Graduate Program Handbook 2019-2020
Mathematics Department Brandeis University

The Brandeis Mathematics Graduate Program provides instruction leading primarily to a Ph.D. in Mathematics. The program also offers a Master of Arts degree in Mathematics. The purpose of this handbook is to provide more program details than are included in the Math Bulletin. It is meant to complement various other sources which apply more broadly to all students at Brandeis University (e.g., the Brandeis University Bulletin, the Rights & Responsibilities Handbook, and information on Disabilities Services and Support) or to students in the Graduate School of Arts and Sciences (e.g., the GSAS Student Handbook and Handbook for Teaching Fellows). Please make sure you read the Bulletin carefully:

- GSAS: https://www.brandeis.edu/registrar/bulletin/provisional/gsas.html
- Math: https://www.brandeis.edu/registrar/bulletin/provisional/courses/subjects/4700.html

This handbook will answer many, but probably not all, of your questions. Further questions about the graduate curriculum and requirements should be directed to the Graduate Advising Head (GAH), Olivier Bernardi or to the interim GAH, Dmitry Kleinbock, during the spring/summer semester 2019. For issues related to undergraduate teaching, consult the Elementary Mathematics Coordinator, Becci Torrey. Concerning non-academic matters such as office assignments, see the Mathematics Department administrator, Catherine Broderick. For academic paperwork and stipend information, see the Grad Affairs Office Academic Administrator, Emily Palmer.

1. The Ph.D. program

Students working towards a Ph.D. in mathematics form the core of the department's graduate program. In order to earn the degree, a student is required to write a dissertation demonstrating significant original research. Accomplishing this typically requires mathematical maturity and expertise well beyond the bachelor's degree. The aim of the Ph.D. program is to provide the necessary background and train students to become successful researchers. Most of the department's Ph.D. recipients pursue academic careers, and many are leading mathematicians. The program begins with required courses on fundamental material. Students then move on to more advanced courses, including reading courses that develop breadth and depth of understanding. To be an enrolled, full-time student, the student must be registered for 12 credits every fall and spring semester. If students would like a course outside the Brandeis math department to count towards your requirements, this requires written approval of the Graduate Advising Head.

By the end of their second year, students should select a dissertation advisor and, by the end of their third year, students should complete their major exam. Students are encouraged to complete their minor exam in their second or third year but must pass it no later than their fourth year. The major exam initiates the stage in which students focus primarily on thesis research under the supervision of their thesis advisor. Students also go through a teaching apprenticeship program which trains them to become effective teachers and each student is required to teach their own section of pre-calculus or calculus for at least four semesters. Ph.D. students making satisfactory progress towards their degree are ordinarily given five years of funding, including a full tuition scholarship, health insurance and a stipend, so that they can focus on their studies and research.

1.1. **The first-year program; required courses**. Our first-year program is devoted to building a strong mathematical foundation.

All students are required to master the material of the following four core courses: Math 131a (Algebra I), Math 141a,b (Real and Complex Analysis), and Math 151a (Topology I). In addition, students are required to take at least three of the following seven courses: Math 131b (Algebra II), Math 140a (Geometric Analysis), Math 151b (Topology II), Math 161a (Advanced Bifurcation Analysis), Math 162a (Numerical Methods), Math 16XX (Probability), and Math 16XX (Partial Differential Equations). Syllabi for all of these courses except for the last three are included as Appendix B. The last three courses are in the process of being approved or developed; the department plans to start offering them on a regular basis within the next two academic years from now.

Each student is responsible for mastering the material in these courses. This requirement can be fulfilled in one of two ways:

> (1) Take the course and earn a satisfactory grade (officially B- to A+, but grades in the B range are often signs of trouble).
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> (2) Place out of the course by demonstrating a thorough understanding of the "core topics" in the syllabus. This must be done during the first two weeks of the semester in which you want to place out of the course. The placement exam (which may be written or oral) is usually given by the faculty member who most recently taught the course. This year's examiners are listed in Appendix A. The Graduate Advising Head may also grant exemption from the course on the basis of evidence of having excelled in a similar course at another university. Students who place out of required courses are expected to take more advanced courses during their first year (see §1.2.1 below).

