5 than any other learning objective. However, the post-quals survey does show a decline in the rating of the learning objectives associated with coping abilities. Conversely, the post-quals survey shows an increase in the rating of the learning objectives associated with readiness to present at the board.

Students were also asked to assess the usefulness of each individual session over the 5 weeks, both immediately following the program as well as after taking qualifying exams, with results presented in Figure 3. The usefulness of hearing the senior grad students' subjective perspectives (the quals panel) was initially perceived as very useful for most students, but this perception changed to less useful after the actual exams. The active communication presentation and nontechnical speed prompts were rated as less useful overall both pre- and post-quals. The spread of usefulness in the nontechnical prompts increased post-quals; two students found them very useful (one more than pre-quals), while one student found them not useful at all (the only response with the lowest possible rating). The math and logic & estimation problems were rated as useful. The wellness & occupational therapy workshop was mostly rated as useful with one student responding neutrally to it post-quals. The demonstration math qual was rated the most useful overall.

IV Discussion

Overall, students felt that they improved in their readiness to present technical material at the board, and improved (but not as significantly) in their ability to cope with the stress of qualifying exams. These results align with the focus of the program, as the majority of activities were geared towards presenting technical material. Furthermore, the activities designed to improve communication skills were naturally more interactive than the workshops surrounding mental well-being. In order to fully participate in the activities designed to improve communication skills, students used more skills emblematic of active learning, while in the workshops on mental well-being, less active participation was requested. Therefore, it is possible that students improved in their readiness to present at the board, but not as much in coping abilities, due to the differences in the number and interactivity of sessions. It is also possible that students simply were not experiencing large amounts of stress at this point in the summer, as most students would have just begun studying full-time at the end of the program. If they were not experiencing much stress, then there could be less room for improvement in this metric.

IV.A Perception of Program Efficacy in meeting Learning Objectives

When students were asked to rate how well the learning objectives of this program were achieved, most students felt that these objectives were achieved at or above a passable level, with only one student rating one objective below passable in each survey. Interestingly, the learning objectives

