Bridging Gaps in Mathematical Preparedness: A Student-Led Summer Course Designed for STEM Graduate Students

Wiete Fehner, Washington University in St. Louis

I am a PhD Candidate in Imaging Science in Dr. Joseph Culver's lab at the Washington University in St. Louis, USA. My research focuses on naturalistic human brain mapping using noninvasive optical imaging. I have always been fascinated by the human brain and mind which led me to pursue a BA in Philosophy (Germany) and an MS in Neuroscience (Finland). Transitioning from a non-engineering background to an engineering graduate program was challenging. This experience motivated me to launch a summer math crash course with fellow graduate students to support those transitioning from interdisciplinary backgrounds into engineering. Now in its fourth year, I am excited to see this program become a university staple and am passionate about sharing it across disciplines.

Dr. Morgan Fogarty, Washington University in St. Louis

Morgan Fogarty, PhD is a Postdoctoral Research Scholar at Washington University in St. Louis (WashU). She earned her BS in Biomedical Engineering from Illinois Institute of Technology, and her MS in Electrical Engineering and PhD in Imaging Science from WashU. Her research focuses on naturalistic brain mapping using high-density diffuse optical tomography (HD-DOT), with long-term goals in developing wearable neuroimaging devices for language-based brain-computer interfaces and early diagnosis of neurological disorders. Through personal challenges adjusting to graduate school, she helped launch the Math Crash Course at WashU to provide support for incoming students. Her educational goals include continuing to find ways to improve the graduate education experience for all students.

Kathleen M Duncan, Washington University in St Louis

McKelvey Engineering Imaging Science PhD Program at Washington University in St Louis, in Biophotonics Research Center and Biomedical Optics and Neurovascular Imaging Lab

Calvin Thomas Foss, Washington University in St. Louis

Ph.D. candidate in the lab of Dr. Adam Bauer studying Alzheimer's Disease in a mouse model using optical brain imaging.

Mr. Sanskar Sanjay Thakur, Washington University in St. Louis

Sanskar Thakur is a Ph.D. candidate in Imaging Science at Washington University in St. Louis, where he develops optical and ultrasound imaging devices for cancer management under Dr. Quing Zhu. He holds a B.E. in Production Engineering from Shivaji University, India, and an M.S. in Mechanical Engineering from IUPUI. After experiencing the inaugural math crash course as a student, Sanskar was inspired by its impact to step into a leadership role, ultimately helping to develop and expand the current curriculum.

Ahmad Shafiullah, Washington University in St. Louis

Ahmad Shafiullah is a doctoral student in the Imaging Science PhD program at Washington University in St. Louis. He received his Bachelor's degree in Electrical and Electronic Engineering (EEE) from the Islamic University of Technology (IUT). Following graduation, he served as a lecturer in the Department of EEE at IUT, where he was involved in designing syllabi, developing course modules, and teaching undergraduate students. These experiences directly inform the student-led summer course described in this paper. His current research focuses on shortwave infrared imaging for dermatological applications, including the detection and analysis of skin-related diseases.

Sung Min Park, Washington University in St. Louis

Sung Min is a PhD candidate in the Imaging Science program at Washington University in St. Louis.

Nischal Khanal, Washington University in St. Louis

Nischal Khanal is a PhD candidate in Imaging Science at Washington University in St. Louis (WashU). He earned his BS in Biomedical Engineering and MS in Electrical Engineering from WashU. His research focuses on integrating optogenetics with deep-learning-based computer vision to map motor function in awake mice in the context of stroke. As a co-founder of the Math Crash Course at WashU, he helps prepare incoming PhD students with foundational coursework in calculus, linear algebra, and signals and systems. His motivations for helping establish the Math Crash Course include building inclusive mentorship structures and helping make the transition into graduate coursework more accessible for students from diverse backgrounds.

Dr. Ty O Easley, Washington University in St. Louis, Department of Mathematics

Ty Easley is a recent graduate of the Washington University in St. Louis Imaging Science PhD program. Their research revolves around applications of constructions in geometry and topology, especially in neuroimaging, and they are passionate about accesible and humanized mathematics education.

Dr. Emily Boyd, Washington University in St. Louis

Emily Boyd is a teaching professor and the Associate Chair for Education in the Department of Mechanical Engineering and Materials science at Washington University in St. Louis. Hear area of expertise is thermal-fluid sciences. She coordinates two summer undergraduate research programs that aim to retain and increase the number of students pursuing engineering degrees and careers.

Dr. Joseph P Culver, Washington University in St. Louis

Joseph P. Culver, PhD, is the Sherwood Moore Professor of Radiology for Mallinckrodt Institute of Radiology (MIR) at Washington University School of Medicine in St. Louis. Culver's work has been at the leading edge of functional and molecular biological imaging, particularly in leveraging noninvasive optical measurements and advancing diffuse optical tomography (DOT) technology. He received his doctorate degree and completed biomedical optics postdoctoral training from the University of Pennsylvania.

Prof. Joseph A. O'Sullivan, Washington University in St. Louis

Joseph A. O'Sullivan is the Samuel C. Sachs Professor of Electrical Engineering at Washington University in St. Louis, with appointments in Electrical & Systems Engineering, Biomedical Engineering, Radiology, and Earth, Environmental and Planetary Science. Prof. O'Sullivan is co-director of the doctoral program in Imaging Science. He is Dean of the University of the University of Missouri-St. Louis/Washington University Joint Engineering Program. He has wide ranging research interests in imaging science and teaches core courses in the mathematics, physics, theory, and practice of imaging.

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Abstract

Interdisciplinary graduate programs foster innovation by integrating diverse perspectives across fields. While these programs create opportunities for broader career paths, they introduce challenges in preparing students from diverse backgrounds for a shared curriculum. Many incoming students require foundational mathematics reinforcement, particularly those transitioning from non-engineering fields into engineering-intensive programs or returning from industry after breaks in formal coursework.

Addressing this challenge, graduate students at Washington University in St. Louis created an annual nine-week Summer Math Crash Course. This voluntary, student-led program was designed to strengthen preparation in linear algebra and calculus while fostering community and peer support prior to the start of graduate study. The course combines self-paced instructional modules with live tutoring, applied research talks, and opportunities for social engagement. In addition to supporting incoming students, the program provides professional development opportunities for current graduate students through teaching, mentoring, and curriculum design.

Program impact was evaluated using course engagement analytics and matched responses to pre- and post-course surveys (N=18) to assess math preparedness, self-efficacy, belonging, and scientific identity. Across iterations, results indicate increased familiarity with core mathematical concepts, improved confidence in math-based coursework, and a strengthened sense of community among participants.

This initiative provides a replicable and scalable framework for student-driven academic support programs adaptable across disciplines and universities to enhance math preparedness, foster community, and promote professional development.

I. Introduction

Given the complexity of modern environmental, biological, and medical challenges, engineering graduate programs are increasingly confronted with the need to prepare students to address inherently interdisciplinary problems [1], [2]. Accordingly, incorporating interdisciplinary training in engineering programs has been shown to improve students' well-being and research performance by exposing them to diverse perspectives and novel problem-solving tools [1], [2], [3]. While such graduate programs provide opportunities for cross-disciplinary collaboration, they also introduce challenges in training students from heterogeneous educational backgrounds [4]. Engineering graduate programs suffer from high rates of attrition, with a main factor being identified as the inability of students to keep up with the programs' high demands [5].