The usual practice, which assumes a strong undergraduate preparation, is to take 131a, 141a, and 151a in the first semester, and 141b and one or two of the seven courses above in the second semester. The remaining required courses are typically taken in the first semester of the second year. There are regular homework assignments in all these classes and most students find the workload heavy. You may find it useful to work together with your classmates.

It is department policy that to continue in good standing you must pass at least two out of the required courses each semester during your first year. If you do not, or if your performance in these courses is judged inadequate, you will be asked to withdraw from the program or warned that failure to improve your performance will result in your withdrawal (see §4.2).

In addition to taking required courses, first-year students are given grading assignments for undergraduate courses and are asked to participate in the department's evening tutoring program, which serves undergraduate students taking pre-calculus and calculus. In preparation for teaching in their second year and beyond, most graduate students participate in the Teaching Apprenticeship Program in the spring of their first year. Students whose native language is not English may be required to participate in the university's ELP (English Language Program) (see 1.4).

1.2 The second and third years; coursework, qualifying and language exams, residency requirement, Master's degree. In general, the second year is the time to finish up the course requirements and begin teaching. Students should also begin taking more advanced courses, including reading courses, and working on their major and minor qualifying exams. If students

are teaching in the fall, they take a Teaching Practicum. By the end of their second year, students should have selected their advisor and completed their language exam (they may also complete this in their third year). By the end of their third year, students should have completed their major exam.

1.2.1 Coursework. In addition to completing any of the seven remaining required courses, second year students must take the "Second Year Seminar" (Math 200a) in the spring semester. This course is less demanding than a lecture course, and is intended as a vehicle for students to gain experience reading research articles and giving talks. The idea is for each student to present a topic as one would in a research seminar. The material is chosen by the student in consultation with the instructor (usually the Graduate Advising Head), and should be taken from journal articles or preprints as opposed to textbooks. The talks should be understandable to the others in the seminar, so the speaker should not assume background beyond the required courses. The speaker can expect a lot of questions and discussion from the audience, as well as advice and feedback on the lectures from the instructor.

In addition to taking more advanced courses, students should begin taking reading courses in their second year. Reading courses are arranged with a professor by an individual student or a small group of students interested in a topic not covered in a standard lecture course. These courses are an essential part of the Ph.D. program and serve several purposes. They allow students to broaden the scope of their studies, develop independence, explore possible thesis areas in depth, and get to know possible advisors. They are also a vehicle for preparing for major and minor exams.

Students also begin attending departmental seminars more often in their second and third years (see 3.1).

Students in their third year are typically ready to commence on their dissertation. Once they have a precise timeline for taking the major exam, they can register for 12 credits of 401D Dissertation Research. We strongly encourage them to enroll in an additional course.

1.2.2 RCR Workshop. All Ph.D. students are required to take the Division of Science Responsible Conduct of Research (RCR) workshop. You should expect to receive an email asking you to sign up for this workshop; all second-year students should sign up for this workshop. For more details, please go here: http://www.brandeis.edu/ora/RCR/index.html.

1.2.3 Qualifying exams. The qualifying examination consists of two parts: a major exam and a minor exam.

The major exam is intended to lay the foundation for your thesis research. For this exam you and your thesis advisor will select an examination committee consisting of three faculty members, one of whom should be your advisor. The committee must be approved by the Graduate Advising Head. The exam should be taken by the end of the third year and will consist of an oral presentation of a research area which is likely to be your thesis topic. During the presentation, you should explain your field of study and some key research questions you intend to explore in your Ph.D. thesis. You should demonstrate a deep understanding of the key results in your field, as well as lay a realistic plan of research. If possible, the presentation should include some precise open questions you intend to tackle and some preliminary results.

At least a week before the major exam takes place you need to provide a short document to the three examiners summarizing your plans for your dissertation. This document, between 1 and 3

pages in length, should contain the abstract of your presentation, the field of research, the main references and possibly an indication of some open questions or preliminary results which could be the basis of your dissertation (of course, this document is in no way binding, as your research may continue to evolve and expand over the subsequent years). Once a date has been decided, the student should email Emily Palmer in the Graduate Affairs Office (scigradoffice@brandeis.edu) with the date and time so that a room can be reserved.