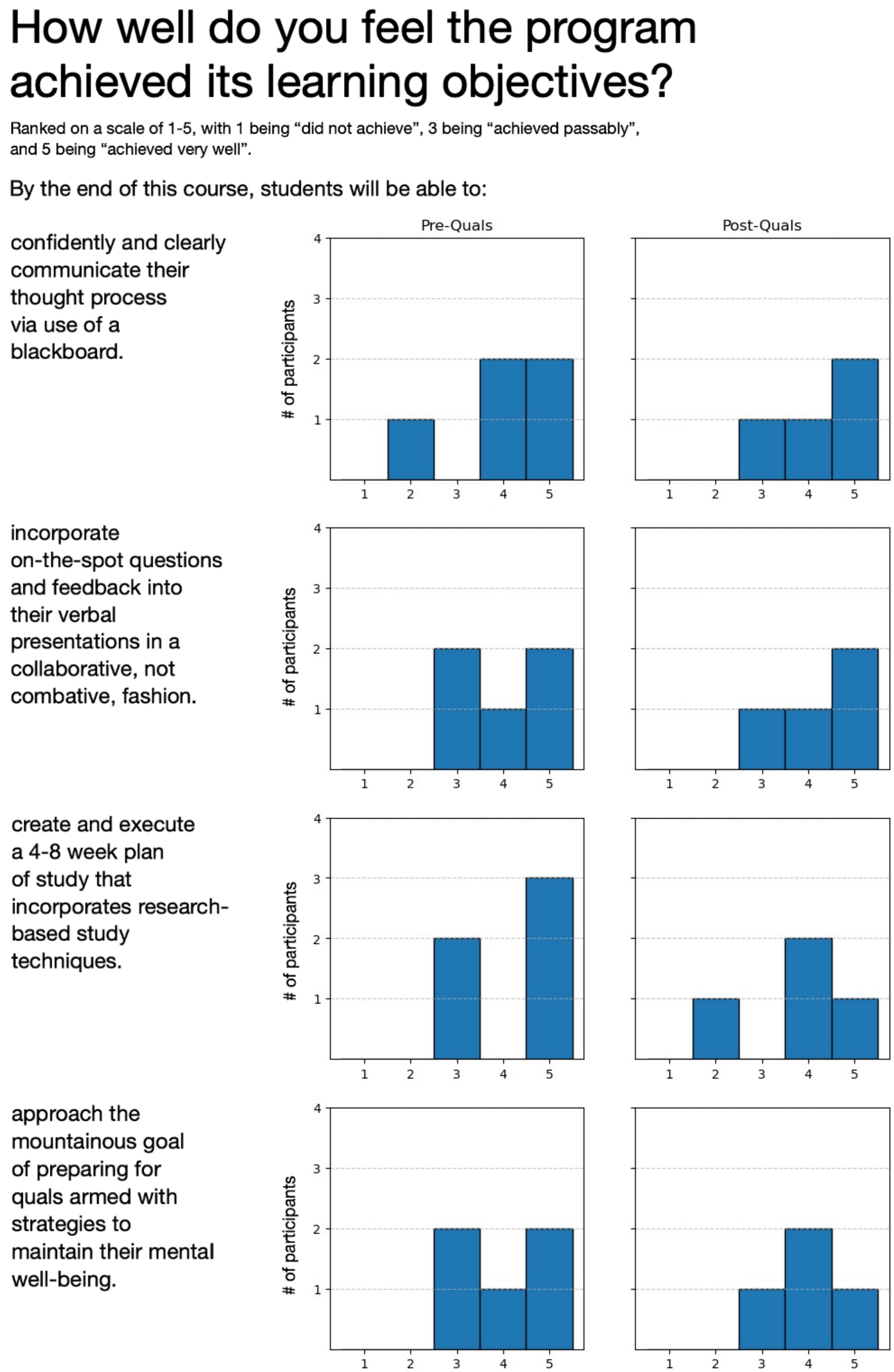


Figure 2: Students’ perceptions of the level to which the preparatory program achieved its learning objectives. The left column of feedback was taken immediately following the program but before the students began formally studying for and taking quals. The right column of feedback was taken immediately after the students took quals to compare their feelings about the program’s usefulness before and after the actual exams.