Although graduate bridge programs have been shown to ease the transition into advanced study and support academic and professional development, they typically emphasize mentoring, professional skills, and social support rather than core disciplinary content [6]. Meanwhile, incoming students may come from non-engineering undergraduate programs or return to academia from extended periods in industry [7]. While diversity of backgrounds is a strength, it introduces challenges for preparing students for a shared, technically rigorous graduate curriculum that relies heavily on a strong foundation in linear algebra (LA) and calculus. Often, incoming graduate students are expected to apply these math concepts immediately, with limited formal review. As a result, disparities in preparation can lead to differences in course performance, increased time investment to "catch-up", reduced availability for research engagement, and heightened stress or diminished self-efficacy. Prior work has documented elevated stress levels and challenges related to psychological well-being and self-efficacy among graduate students more broadly [8], [9], which may be exacerbated when students feel underprepared for core technical coursework. Importantly, self-efficacy, a person's belief in their capabilities [10], [11], has been shown to influence academic performance [12]. Yet the existing coursework structure often assumes a degree of homogeneity in prior preparation, which does not reflect the reality of interdisciplinary cohorts. These factors underscore a clear need for flexible, graduate-level interventions that address foundational math preparedness, support diverse student backgrounds, and foster equitable entry into interdisciplinary engineering programs.

Beyond individual academic outcomes, teamwork and collaboration are essential components of a successful graduate research career [13], [14], [15], [16]. Effective collaboration depends not only on content knowledge but also on the willingness and confidence to engage with peers. Educational research shows that social inclusion supports academic performance and can be promoted by increasing contact across groups and intentionally encouraging positive peer interactions among students from diverse backgrounds [17]. Accordingly, programs that foster interdisciplinary interaction, peer support, and community building alongside academic preparation may help mitigate both academic and psychological challenges faced by incoming graduate students [18]. These factors highlight the importance of graduate-level interventions that simultaneously address foundational math preparedness, foster inclusive peer communities, and promote equitable participation and success in interdisciplinary engineering programs.

In response to these needs, a wide range of preparedness and transition programs have emerged across disciplines, including bootcamps, bridge programs, summer refreshers, and online intensive programs aimed at skill acquisition or remediation. Examples include coding bootcamps for career transitions [19], as well as academic programs such as the Neuromatch Academy [20] and NeuroHackademy [21], which provide intensive training in computational neuroscience. Similar models are also common in quantitatively intensive disciplines, including short "math bootcamps" or refresher courses for incoming PhD students in economics, statistics, engineering, or broader STEM fields offered at institutions such as Washington University in St. Louis (WashU) [22], Stanford University [23], the University of Pennsylvania [24], or University of California Berkeley [25]. However, few of these efforts are student-led, free of cost, or intentionally designed to combine academic preparation with peer mentoring and community building.

Imaging Science at WashU [26] is a relatively new interdisciplinary PhD program that draws students from engineering, physics, neuroscience, and related fields. In this context, we define interdisciplinary diversity as heterogeneous perspectives arising from varied educational trajectories, disciplinary training, and professional experiences. A significant portion of the Imaging Science cohort does not come directly from undergraduate studies; instead, many earned a master's degree beforehand or worked in academia or industry. As a result, the founders of this initiative, all Imaging Science PhD students, observed and personally experienced substantial variability in incoming students' math preparedness. Deficiencies in fundamental mathematics, such as calculus and LA, can make the first semester of engineering graduate coursework challenging, even for otherwise strong students. Inspired by existing bootcamp-style preparedness models, but recognizing the specific needs of interdisciplinary graduate students, we developed a summer math crash course (MCC) explicitly tailored to incoming graduate students in Imaging Science. Beyond reinforcing core mathematical foundations, a central goal of this initiative was to foster community building and peer-to-peer learning early in the program. The curriculum was designed and delivered by graduate students for graduate students, with the intent that incoming doctoral students are more likely to candidly discuss their preparedness gaps with their peers [27], [28]. Since the beginning of the MCC, we observed that the challenges addressed by this initiative are not unique to Imaging Science but common across many graduate programs. In response, the MCC was progressively opened to graduate students and researchers across WashU and, more recently, to external participants.

In this paper, we assess this initiative to demonstrate the impact of student-led preparedness programs and share a replicable framework for graduate STEM education. We first introduce the design principles and structure of the program, then present evaluation results assessing both academic preparedness and community outcomes. Finally, we discuss lessons learned, limitations, and broader implications for supporting transitions into interdisciplinary graduate programs.

II. Math Crash Course Content and Structure

The MCC was developed in 2022 by WashU graduate students in the Imaging Science program, with guidance from program advisors and teaching faculty, to support incoming engineering graduate students in preparing for graduate-level coursework. Since then, it has been offered annually and iteratively refined. The MCC is a self-paced, compact summer course designed to reinforce key mathematical concepts in LA and calculus while fostering early community building prior to the start of graduate school. Here, we focus on the 2025 implementation.

Curriculum developers drew on their graduate school experience and feedback from senior faculty to address gaps in mathematical preparedness among incoming graduate students. The content emphasized foundational concepts in LA and calculus most relevant to first-year engineering students, especially those from non-engineering backgrounds. Rather than aiming for comprehensive coverage, the MCC was designed to promote familiarity, confidence, and readiness to engage with mathematically intensive material during the academic year.

In LA, the curriculum prioritized core matrix fundamentals as a bridge to eigen decomposition and singular value decomposition (SVD), which are relevant to many data analysis methods and to the mathematical foundations of imaging applications. These concepts were reinforced through applied examples, such as principal component analysis (PCA) and support vector machines (SVM), allowing students to connect abstract LA concepts to real-world computational applications. For calculus, the course emphasized differentiation and integration as fundamental tools, branching into convolution and Fourier transforms. These topics were selected because they frequently appear across engineering coursework, signal processing, and imaging science, and are fundamental to understanding both theoretical and applied problems.

The 9-week course featured beginner and advanced pathways, ensuring the material remained accessible to students with diverse backgrounds and availabilities. LA was covered during the first five weeks, followed by four weeks of calculus. This asynchronous approach allowed students to follow pathways with different weekly time commitments (5, 10, and 15 hours per week) to accommodate their schedule and learning pace. These pathways were published in advance of the course start date to give students time to plan their schedule.

Instructional materials included standard textbooks, curated online resources, and guided Python coding examples implemented in Google Colab. Coding modules were designed to demonstrate how mathematical concepts translate into computational workflows commonly used in research. The curriculum was module-based with each module including a reading assignment and an associated problem set. The course mirrors WashU's academic environment by utilizing Canvas, ensuring students gain proficiency with the primary learning platform used at the university.

To address both academic preparedness and social integration, the course combined asynchronous modules, live tutoring sessions, applied research talks, and community events. Tutoring sessions were held four times a week, with two beginner and two advanced sections. These sections allowed students to ask questions, review concepts, and interact with current graduate students. Tutors were selected based on their experience and expertise with the course material and were often participants from previous iterations of the course. All tutors were enrolled in the PhD program in Imaging Science at WashU, and the tutoring experience optionally fulfilled the mentored teaching experience (MTE) requirement. Weekly meetings with faculty and the curriculum team supported tutor development in teaching and communication.

To allow students to evaluate their progress, two forms of assessment were used throughout the course. Weekly Canvas submissions allowed students to upload assignments for personalized feedback. This asynchronous model ensured that even students unable to attend tutoring sessions benefited from tutor guidance. Additionally, weekly multiple-choice quizzes allowed students to assess their progress with immediate feedback. These quizzes were designed to be short, 5-question, assessments that could be attempted unlimited times. Students who submitted at least three quizzes within a subject area earned a corresponding completion certificate, which functioned as an engagement-based recognition rather than a performance-based credential.