The dissertation advisor must give his/her approval for the major exam to take place, and in particular you need to have chosen your advisor and field of research well ahead of the exam (preferably, during the 2nd year). At the end of the exam, the committee will write a report for the student to review. In case the jury is not satisfied with the presentation, the major exam can be retaken once, but no later than the first semester of the 4th year.

The minor exam is intended to provide some additional breadth of your math education. For that exam, you choose an area of mathematics and ask a faculty member, who should not be your thesis advisor but could be a member of the major examination committee, to be your examiner. The minor exam needs to be taken no later than the end of the 4th year, but students are encouraged to pass it in their second or third year. It needs to be on a topic which is distinct from your main thesis research, though it can be related or have applications to it (for example, number theory and *K*-theory). For students in their 2nd and higher years who have not completed their minor exam, the Graduate Affairs Office will send a Google form at the beginning of each semester. Please complete the form to indicate whether you are planning on taking a minor exam and with which examiner during the semester.

There are two typical types of work who would qualify as a minor exam. First, you may enroll in any of the graduate elective courses and make an agreement with the faculty member teaching the course that it will be the vehicle for your minor exam. In addition to the course work, you will meet occasionally with the examiner to discuss your progress, and you will present a talk on the topic of the course, either in class or at a departmental seminar. At the end of the semester, the examiner will administer an oral exam on an additional topic related to the course. The second option is that you enroll in a reading course (numbered 299 or 399) with the examiner. In this option, you will also present a talk on the topic of the reading course, and the examiner will administer an oral exam.

At the completion of either exam, the committee chair (examiner) will fill out a form certifying that you have passed. As soon as you have completed the exam, please turn in the form with the correct date to the Graduate Affairs Office. If the exam needs to be retaken, the student should submit a new form once the exam has been taken and passed.

1.2.4 Language exam. Students typically complete their language exam in their second year but may also complete it in their third year. Students are required to have some knowledge of French, German, or Russian, for which the requirement is to be able to read mathematical literature in that language without difficulty. The department designates an examiner each year for each of these languages. The exam should be scheduled with the designated examiner, and may be retaken several times without penalty. To pass the exam, you will need to translate a page of a mathematical paper or text in the language. To prepare for the exam, you should first acquire some basic skill in the language, and then read some mathematical texts carefully in an area of interest to learn the mathematical terms. The language examiner can provide suggestions for practice texts. You can also audit Brandeis undergraduate language courses, or take courses given by the graduate school tailored for graduate language exam preparation.

1.2.5 Residency requirement. The minimum academic residence requirement for the Ph.D. is three years.

1.2.6 Master's degree. Students who have successfully completed the seven required courses (see section 1.1) plus one other MATH course numbered 130 or higher (which may be a reading course) and have been in residence for at least 1 year are eligible for a Master's degree, and are encouraged to apply for it, without charge (see 2).

1.3 The fourth and fifth years, the thesis, applying for jobs. The emphasis in these years should of course be on finishing your thesis. Students should make significant progress on their theses in their fourth year. Exceptional students will complete their theses and graduate in four years. A student's final year is devoted primarily to writing up the thesis, applying for jobs and making the transition from a graduate student to a mathematician working in academia or in industry.

1.3.1 Time-to-degree. Students are required to spend at least three years in the program in order to be eligible for a Ph.D. Students may file an application with the Graduate School to have up to one year of graduate work at another institution applied towards their Ph.D. Some students finish in four years; most take five. Occasionally students take an extra semester or more. Scholarships, health insurance and stipends are guaranteed through year five for students in good academic standing. Support beyond the fifth year is granted only under exceptional circumstances. (See 4.3.)

Students who have maintained good academic standing but have not completed the Ph.D. by their fifth year may continue to work towards the degree. A total of up to eight years are allowed; students requiring more time can apply for an extension.