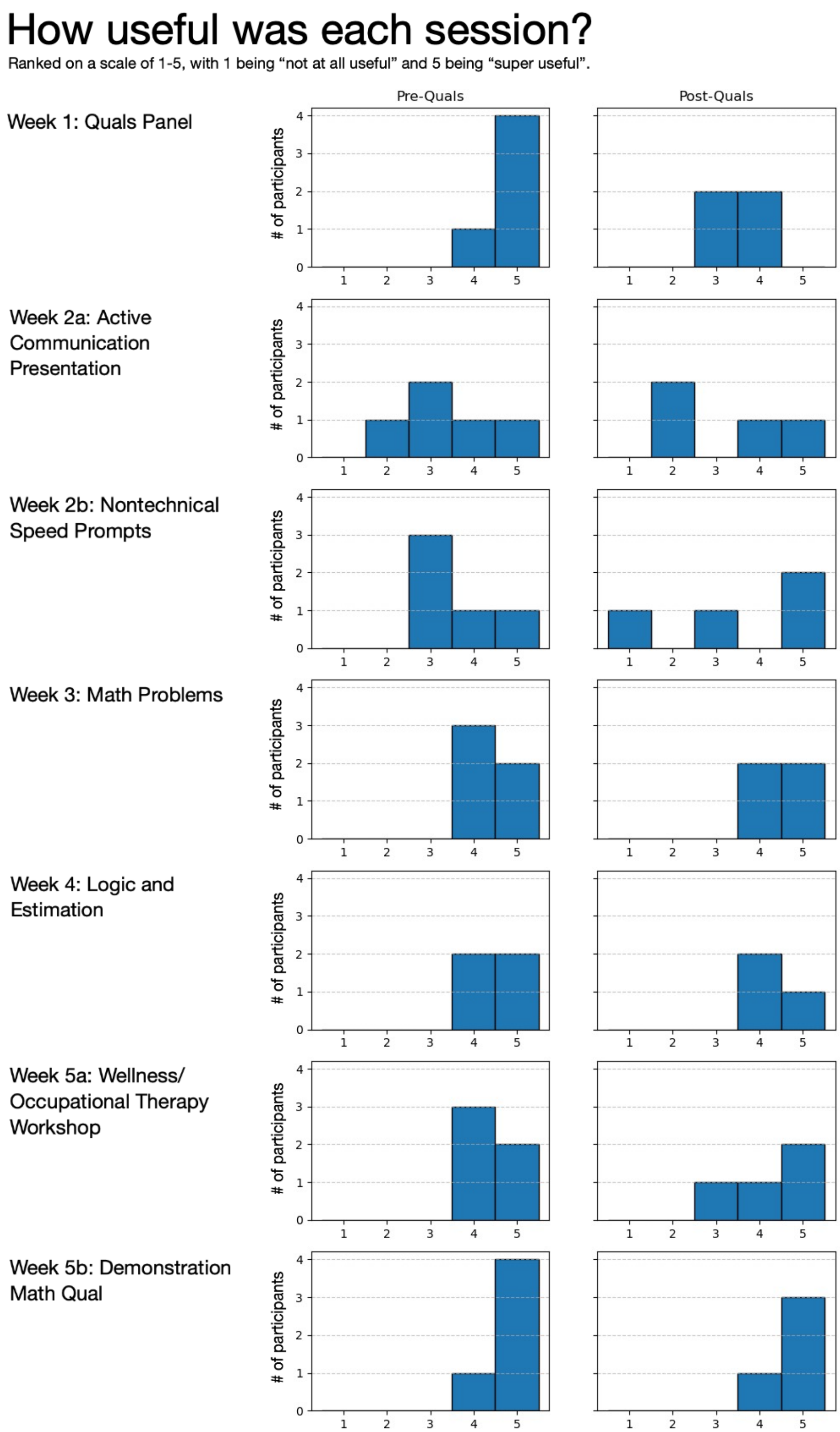


Figure 3: Students' perceptions of usefulness of each individual session from week 1 through week 5. The left column of feedback was taken immediately following the preparatory program but before the students began formally studying for and taking quals. The right column of feedback was taken immediately after the students took quals to compare their feelings about the program's usefulness before and after the actual exams.

associated with coping abilities did not show a lower score than the learning objectives associated with readiness to present at the board on the first survey. This stands in contrast to students' rating(s) of their self-improvement in these two areas, as discussed previously.

This disparity could be reflective of language used in the learning objectives, which makes their link to coping with the stress of qualifying exams less explicit. For the third learning objective ("Create and execute a 4-8 week plan of study that incorporates research-based study techniques"), students may not recognize that creating and executing an appropriate study plan is, in fact, a coping skill. In addition, the last learning objective ("Approach the mountainous goal of preparing for quals armed with strategies to maintain their mental well-being") is phrased in such a way that it could be achieved if students learned, but did not fully comprehend how to implement, strategies to maintain their mental well-being. One interpretation then is that students finished the program with a toolkit full of coping strategies (including a study plan), and yet may not have felt confident in utilizing those coping strategies to alleviate the stress of quals. Given that students had not yet started full-time study at the time of the first survey, they may not have had the opportunity to put these skills and strategies into practice, and would not have gained that confidence yet.

Considering the temporal evolution of students' ratings of the efficacy of the program in achieving its learning objectives, we see that the learning objectives associated with readiness to present at the board increased in rating between the first and second survey, while the learning objectives associated with coping abilities decreased in rating. This is likely also related to students not having begun full-time study at the point of the first survey, and then having the full spectrum of the quals experience to reflect upon in the second survey.

The qualifying exam process is stressful and difficult for students in many individual ways, but it is fairly common to experience an increase in stress as the exams approach. Immediately after taking the exams, and thus immediately after a high point of stress, it is unsurprising that students would rate the learning objectives associated with coping abilities lower. Similarly, immediately after taking the exams, students are primed to consider the skills that they exhibited during the exams: namely, those associated with readiness to present at the board. They may rate these learning objectives higher because they now have concrete evidence that, throughout their study and perhaps in their qualifying exams, they were able to fulfill these objectives.