Complementing the formal structure of Canvas, the MCC promoted community engagement through Discord, providing a platform for announcements, real-time student feedback, and informal discussions. The discussions on Discord ranged from course topics to candid questions regarding student life at WashU. The MCC also hosted three social events, both in person and via Discord, and a series of five research talks throughout the summer to further bolster engagement and interaction. While the social events encouraged networking, the research presentations (3 LA and 2 Calculus) were delivered by current engineering graduate students and contextualized course concepts within real-world applications.

To facilitate the use of the MCC at other universities, the course materials are available here: https://github.com/math-crash-course/gaps_in_math_prep. This includes all modules, textbook recommendations, YouTube videos, and assessments.

III. Methods

A. Survey Development

To assess math preparedness, performance, and sentiment throughout the 2025 MCC, a pre- and post-course survey was distributed to students. The pre- and post-surveys consisted of three sections: demographics, community and belonging, and mathematics. The post-first-semester survey was distributed at the end of the first semester to all students in a required first-semester Imaging Science course to determine whether the MCC impacted students' preparedness. This post-first-semester survey includes students who did and did not complete the MCC.

The pre- and post-MCC performance assessments consisted of 9-10 multiple-choice questions for LA and calculus. Students were asked to complete the questions based on their enrolled courses. The questions for the pre- and post-surveys assessed the same underlying mathematical concepts taught in the course but included variations to prevent recall effects. Students were asked to complete the survey without outside materials to ensure an unbiased result. An "I don't know" option was included for each question to avoid skewing the results through guessing. To complement assessing math competencies through problem solving, students were asked to report their confidence in their ability to solve math problems using a 5-point Likert-scale (strongly disagree to strongly agree).

To assess sense of community and belonging, the survey included 14 5-point Likert-scale questions covering broad topics such as belonging, scientific identity, and self-efficacy. These questions were designed to evaluate students' perceptions of the WashU community before and after the course. Specifically, we aimed to understand students' feelings of belonging, comfort in seeking help, and readiness to successfully complete their degree. A representative subset of questions from each section is reported.

Finally, for the post-first-semester survey, the focus was on community and belonging, as well as the relevance of the MCC to their research and coursework. All questions were presented on a 5-point Likert Scale from strongly disagree to strongly agree. The surveys were not timed but were designed to be completed in approximately 15 minutes.

All surveys were administered using Qualtrics for Sensitive Data [29]. The survey instruments were developed specifically for this study in collaboration with an educational assessment expert to ensure alignment with the course learning objectives. This was the first deployment of these instruments. Survey items were informed by previously published instruments assessing [30], [31]. Mathematics content questions were developed in collaboration with curriculum developers and were designed to directly assess core concepts taught during the course. Content validity was established through iterative review with course directors, faculty, and course developers.

B. Focus Group Development

To supplement survey data with qualitative insights, three focus groups were convened to capture students' and tutors' impressions of the course. These focus groups included: 1) students who started but did not complete the course, 2) students who completed the course with a certificate, and 3) curriculum developers and tutors. During these 1-hour-long focus group meetings, a set of 6-8 questions was used as the starting point for discussion. For students, these questions included how participating in the MCC impacted their coursework and research, what challenges they faced in course progress and completion, and whether they would recommend the course to other students. For tutors and curriculum developers, the questions focused on their motivations for participating in MCC, the acquisition of any professional development skills, and their overall endorsement of the tutoring experience to other students. Additionally, these focus groups served as feedback for future course iterations. The focus groups were held on Zoom and recorded for transcription.

C. Student Recruitment

For the 2025 MCC cohort, students were asked to complete a pre- and post-survey to evaluate the course's impact on their math preparedness and sense of social belonging. The pre- and post-surveys were distributed to 104 students before and after the course, respectively. Each student received a participant ID to keep responses anonymous from the data analysis team, while enabling matching of pre- and post-survey responses. Students received new participant IDs for completion of the post-first-semester survey independent from the pre- and post-surveys. A total of 18 students completed both the pre- and post-surveys, and the analysis will focus on the matched results. To evaluate the perceived effectiveness of the MCC after completing the first semester of graduate-level coursework, a post-first-semester survey was distributed to a cohort of 28 students from one of the first-year Imaging Science courses (Mathematics of Imaging Science). A total of 18 students completed the survey, of whom 6 participated in the MCC. Informed consent was obtained from all participants, and consent procedures followed the IRB protocol approved by the Human Research Protection Office at Washington University in St. Louis.

D. Survey Analysis

Only responses from students who completed both the pre- and post-surveys were included in the matched analysis of survey data (N=18). Analyses were conducted separately for belonging and confidence in ability (Likert-scale items) and for mathematics performance items.

To visualize changes in Likert-scale responses between the pre- and post-surveys, results were displayed using diverging bar charts, with neutral responses (“neither agree nor disagree”) shown as a separate category. This visualization facilitates a clear comparison of shifts in response distributions over time.

To assess improvements in mathematics performance, responses were analyzed at both the within-participant and group levels. Blank responses were treated as missing values to avoid penalizing non-responses or skewing performance estimates. Four students were excluded from the within-participant analysis due to missing responses in either the pre- or post-survey math sections, resulting in a final within-participant sample of N=14. We first asked whether individual students demonstrated consistent improvement in mathematics performance following the intervention. For each participant, correct responses were summed and converted into proportions of correct answers across attempted questions for the pre- and post-surveys. Within-student changes in performance were visualized using spaghetti plots connecting pre- and post-survey proportions. Group-level mean and median performance were computed. To test for statistically significant differences between paired pre- and post-survey performance at the group level, a paired Wilcoxon signed-rank test was conducted, given the small sample size and non-normal distribution of proportion scores. In addition, a sign test (binomial test) was performed to evaluate whether the number of students showing improvement exceeded the number showing declines, providing a complementary, distribution-free assessment of directional change.

Next, we asked whether performance improved at the question level. For each question, the proportion of correct responses was computed as the number of correct answers divided by the total number of attempted responses (excluding missing values). These proportions were computed separately for the pre- and post-surveys. Mean proportions and associated standard errors of the mean (SEM) were then calculated across questions for three response categories: correct, incorrect, and “I don’t know.” Paired Wilcoxon signed-rank tests were used to assess whether pre-to-post changes in these proportions were statistically significant across questions. Results were visualized using bar charts with error bars representing SEM.

For the post-first-semester survey, responses were included from students who completed the survey (N=18). The responses were independent and not matched to the pre- and post-surveys. Analyses followed the same procedures used for the pre- and post-survey Likert data.

E. Course Engagement Analysis

To assess engagement with course materials, we supplemented the survey data with historical and current participation data. This included engagement metrics extracted from Canvas [32] for 2023 to 2025, including activity status, page views, and quiz submissions. Note, the 2022 iteration was offered on a different platform and is therefore excluded. Additionally, we included completion certificate numbers for all iterations.