IV.B Utility of Individual Program Sessions

Students were also asked to rate the utility of each of the individual sessions within the program. Though they initially rated the utility of the quals panel highly, student ratings of this session decreased post-quals. This may be because throughout the quals preparation period, students receive more official information about the qualifying exam process; however, this doesn't seem likely because students reported experiencing a lack of clear communication from the department on qualifying exams. The disparity of usefulness in the quals panel before and after the exams could be a reflection of students realizing just how subjective the actual experience really is. It may be comforting to hear from older graduate students and receive advice in the very beginning, but each experience of the process is ultimately unique.

Students reported mixed feelings about the active communication presentation and nontechnical speed prompts, with these sessions perceived as less useful compared to others both pre- and post-quals. This could be due to an individual student's prior experience with these skills outside of the curriculum and the program, or it could be due to students' lack of awareness of their communication skill level (and therefore reduced value placed on intentional practice of these skills). Our intention with the active communication presentation was to teach various actionable and practical communication skills for students to practice during the preparatory program and within their own study groups. Speed prompts were designed to introduce students to speaking and writing at the board with less emphasis on finding a correct technical answer, easing them into the program. One student responded particularly positively to these early sessions, expressing in written feedback they were really useful as a good introduction. Others were more eager to get to the technical board practice. It makes sense that the math and logic & estimation problems were rated as useful, as these sessions were most similar in format and content to the actual qualifying exams. One student reported that it was a big leap between the short board problems and the full practice exams, so it may be worth exploring a more intermediate step in future iterations of the preparatory program and expanding the technical content of the sessions.

V Conclusions

While the small sample size of students participating in the program prevents any understanding of the generalizability of our data, we have presented a successful case study that has the potential to improve student success, well-being, and equity throughout the qualifying exam process. It is our hope that this case study may provide inspiration for the implementation of similar programs elsewhere.

Our preparatory program is student-driven and can be implemented regardless of faculty participation, but we encourage students to work with faculty when possible. This program is one part of a broader re-imagining of what the qualifying exam process can look like, what it can achieve and promote within the student body, and ultimately, what it means to be a qualified PhD student. These are questions best explored by the entire academic community. Peer-led programs like the one discussed herein present a dual opportunity for student development. While the primary focus is to support students through their qualifying exam preparation, there are positive unintended consequences for the students leading the program itself. By way of curricular mapping, facilitation and assessment, senior students are not only expanding leadership skills, but more importantly, refining a pedagogical approach. This skill set is seamlessly transferable to professorship. These positive unintended consequences merit further exploration.

There is, of course, more work that could be done to increase equity throughout the qualifying exam process involving active participation of academic departments. For instance, transparency can be increased through the use of a rubric or otherwise clearly stated criteria for a 'passing' evaluation. Also, the exam could be framed as an opportunity for every student to learn about themselves and improve by creating the expectation that examiners will provide all students with both positive and critical feedback. Furthermore, the implicit soft skills that are tested by oral qualifying exams could be made more explicit and potentially broadened to include a wider range of communication styles and ways of being.

We envision any departmental reform process, qualifying exams and beyond, to be a collaborative one with faculty working alongside students. The Carnegie Foundation's book, "The Formation of Scholars: Rethinking Doctoral Education for the Twenty-First Century" explores many avenues of growth for higher education. One of their key highlights is the importance of student involvement in evolving an educational program. Students are "the secret weapon for change", and they found that when faculty were asked to work alongside students while reforming their programs, the faculty's most transformative insight was "a newfound respect for students as agents of change" [4]. We are grateful to participate as agents of change in shaping our own program and to contribute this small but significant piece of student-developed insight to both our graduate department and the engineering graduate education community at large.