IV. Results:

A. Course Registration and Demographics

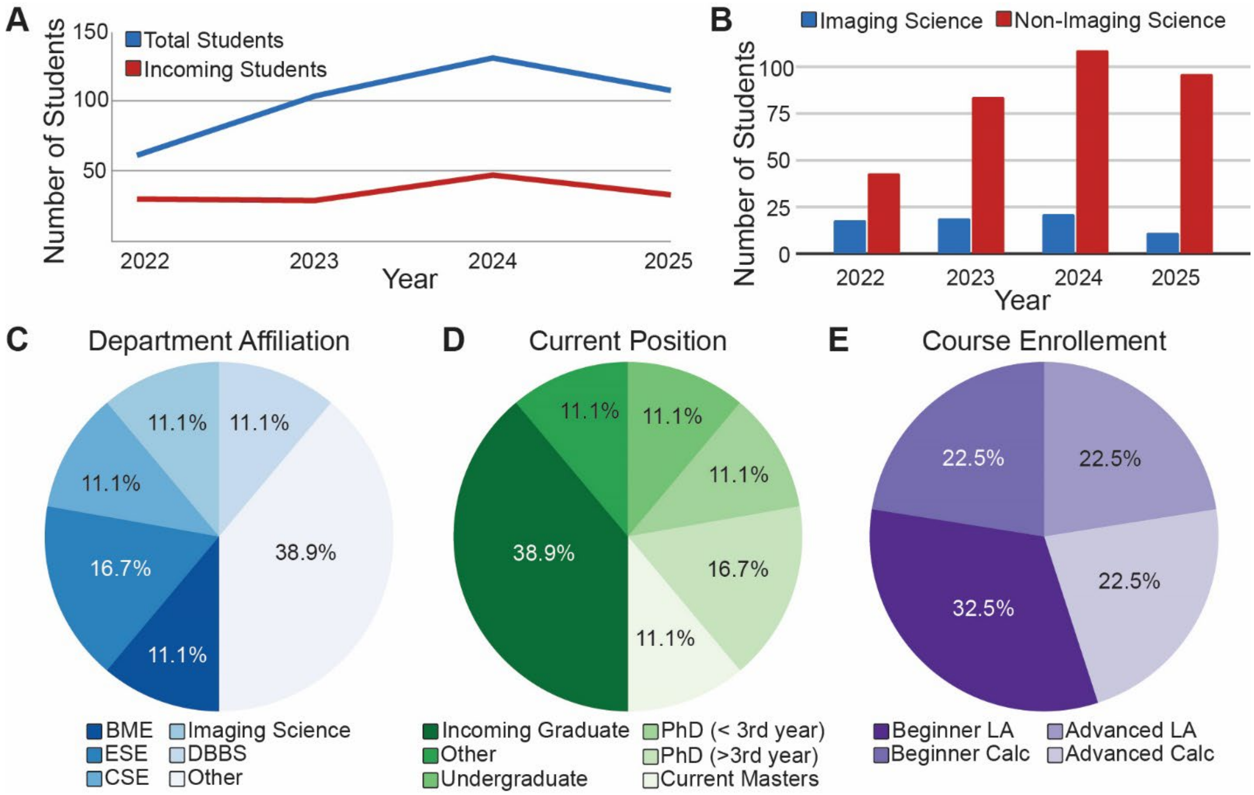

Figure 1: Course registration and demographics. (A) Registration for the MCC has ranged from 61 to 130 students between 2022 and 2025, with 30 to 47 incoming graduate students per year. (B) The course was developed for Imaging Science PhD students but also attracted students from other departments and programs. (C) Among the students included in the subsequent analysis, half are enrolled in an engineering department, a distribution representative of our overall course enrollment. (D) Around 40% of the students are incoming graduate students, which is the target group for the Math Crash Course. (E) Students enrolled in the beginner and advanced LA and beginner and advanced calculus courses in comparable proportions, with beginner LA showing highest enrollment.

To evaluate engagement with MCC, we examined registration trends across program iterations, including total enrollment and the proportion of incoming graduate students and Imaging Science participants (**Fig. 1A–B**). From 2022 to 2025, annual registrations ranged from 61 to 130 (2022: 61; 2023: 103; 2024: 130; 2025: 107 students). Of these, 30 to 47 participants per year were incoming graduate students, corresponding to 49% in 2022 and 31% in 2025 (2022: 49%; 2023: 28%; 2024: 36%; 2025: 31% of students) (**Fig. 1A**). The decrease in the proportion of incoming PhD students coincided with expanding course access to a broader audience across departments, reflecting the relevance of foundational LA and calculus concepts to a wide range of disciplines. The proportion of Imaging Science students declined from approximately 30% in the first year to 10% in the most recent iteration, with absolute counts ranging from 11 to 21 students per year (2022: 18; 2023: 19; 2024: 21; 2025: 11 students) (**Fig. 1B**). This trend likely reflects both variation in Imaging Science cohort sizes across years and increased participation from students outside the program as the course became more broadly accessible. Participant demographics reflected substantial disciplinary diversity. Between 30% and 45% of registered participants across iterations were affiliated with non-engineering departments. Registered students were consistently from more than 15 distinct academic departments. Among matched survey respondents, seven reported their most recent degree outside engineering.

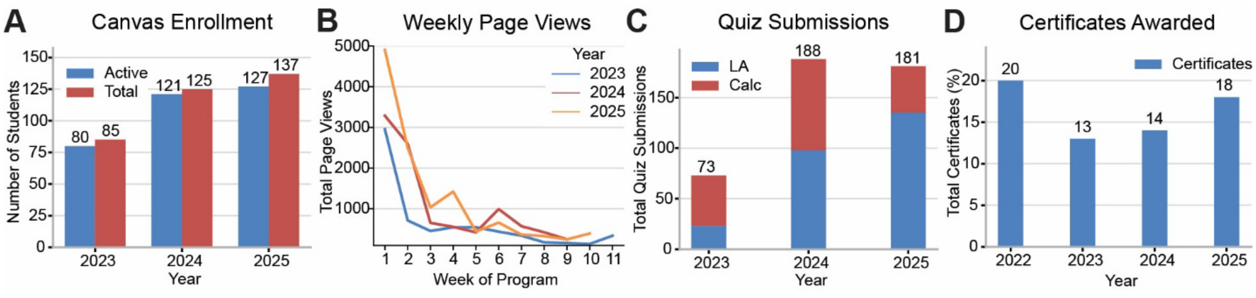

Figure 2: Course engagement across the years. Canvas-based engagement metrics summarizing student participation in the MCC across three cohorts. (A) Acceptance of Canvas course invitations. Students were counted as active if they engaged in at least one course-related activity. (B) Weekly page views by cohort, aligned to program week. Curriculum structure differs by year: in 2023, Weeks 1-4 covered calculus, Weeks 5-9 covered LA, and Weeks 10-11 covered Signals and Systems (an advanced calculus module). In 2024 and 2025, Signals and Systems content was integrated into the second half of the calculus sequence, and Weeks 1-5 covered LA and Weeks 4-9 covered calculus. (C) Quiz and assignment submissions, summarized by major curriculum phase (LA and calculus). Specifically, quiz submissions were as follows: 2023: 50 calculus, 23 LA; 2024: 90 calculus, 98 LA; and 2025: 135 LA, 46 calculus. (D) Certificates of completion issued from 2022-2025 were awarded based on engagement rather than performance. Canvas analytics for 2022 are not shown because that cohort was administered through Notion rather than Canvas.