References

[1] J. B. King, T. Mitchell, A. McIntosh, and J. Bell-Ellwanger, "Advancing Diversity and Inclusion in Higher Education: Key Data Highlights Focusing on Race and Ethnicity and Promising Practices." [Online]. Available: https://www2.ed.gov/rschstat/research/pubs/advancing-diversity-inclusion.pdf

[2] E. J. Theobald, M. J. Hill, E. Tran, S. Agrawal, E. N. Arroyo, S. Behling, N. Chambwe, D. L. Cintrón, J. D. Cooper, G. Dunster, J. A. Grummer, K. Hennessey, J. Hsiao, N. Iranon, L. Jones, H. Jordt, M. Keller, M. E. Lacey, C. E. Littlefield, A. Lowe, S. Newman, V. Okolo, S. Olroyd, B. R. Peecook, S. B. Pickett, D. L. Slager, I. W. Caviedes-Solis, K. E. Stanchak, V. Sundaravardan, C. Valdebenito, C. R. Williams, K. Zinsli, and S. Freeman, "Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering, and math," *Proceedings of the National Academy of Sciences*, vol. 117, no. 12, pp. 6476–6483, 2020. [Online]. Available: https://pnas.org/doi/full/10.1073/pnas.1916903117

[3] J. Gunn. (2018) What Equity Really Means in Schools. Resilient Educator. [Online]. Available: https://resilienteducator.com/classroom-resources/what-equity-really-means-in-schools/ (accessed Feb. 28 2023)

[4] G. E. Walker and the Carnegie Foundation for the Advancement of Teaching, Eds., *The Formation of Scholars: Rethinking Doctoral Education for the Twenty-First Century*, 1st ed. Jossey-Bass, 2008, OCLC: ocn166368350.

[5] S. Guloy, G. Hum, and D. K. O'Neill, "Voices at the gate: Faculty members' and students' differing perspectives on the purposes of the PhD comprehensive examination," *Assessment & Evaluation in Higher Education*, vol. 45, no. 2, pp. 279–291, 2020. [Online]. Available: https://www.tandfonline.com/doi/full/10.1080/02602938.2019.1637819

[6] J. Posselt and R. Liera, "Doctoral Candidacy and Qualifying Exams: A Guide to Contexts, Costs for Equity, and Possibilities of Transformation," 2022.

[7] C. R. McAdams and D. L. Robertson, "An Informed Look at Doctoral Vivas (Oral Examinations) in the Preparation of Counselor Educators," *Counselor Education and Supervision*, vol. 51, no. 3, pp. 176–188, 2012. [Online]. Available: https://onlinelibrary.wiley.com/doi/10.1002/j.1556-6978.2012.00013.x

[8] A. Loumansky and S. Jackson, "Out of the Frying Pan into the Viva," *Journal of International Women's Studies*, vol. 5, no. 3, 2004.

[9] S. J. Correll, K. R. Weisshaar, A. T. Wynn, and J. D. Wehner, "Inside the Black Box of Organizational Life: The Gendered Language of Performance Assessment," *American Sociological Review*, vol. 85, no. 6, pp. 1022–1050, 2020. [Online]. Available: http://journals.sagepub.com/doi/10.1177/0003122420962080

[10] S. Chen, K. R. Binning, K. J. Manke, S. T. Brady, E. M. McGreevy, L. Betancur, L. B. Limeri, and N. Kaufmann, “Am I a Science Person? A Strong Science Identity Bolsters Minority Students’ Sense of Belonging and Performance in College,” *Personality and Social Psychology Bulletin*, vol. 47, no. 4, pp. 593–606, 2021. [Online]. Available: https://journals.sagepub.com/doi/pdf/10.1177/0146167220936480

[11] A. G. Greenwald and M. R. Banaji, “Implicit Social Cognition: Attitudes, Self-Esteem, and Stereotypes,” *Psychological Review*, vol. 102, no. 1, pp. 4–27, 1995.

[12] S. T. Fiske, “Stereotyping, prejudice, and discrimination.” in *The Handbook of Social Psychology, Vols. 1-2, 4th ed.* McGraw-Hill, 1998, pp. 357–411.

[13] A. Walsh, “An exploration of Biggs’ constructive alignment in the context of work-based learning,” *Assessment & Evaluation in Higher Education*, vol. 32, no. 1, pp. 79–87, 2007.