To further characterize participants in the 2025 cohort, demographic information was analyzed for students who completed the survey (**Fig. 1D–E**). Imaging Science students accounted for 11% of respondents, closely matching their overall representation in the course (10%). Approximately 40% of participants were enrolled in other engineering programs. The remaining 50% of students came from programs within the Division of Biology and Biomedical Sciences (DBBS, 11%) and other non-engineering degree programs (39%). Incoming graduate students comprised approximately 39% of respondents, while another 39% were continuing graduate students (Master's and PhD), 11% were current undergraduate students, and 11% identified as holding other positions. Regarding course level and content selection, 55% of participants were enrolled in the beginner track and 45% in the advanced track. Similarly, 55% selected LA content and 45% selected calculus content, indicating a modest skew toward introductory LA material. Together, these distributions suggest that while the MCC primarily supports preparedness for graduate-level coursework, its content also attracts and serves students from diverse disciplines and training stages.

B. Engagement with Course Materials

To evaluate engagement with course materials, we analyzed Canvas activity data and certificate completion across course iterations. It is important to note that the MCC intentionally carries no grades, academic credit, or cost, and participation is not required, resulting in minimal external pressure to complete course components.

From 2023 to 2025, Canvas enrollment ranged from 85 to 137 students. Across all years, more than 90% of enrolled students were classified as "active" by Canvas, defined as engaging in at least one course-related activity such as viewing pages (**Fig. 2A**). Canvas enrollment numbers exceeded formal registration counts (**Fig. 1A**), as access to course materials was granted to additional students who requested participation after the initial registration period. Weekly page view data revealed high engagement during the first two weeks of the course, followed by a substantial decline in subsequent weeks (**Fig. 2B**). This pattern is consistent with the voluntary, pre-term nature of the course and the competing responsibilities faced by current and incoming graduate students during this period, including relocation, work, and other academic responsibilities.

Quizzes accompanying weekly modules were used to assess students' engagement with core mathematical concepts. Quiz submission patterns varied by year and subject area (**Fig. 2C**). In 2023, more calculus quizzes were submitted than LA quizzes, whereas in 2024 and 2025, LA submissions exceeded calculus submissions. This shift corresponds to changes in course structure: the 2022 and 2023 iterations began with calculus modules, while the 2024 and 2025 iterations began with LA. Finally, participant engagement was assessed using certificate completion rates, which ranged from 13% to 20% across years (**Fig. 2D**).

Engagement metrics indicate sustained interest in the MCC over multiple years, with consistently high levels of active participation despite the course's fully voluntary, self-paced structure.

C. Evaluating the Impact on Confidence in Math Skills

To evaluate the course's impact on confidence in the ability to solve math problems, we analyzed matched Likert-scale data from participants' pre- and post-course survey responses (**Fig. 3A**).

Before the course, two students reported "somewhat disagree" in response to whether they felt confident in their ability to be successful in their math-based coursework. Following the course, no students reported disagreement, and more students reported agreement with this statement, indicating increased confidence—a key outcome of this course. These findings align with the post-first-semester survey (**Fig. 5**). Students who did not join the MCC felt less confident in their math coursework ability. This suggests that early exposure to core mathematical concepts may support a more confident transition to graduate school. Qualitative data from the focus group reinforces these findings. Students emphasized that the MCC improved their familiarity with math concepts, with one student reporting: "*It was just nice to have even a familiarity of some of the terms.*"

While a nine-week course is insufficient time to cover all aspects of LA and calculus in depth, its primary goal was to provide students with a foundation for course-relevant materials. Another student described the course as helping to reengage with mathematical thinking after time away from formal coursework: "[It] *set a tone for how the math side of my brain works again, since it hasn't been used in so long*". Even students who felt confident in their skills reported a benefit: "*It's really helpful, even if you kind of feel confident just to build those skills back up*".

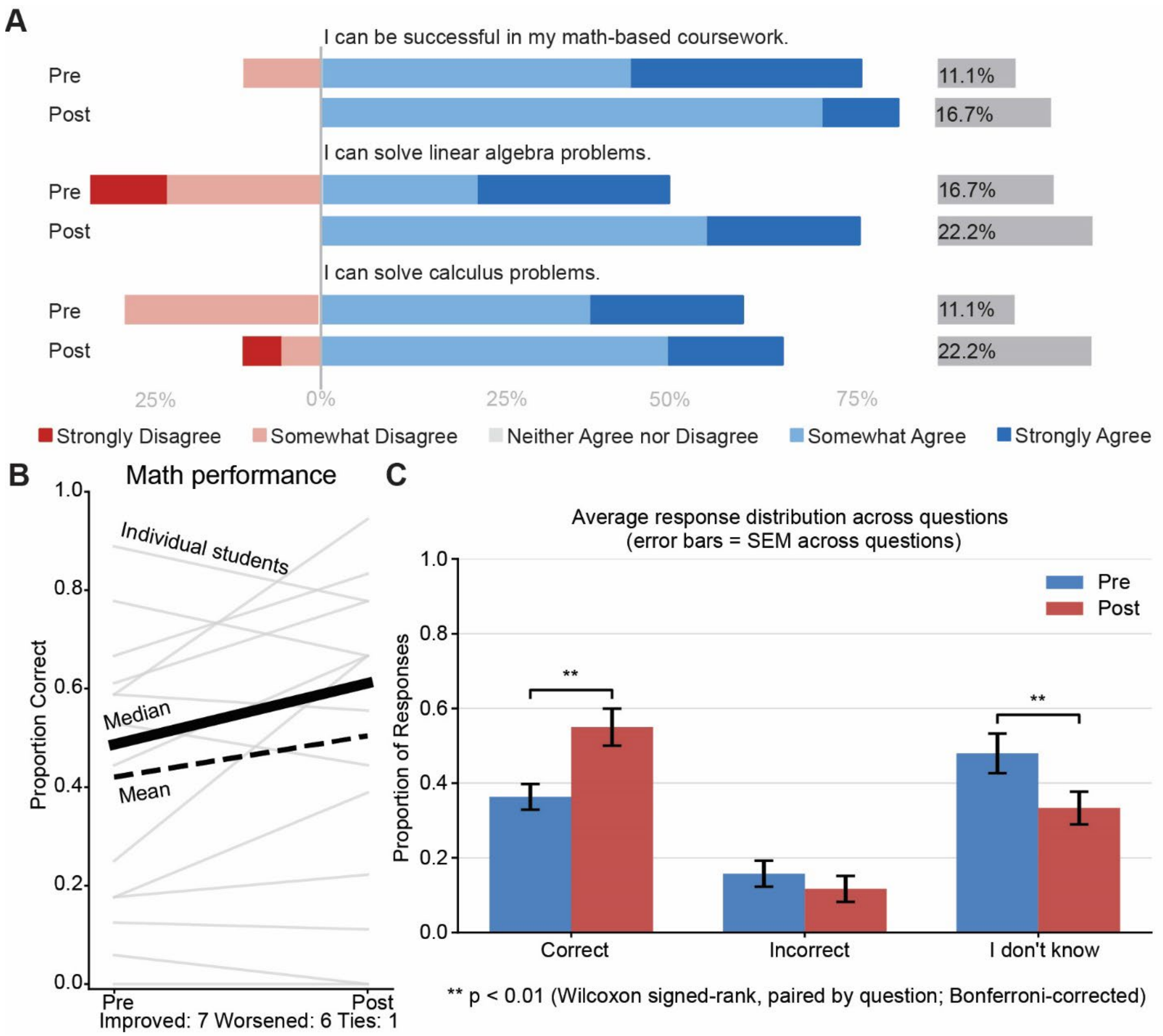

Figure 3: Mathematical confidence and performance. Matched pre- and post-survey results from students who completed both surveys (N=18). (A) Self-reported confidence in math-based coursework and in solving LA and calculus problems, assessed using a 5-point Likert scale. Following the Math Crash Course, responses shifted toward higher agreement. (B) Within-student math performance, quantified as the proportion of correctly answered LA and calculus questions per student. Individual trajectories are shown (gray), along with group mean (dashed) and median (solid). While group-level mean and median performance increased, individual changes were heterogeneous, and the paired Wilcoxon signed-rank test was not significant ($p = 0.15$). (C) Question-level response distributions across students, averaged across questions (error bars = SEM across questions). The proportion of correct responses increased and "I don't know" responses decreased significantly from pre to post (Wilcoxon signed-rank test, paired by question; Bonferroni-corrected $^{**}p < 0.01$), while incorrect responses did not change significantly.

Additionally, students were asked to evaluate their ability to solve LA and calculus problems. Before the course, a third of the students reported a "strongly disagree" or "somewhat disagree" response to the statement "I can solve LA problems", indicating that many participants enrolled to fill a mathematical knowledge gap. After the course, most students reported feeling confident in solving LA problems. Alternatively, in calculus, while the number of students who disagreed with the statement "I can solve calculus problems" decreased, some still felt unable to solve these problems. This may be explained by declining participation in the calculus course, leading to fewer students completing the materials. This is a consequence of a voluntary course, as students may not be able to complete it due to other commitments.

Overall, matched pre- and post-survey responses show a clear shift toward increased confidence in math-based coursework following the Math Crash Course, with no participants reporting decreased confidence after completion.

D. Evaluating the Impact on Math Performance

To quantitatively assess within-participant changes in performance following the intervention, we compared the proportion of correct responses for each participant on the pre- and post-surveys (**Fig. 3B**). At the group level, performance showed an overall upward trend: mean accuracy increased from 37% ± 29% to 51% ± 30% (Mean ± SD), and median performance increased from 25% to 61% correct responses. However, individual-level changes were heterogeneous. Seven students showed improved performance, six exhibited decreased performance, and one student showed no change. Consistent with this variability, a paired Wilcoxon signed-rank test did not indicate a statistically significant difference between pre- and post-survey performance ($p = 0.15$). A complementary sign test likewise showed no evidence of a systematic directional change across participants ($p = 1.00$). Given the small sample size and substantial inter-individual variability, these analyses were likely underpowered to detect within-participant effects.

To assess changes in performance at the question level, we compared response distributions across questions between the pre- and post-surveys. Across questions, the proportion of correct responses increased, while the proportion of "I don't know" responses decreased from pre to post intervention (**Fig. 3C**). To evaluate whether these shifts were systematic across questions, paired nonparametric tests were conducted at the question level. These analyses are descriptive in nature and complement the within-participant analyses by characterizing aggregate changes in question-level response patterns. Error bars denote the standard error of the mean (SEM) across questions. On average, correct responses increased from 36% ± 3% to 55% ± 5%, while "I don't know" responses decreased from 48% ± 5% to 33% ± 4%. The proportion of incorrect responses showed a smaller change (16% ± 3% pre and 12% ± 3% post). Paired Wilcoxon signed-rank tests across questions indicated a significant increase in correct responses ($p < 0.01$) and a significant decrease in "I don't know" responses ($p < 0.01$), whereas changes in incorrect responses were not statistically significant ($p = 0.20$). A Bonferroni correction was applied to account for multiple comparisons.

These results suggest that although within-participant performance changes were heterogeneous and did not reach statistical significance, the intervention was associated with a consistent shift in response distributions across questions, characterized by increased correctness and reduced uncertainty. This pattern is consistent with improved conceptual familiarity and confidence across topic areas, even in the absence of uniform gains at the individual level.

E. Evaluating the Impact on Student Life

To assess the impact of the MCC on student life, we evaluated Likert-scale responses to a subset of questions on belonging, self-efficacy, and scientific identity (**Fig. 4**). Overall, these responses indicate an increased sense of belonging and confidence among students post-intervention.

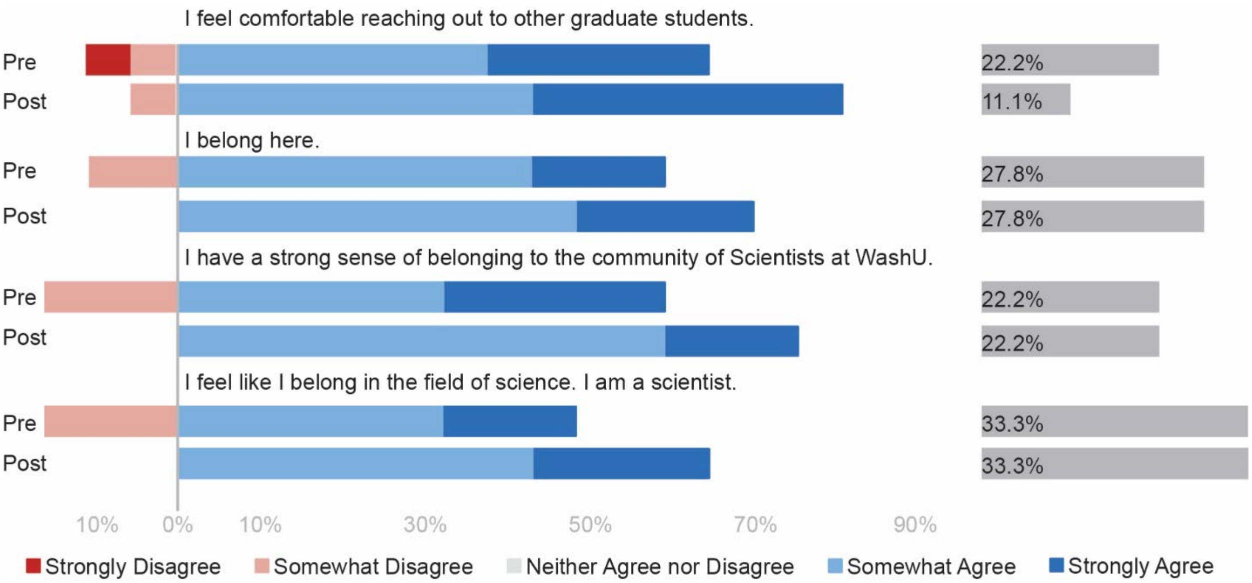

Figure 4: Pre- and post-intervention behavioral data. Matched pre- and post-survey results from students who completed both surveys (N=18). Students who completed the MCC reported an increase in feelings of belonging in graduate school, at WashU, and in the field of science. Students also reported increased feelings of confidence in their math-based coursework and ability to complete their degree programs.

One goal of the MCC was to introduce incoming students to the graduate student community prior to the start of the academic year, providing them opportunities to ask questions about coursework, research, and life as a graduate student at WashU. Consistent with this goal, pre- and post-survey responses indicated an increase in students' comfort in reaching out to other graduate students (**Fig. 4**). Students also reported a stronger sense of belonging within the broader scientific community at WashU. Establishing this sense of community and social peer network before the start of the fall semester promotes a smoother transition into graduate student life.