[14] D. Boud and N. Falchikov, “Aligning assessment with long-term learning,” *Assessment & Evaluation in Higher Education*, vol. 31, no. 4, pp. 399–413, 2006.

[15] N. Kober, *Reaching Students: What Research Says About Effective Instruction in Undergraduate Science and Engineering*. National Academies Press, 2015, pages: 18687. [Online]. Available: http://www.nap.edu/catalog/18687

[16] ABET, “Criteria for Accrediting Engineering Programs,” 2016. [Online]. Available: https://www.abet.org/wp-content/uploads/2022/01/2022-23-EAC-Criteria.pdf

[17] R. Munroe. (2012) ”What If? A Mole of Moles”. xkcd. [Online]. Available: https://what-if.xkcd.com/4/ (accessed Feb. 28 2023)

[18] B. R. Belland, *Scaffolding: Definition, Current Debates, and Future Directions*. New York, NY: Springer New York, 2014, pp. 505–518. [Online]. Available: https://doi.org/10.1007/978-1-4614-3185-5_39

[19] S. Ambrose, M. W. Bridges, M. DiPietro, M. C. Lovett, and M. K. Norman, *How Learning Works: Seven Research-Based Principles for Smart Teaching*, 1st ed. Jossey-Bass, 2010.

[20] F. Jentsch, M. Curtis, and E. Salas, *Simulation in aviation training*. Routledge, Taylor and Francis Group, 2016, OCLC: 987911167.

[21] Philip Exeter Academy, “Math Teaching Materials.” [Online]. Available: https://www.abet.org/wp-content/uploads/2022/01/2022-23-EAC-Criteria.pdf

[22] E. F. Redish. (2002) University of maryland fermi problems site. [Online]. Available: http://www.physics.umd.edu/perg/fermi/fermi.htm

Appendix A Prompts and Problems

Week 2: Speed Prompts

- Tell us the plot of your favorite movie or TV show.
- What's the difference between these things?
  - Sweets, treats, and desserts
  - Crackers and chips
- Which is better, the summer or winter Olympics?
- What sport should be in the Olympics but isn't?
- What sport or event is the best of the Olympics?
- What is the best streaming service?
- Explain how to make the best peanut butter and jelly sandwich.
- What rules govern an automatic door?
- Draw a rough map of campus.
- Draw a rough map of your hometown or undergrad town.
- Draw a rough map of your undergraduate campus.
- Diagram the important parts of an airplane and how it works.
- Diagram the important parts of a rocket and how it works.
- Diagram the important parts of a quadcopter and how it works.
- Diagram the important parts of a click pen and how it works.
- Diagram the important parts of a stapler and how it works.
- Diagram the important parts of a car and how it works.
- Sketch a 4-way traffic intersection. How does it work? What are the light patterns? How does adding or removing lanes change things?
- Which is better, cats or dogs?

Week 3: Math Problems

Word problems are sourced from one author's previous curriculum at Phillips Exeter Academy. [21]

- Alex the geologist is in the desert, 10 miles from a long, straight road. On the road, Alex's jeep can go 50 miles per hour, but in the desert sands, it can only go 30 miles per hour. Alex is very thirsty and wants to buy some lemonade at a gas station which is 20 miles down the road from the point on the road, N, nearest to Alex. If Alex takes the fastest route possible, it will take only 40 minutes to get to the gas station and sip some cool lemonade. What route should Alex take? What if the gas station is 30 miles down the road?
- A circular table is placed in a corner of a room so that it touches both walls. A mark is made on the edge of the table, exactly 18 inches from one wall and 25 inches from the other. What is the radius of the table?
- From the top of Mt Washington, which is 6288 feet above sea level, how far is it to the horizon?
- Find simpler, equivalent expressions for the following. All parts should involve drawing a unit circle.
  - $\sin(180+\theta)$
  - $\cos(180+\theta)$