Qualitative data from focus groups with students who participated in the course support these findings. Students mentioned that using Discord felt more personal than using email, facilitating informal interactions throughout the course. Research talks by current graduate students were also cited as contributing to an increased sense of connection. Several students suggested that future iterations could incorporate additional activities to increase accountability and to strengthen peer relationships. When asked about the greatest takeaway from the Math Crash Course, one student remarked: *"I would say that the most important thing that I gained was probably the community aspect of it."*

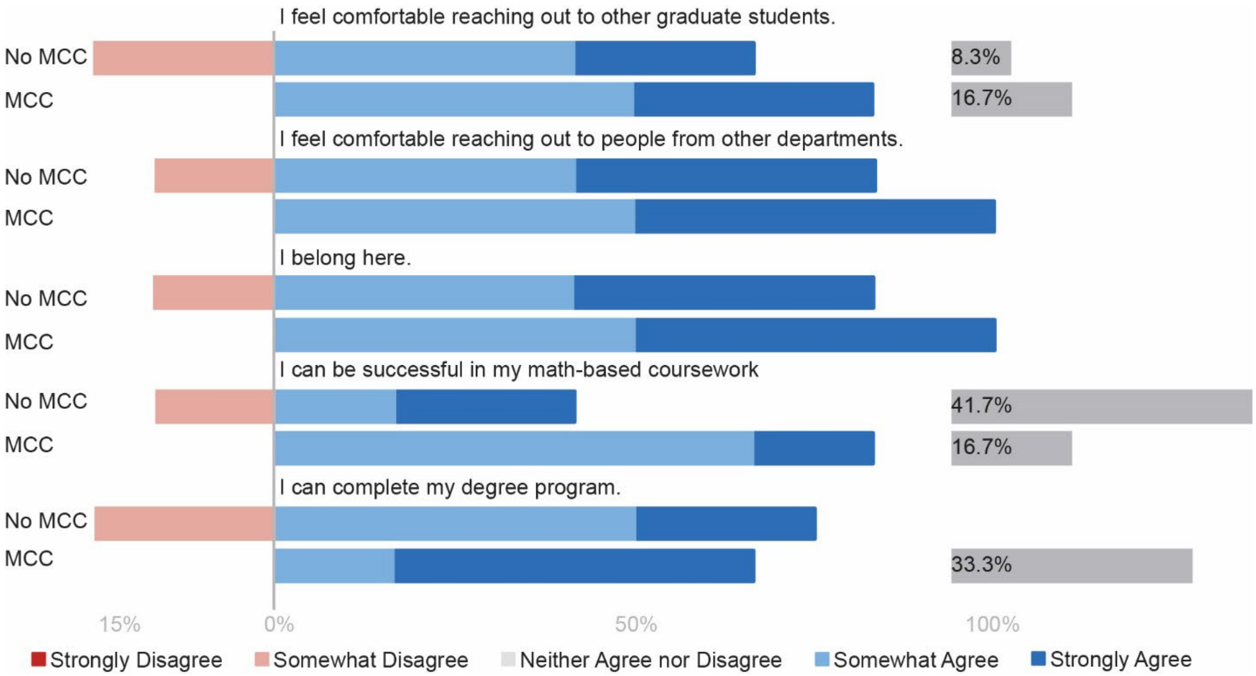

Figure 5: Post-first-semester survey. A Likert-scale survey assessing belonging, self-efficacy, and scientific identity was administered to students enrolled in a required first-semester Imaging Science graduate course. Responses were collected independently of the pre- and post- MCC surveys and were not matched at the individual level (N = 18 total respondents; N = 6 MCC participants). Students who participated in the MCC reported higher feelings of belonging, confidence, and comfort engaging with peers compared to non-participants, suggesting a lasting positive impact of early community-building and preparedness activities.

To examine longer-term effects, a post-first-semester survey was administered during one of the required first-year Imaging Science graduate courses. This survey assessed the sense of belonging, self-efficacy, and scientific identity among students who did and did not take the MCC (**Fig. 5**). Students who participated in the MCC reported greater comfort in reaching out to other students, including people from different departments. Given the interdisciplinary nature of Imaging Science and research in general, collaboration between different departments is crucial. Additionally, students expressed stronger feelings of belonging and confidence in completing their graduate degree program. Overall, these results demonstrate that students who participated in the MCC felt a greater sense of community compared to students who did not participate.

F. Professional Development through the Math Crash Course

In addition to benefits for the participants, the MCC also supported professional development for tutors and curriculum developers. Students who initially participated in the MCC often transitioned into tutor roles and, in many cases, into course leadership positions. Focus group data indicated that tutors experienced an increased sense of community, professional growth in teaching and communication skills, and a strong sense of ownership over the MCC. One tutor reported: "*Even as a tutor, I felt like being part of it gives you the feeling that you belong to a community.*" This sense of community is often a motivating factor for tutors and curriculum developers joining the team, and it drives each new iteration of the MCC. Having recently completed its fourth iteration, the course has become a cornerstone of the Imaging Science community. This was a driving factor for a tutor who reported: *"I just wanted to participate and be part of the bigger imaging science community."*

As a student-led initiative, tutors and curriculum developers feel a strong sense of ownership over the materials. This sense of ownership is crucial and drives improvement in each iteration, as feedback from engineering graduate students is carefully integrated into the course. Students from previous MCC iterations often join the team to implement their feedback and give back to the community. When asked whether they would recommend being a tutor to a friend, one tutor reported: "*It's our course to lead. That's also a motivation to ask people to join this team.*"

Tutors and curriculum developers also develop professionally by gaining hands-on experience in teaching and course development. These skills are beneficial to students looking towards careers in academia, with one tutor reporting career exploration as a reason for joining the team: *"I wanted to explore my career in academia and teaching."* After the course, tutors reported feeling more confident in teaching mathematical concepts and a deeper understanding of LA and calculus through instruction. Participation in the course development provided hands-on experience with curriculum design, delivery, assessment, and iterative improvement of course materials. Overall, the professional development experience left one tutor remarking: "*After that experience, I felt like I could relate a bit more with the faculty in WashU.*"

TABLE I

Professional Development Pipeline. 4 stages define the professional development of students transitioning from course attendees to curriculum developers.

Stage	**Role**	**Goal**	**Impact**
1	Incoming Student	Fulfill or refresh gaps in math knowledge and integrate within a like-minded community	Reduce initial course catch-up time and stress
2	Course Participant	Gain understanding of and confidence in foundational LA/Calc courses through modules, tutoring sessions, and social interactions	Reduce cognitive barrier and establish peer connections
3	Graduate Tutor	Deliver instruction and provide feedback to incoming students. Build better mentoring skills	Mentored teaching experience and team building
4	Curriculum Developer	Iterate on course design, build assessments, and gain experience in management/administration	Experience in academic leadership

A standout feature of the MCC is its capacity as a long-term professional development pipeline (**Table I**), transforming incoming students uncertain about their mathematical ability into curriculum leaders through a four-stage process within a sustainable, student-led ecosystem. This progression is driven by the fact that tutors navigate the same curriculum as their students and have a unique understanding of the specific preparedness gaps their peers face when participating in the course. By Stage 4, participants reported feeling a stronger sense of community, an increased ability to relate with "faculty in WashU", bridging the gap between student and professional academic roles. This pipeline structure is reflected quantitatively in the composition of the instructional team. In 2023, 2024, and 2025, former MCC participants comprised 30%, 73%, and 67%, respectively, of the combined team of tutors and curriculum developers (team size: 10 in 2023; 15 in 2024 and 2025). In addition, there was intentional overlap between curriculum developers and tutors, which increased over time (2023: 17%, 2024: 40%, 2025: 58%). This design ensured that tutoring sessions were closely aligned with the curriculum while allowing curriculum development to be continuously informed by direct interactions with students. Together, these structures support a feedback loop in which instructional content, tutoring practices, and student needs mutually reinforce one another.

Collectively, these findings highlight that the MCC is not only a preparedness intervention for incoming students but also a sustainable, student-led initiative that fosters community, professional development, and shared ownership within the Imaging Science program.