  - $\tan(180+\theta)$

- In 1904, Helge von Koch invented his snowflake, which is probably the first published example of a fractal. It is the result of an endless sequence of stages: Stage 0 (the initial configuration) consists of an equilateral triangle, whose sides are 1 unit long. Stage 1 is obtained from stage 0 by replacing the middle third of each edge by a pair of segments, arranged so that a small equilateral triangle protrudes from that edge. In general, each stage is a polygon that is obtained by applying the middle-third construction to every edge of the preceding stage.
  - Sketch stage 2.
  - Stage 0 has three edges, and stage 1 has twelve. How many edges do stages 2 and 3 have? How many edges does stage n have?
  - Stage 1 has twelve vertices. How many vertices does stage n have?
  - How long is each edge of stage 1? of stage 2? of stage n?
  - What is the perimeter of stage 1? of stage 2? of stage n?
  - Does the snowflake have finite perimeter?
  - Is the area enclosed by the snowflake finite?
- Illuminated by the rays of the setting sun, Andy rides alone on a merry-go-round, casting a moving shadow on a wall. The merry-go-round is turning 40 degrees per second. As the top view shows, Andy is 24 feet from its center, and the sun's rays are perpendicular to the wall. Let N be the point on the wall that is closest to the merry-go-round. What is the speed (feet per second) of Andy's shadow when it passes N? What is the speed of this shadow when it is 12 feet from N?
- Draw a square with vertices (0, 0), (1, 0), (1, 1), and (0, 1), then draw an adjacent r $\times$ r square with vertices (1, 0) and (1 + r, 0). In terms of r, find the x-intercept of the straight line that goes through the upper right corners of the two squares.
- Robin is mowing a rectangular field that measures 24 yards by 32 yards, by pushing the mower around and around the outside of the plot. This creates a widening border that surrounds the unmowed grass in the center. During a brief rest, Robin wonders whether the job is half done yet. How wide is the uniform mowed border when Robin is half done?
- Given that P is three fifths of the way from A to B, and that Q is one third of the way from P to B, describe the location of Q in relation to A and B.
- Starting with a 2 $\times$ 4 $\times$ 4 wooden block, Sasha sculpted an object that has isosceles, triangular cross-sections perpendicular to the 2 $\times$ 4 rectangular base. The height of each isosceles triangle equals its distance from the short end of the block. What is the volume of the object?
- Sasha took a wooden cylinder and created an interesting sculpture from it. The finished object is 6 inches tall and 6 inches in diameter. It has square cross-sections perpendicular to the circular base of the cylinder, and is the largest possible shape that has this property. What is the volume of the object?
- P = (cos(t),sin(t)) and A = (1, 0) are on the unit circle, and Q = (1, t) makes tangent segment AQ have the same length as minor arc AP. The line through P and Q intersects the x-axis at R = (r, 0). Express r in terms of t.
- Graph y = (bx $-$ 5)/(bx + 3) , assuming that the base b is greater than 1. Identify both asymptotes. Does this graph have symmetry?
- Consider a honeycomb pattern which consists of two rows of numbered hexagons. The bottom row consists of odd-numbered hexagons in order from 1-13, and the centered top row consists of even-numbered hexagons in order from 2-12. A honeybee crawls from hexagon number 1 to hexagon number 13, always moving from one hexagon to an adjacent hexagon whose number is greater. How many different paths are there?
- Multiply each of the following by 1 $-$ r:
  - $1 + r$
  - $1 + r + r^2$