V. Discussion

A. Limitations

Several limitations should be considered when interpreting these findings. Participation in the MCC was entirely voluntary, which may introduce self-selection bias toward students who are more motivated, proactive, or concerned about their preparedness. As a result, outcomes may not generalize to students who are less inclined to engage in optional preparatory activities. The sample sizes for matched pre- and post-survey analyses were modest, limiting statistical power for detecting within-student performance changes.

While individual gains in math performance were not statistically significant, the results suggest that the MCC functioned as "course-primer" rather than a traditional mastery-focused course. The most significant shift was the decrease in "I don't know" responses from 48% to 33% ($p < 0.01$). This reduced uncertainty, combined with the significant increase in correct responses, serves as evidence of lowered cognitive barrier. Over the nine-weeks, students re-engaged with mathematical thinking and established a baseline familiarity with the presented concepts. When students encounter these topics in their graduate curriculum, the material presents as a familiar framework in need of further exploration rather than a source of novel stress. This is evidenced by the post-first-semester survey, where MCC participants maintained higher levels of confidence than non-participants. This pattern mirrors findings from another short-duration math preparedness intervention for incoming chemistry graduate students, in which gains in confidence and self-efficacy were more pronounced than changes in objective performance [25].

The discrepancy between total enrollment (N=137) and survey respondents (N=18) may also introduce potential selection bias. This 13% response rate could suggest that this sample represents a "highly motivated" outlier group whose completion of optional assessments reflects an above average level of engagement. However, the demographic split between beginner and advanced tracks in the sample mirrors the trend in overall registration, suggesting that these respondents remain representative of the overall program demographics.

B. Future Considerations

Guided by four years of implementation data and participant feedback, several refinements are considered for future iterations of the Math Crash Course. We plan to shorten the course to a six-week format, emphasizing four weeks of LA and two weeks of advanced calculus concepts. This modification reflects the observed decline in engagement over the summer months and aligns with the structure of comparable preparedness programs, which are typically substantially shorter (e.g., Neuromatch Academy: 3 weeks [20]; NeuroHackademy: 2 weeks [21]; math preparedness programs for chemistry graduate students: ~1 week [25]; economics PhD math bootcamps: typically 3-5 weeks [22], [24]). While LA concepts are broadly applicable across disciplines, advanced calculus topics such as convolution and the Fourier Transform remain critical to engineering applications. Additionally, differentiation and integration typically do not require extensive review for many incoming engineering students. To simplify the course structure, future iterations will streamline participation pathways into a single 10-hour-per-week track.

Focus groups proved to be an especially valuable source of actionable feedback, and we plan to formalize these sessions as a recurring component of course evaluation. In response to student suggestions, future versions of the MCC should incorporate light gamification, such as team-based participation and progress dashboards, to encourage sustained engagement in a voluntary learning environment. Additionally, structured peer-interactions could be strengthened through assigned study groups or "study buddies" to promote accountability, normalize help-seeking behaviors, and further support community building. Together, these changes would balance academic preparedness with motivation and social integration, while improving scalability and accessibility for diverse student populations. Collectively, these refinements reflect an intentional shift toward a shorter, more focused, and community-driven preparedness model that can be readily adapted to other interdisciplinary graduate programs.

To better understand the longitudinal effects of the intervention and increase participation rates, the post-first-semester survey could be supplemented with an earlier survey in the first semester. Additionally, surveys could be distributed to other first-semester engineering courses to capture a larger cohort. Offering compensation for participants' time can also incentivize students to participate in surveys.

VI. Conclusions

Here, the goal was to develop and implement a teaching intervention to prepare incoming engineering graduate students for the rigorous mathematical coursework and to introduce them to the WashU community. Over the past four iterations, this goal has been met as the MCC is now a cornerstone of the Imaging Science PhD program. In the 2025 iteration of the course, we quantified the benefits of the MCC through pre- and post-course survey materials, focus groups, and a post-first-semester survey in a core engineering course. While engagement with course materials dips during the first weeks of the course, students who did engage showed a marginal improvement in math skill and a strong improvement in their sense of belonging. Results demonstrate a clear increase in math confidence and preparedness (**Fig. 3**) and a stronger sense of belonging in the WashU community (**Figs. 4–5**). This increase in confidence has downstream effects on students' well-being and mental health [8]. Along with the students, MCC tutors and curriculum developers similarly reported feeling more connected to the community and gaining professional development skills through the MCC. These feelings of community and belonging are shown to influence doctoral students' success [18].

Consistent with our definition of interdisciplinary diversity as variation in educational trajectories and disciplinary training, the MCC engaged students from a wide range of academic backgrounds, including substantial participation from non-engineering departments. This heterogeneity in prior training underscores the importance of structured support for foundational mathematics in interdisciplinary graduate programs.

Beyond the current implementation, this initiative establishes a replicable framework for a student-driven academic support program that can be adapted across disciplines and institutions. The Summer Math Crash Course has undergone four iterative implementations with continuous refinement based on student and instructor feedback and has become a sustained component of the engineering academic community at Washington University in St. Louis. To support broader adoption, all course materials are openly available upon publication. Together, this structure lowers the barrier for implementation at other universities and provides a scalable model for improving foundational mathematics access for students from diverse academic backgrounds.

Overall, this student-led MCC stands in contrast to traditional, faculty-driven courses by facilitating peer-to-peer interactions and encouraging community involvement.

VII. Acknowledgments

We thank all contributors to the course, including founders, curriculum developers, tutors, and advisors. Their roles are detailed below.

Course founders: Wiete Fehner, Morgan Fogarty, Ty O. Easley, Sung Min Park, Nischal Khanal. *Course Leadership:* Wiete Fehner, Morgan Fogarty, Ty O. Easley, Sung Min Park, Nischal Khanal, Sanskar Thakur, Mahshid Naghashzadeh, Suraj Khochare, Kweku Enninful, Kathleen Duncan, Calvin Foss, and Ahmad Shafiullah. *Curriculum Development:* Wiete Fehner, Morgan Fogarty, Ty O. Easley, Sung Min Park, Nischal Khanal, Sanskar Thakur, Mahshid Naghashzadeh, AJ Adkins, Braden Yang, Kweku Enninful, Yuanxin Qiu, Kathleen Duncan, Calvin Foss, Suraj Khochare, Ahmad Shafiullah, Ahmad Chowdhury, Yash Thacker, Jiantao Zhu, Sanjida Ali, Jason Trobaugh, Christine M. O'Brien, and Matthew D. Lew. *Tutors:* Wiete Fehner, Ty O. Easley, Sung Min Park, Nischal Khanal, Mahshid Naghashzadeh, Sanskar Thakur, Kathleen Duncan, Calvin Foss, Ahmad Shafiullah, AJ Adkins, Braden Yang, Flora Sun, Kweku Enninful, Yuanxin Qiu, Ahmad Chowdhury, Suraj Khochare, Uttkarsh Chaurasia, Yash Thacker, Jiantao Zhu, Sanjida Ali, and Puja Ghosh. *Mentorship and Faculty Advisors:* Joseph P. Culver and Joseph A. O'Sullivan. *Course Assessment Lead:* Emily Boyd.

We also thank Abhinav K. Jha for his help with the post-first-semester survey. This project was made possible by an active and engaged community, and we are deeply grateful for their dedication and effort. We acknowledge funding support from WashU through the McKelvey School of Engineering and the Mallinckrodt Institute of Radiology at the School of Medicine.

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