- $1 + r + r^2 + ... + r^{1995}$

- A wheel of radius 1 meter is centered at the origin, and a rod AB of length 3 meters is attached at A to the rim of the wheel. The wheel is turning counterclockwise, one rotation every 4 seconds, and, as it turns, the other end B = (b(t), 0) of the rod is constrained to slide back and forth along a segment of the x-axis. Find b(t).
- Three distinct vertices of a cube are to be randomly chosen. What is the probability that they will be the vertices of an equilateral triangle?
- Find the following sums.
  - $1 + 2 + 3 + ... + 100$
  - $156 + 179 + 202 + ... + 1996$
  - $1 + 2 + 3 + ... + n$
- A bug jumps from lattice point to lattice point on a piece of graph paper, one jump per second, as follows: From (m, n), there is a 60 percent chance that the bug jumps to (m + 1, n) and a 40 percent chance that it jumps to (m, n+ 1).
  - Find all the places the bug could be, two seconds after it leaves the origin (0, 0).
  - Are all places equally likely?
  - It would take the bug five seconds to reach (3, 2) from the origin. How likely is it that this will actually happen?
- Andy is riding a merry-go-round, whose radius is 25 feet and which is turning 36 degrees per second. Seeing a friend in the crowd, Andy steps off the outer edge of the merry-go-round and suddenly finds it necessary to run. How many miles per hour will he run at?
- A segment that is a units long makes a C-degree angle with a segment that is b units long. In terms of a, b, and C, find the length of the third side of the triangle. What is the area of the triangle defined by a, b, and C?
- A coin of radius 1 cm is tossed onto a plane surface that has been tesselated by right triangles whose sides are 8 cm, 15 cm, and 17 cm long. What is the probability that the coin lands within one of the triangles?
- Devon's bike has wheels that are 27 inches in diameter. After the front wheel picks up a tack, Devon rolls another 100 feet and stops. How far above the ground is the tack?
- Describe all the points on the earth's surface that are exactly 4000 miles from the North Pole.
- Given a triangle ABC in which angle B is exactly twice the size of angle C, must it be true that side AC is exactly twice the size of side AB? Could it be true?

Week 4: Logic and Estimation Problems

- How many steps would it take to walk from LA to NYC?
- It's 3:25 (or any time). What is the angle between the hands on an analog clock? After 3:25 (or any time), when is the next time the minute and hour hands will overlap?
- You have a set of 3 cup and 5 cup measuring cups, but would like to measure out 2 cups of water exactly. How would you do it? Note that there are no markings other than the total volume of the cups you have on hand.
- Place n queens on a n x n chess board (n>3) such that no queen can take another (i.e. no more than one queen on each row, column and diagonal).
- The Monty Hall problem. Contestants are faced with three doors, one of which has a valuable prize (usually a car), and the other two which have a goat. After the contestant chooses a door, the host opens a different door to reveal a goat and offers them the chance to switch their chosen door. Should they switch (assuming they want the car)?
- A cart is accelerating on an infinitely long, level track at a constant rate of 1g. It is carrying a bucket of water. What angle does the water make with the ground? If a ping-pong ball were somehow placed in the center of the bucket (assuming it is moving at the same speed as the water), which direction, if any, would it move?

- A farmer needs to cross a river with his fox, chicken, and bag corn. The problem is the boat only can fit the farmer and one other thing, and the fox and chicken are hungry. If the farmer leaves the fox alone with the chicken on a bank, the fox will eat the chicken, and if they leave the chicken alone with the corn, the chicken will eat the corn. What should the farmer do?
- If seven days after 70 days ago was a Sunday, seven days before 70 days from today is what day of the week?
- Estimate how massive the moon is.
- About how large is a mole of moles (the small mammals) in radius [17]?
- How many buckets of paint would it take to paint the entire land area of the world [17]?
- Estimate the total number of hairs on your head [22].
- One suggestion for putting satellites into orbit cheaply without using rockets is to build a tower 300 km high containing an elevator. One would put the payload in the elevator, lift it to the top, and just step out into orbit. Ignoring other problems (such as structural strain on the tower), estimate the weight of such a tower if its base were the size of Washington DC and it were made of steel [22].
- Estimate the total amount of time students in the US spent during this past year studying for exams in college [22].
- A floppy disk for a computer stores information by magnetizing small regions of the disk. For a typical floppy disk, estimate the area of the disk that corresponds to a single bit of information [22].
- Estimate the number of blades of grass a typical suburban house's lawn has [22].
- How much air (mass) is there in the room you are in [22]?
- Estimate the angular momentum (about Earth's axis) that your body has as a result of the earth's turning on its axis.
- Estimate the kinetic energy the Earth has as a result of its orbiting the sun (assuming the sun is fixed in an inertial frame).
- An earthquake knocks off every book from the main campus library. How many hours of work would it take to put them back? How many undergrads would they need to hire?