1.3.2 Coursework. In addition to enrolling in 12 credits of 401D Dissertation Research course with your advisor, you are encouraged to attend seminars; fourth-year students are also encouraged to take one lecture course a semester, usually a "topics" course. While it is important to focus on your thesis problem, is also important to continue developing perspective and breadth in mathematics.

1.3.3 The thesis. A Ph.D. dissertation is an original and substantial piece of research. The thesis topic might be suggested by your advisor, or it may be your own choice approved by your advisor. While you are likely to work closely with your advisor, the research must be primarily yours in both ideas and details. The advisor's role is to advise, to listen to your ideas and provide feedback, to point you to relevant literature and, occasionally, to suggest possible approaches when you are stuck.

A student is sometimes interested in working with a mathematician at another university (for example, Harvard or MIT). If that person agrees to act as your advisor, you must also have an official advisor at Brandeis who monitors your progress.

1.3.4 The defense. Your dissertation examination committee will be at least three faculty members, approved by the Graduate Advising Head. Your advisor is the chair of the examination committee and will help choose the other members. One committee member must come from outside the department. This is usually a mathematician at another institution, but it can also be a Brandeis faculty member from another department (for example, physics or computer science). You then need to coordinate the scheduling of the thesis defense with your committee and our Academic Administrator, Emily Palmer, in the Graduate Affairs Office.

Copies of your thesis need to be given to the examination committee at least two weeks before the defense date. During the defense, you should give a short lecture (40–50 minutes) explaining the results in your thesis, and be prepared to answer questions about it. After the exam, the committee deliberates in private before informing you of the outcome.

In the unlikely event that there are serious problems with the thesis, the committee is expected to identify them before the defense. In that case the defense would be rescheduled after the problems are resolved. It is not unusual, however, for the committee to request minor corrections to the thesis. If the committee requests substantial revisions, then these must be completed and approved within six months or another defense is required.

At the beginning of the semester in which you defend, you should be in close contact with our Academic Administrator in the Grad Affairs Office, as well as with the International Students and Scholars Office (ISSO) if you are an international student. The Academic Administrator will review with you important deadlines regarding your dissertation, health insurance and stipend end date. You will also want to hand in ALL forms to the Grad Affairs Office before you take them to the Registrar or Graduate School in Kutz. Please see Appendix E for additional information.

1.3.5 The job search. Most of our students go on to successful academic careers after graduating, though some pursue non-academic careers. Be warned though that the application process can be time-consuming and emotionally draining.

Most application deadlines for academic jobs are between mid-December and mid-February, so you should begin working on your application in the fall of your final year. Job listings for most academic positions in the US and Canada are posted on the American Mathematical Society website at http://www.ams.org/eims/ as well as at http://www.mathjobs.org/. The latter website can be used to apply for jobs.

Most institutions request a description of your research, a curriculum vita (a brief academic version of a resume) and at least three letters of recommendation including one that specifically addresses your teaching skills. Some places ask for a statement of teaching philosophy as well. Your advisor will help you decide who to ask for research letters, and the Elementary Mathematics Coordinator usually writes a teaching letter. The application materials should be uploaded to http://www.mathjobs.org/ or mailed directly to those departments which do not advertise there.

Do not underestimate the importance of demonstrating your teaching ability to potential employers. It is the most important factor when applying for jobs at most small colleges. It is also a major factor in hiring decisions in departments that emphasize research. It is even a significant factor when applying for non-academic jobs since it reflects on your communication skills. An outstanding teaching performance as a graduate student translates into strong teaching recommendations and student evaluations. The department provides excellent training and support to help you improve your teaching skills (see 1.4), but successful teaching requires a serious effort on your part as well.

Some students pursue non-academic careers (e.g. in finance, data science, computer science) after graduating. In addition to seeking advice from faculty and alumni, we highly recommend creating a Brandeis Handshake account (Brandeis's equivalent of LinkedIn) and making an appointment with the Brandeis GSAS Center for Career and Professional Development. The Center provides one-on-one coaching on interviewing, networking, resumes and CVs. During

the semester, we recommend reading postings on Handshake and emails about career-related networking events, such as data science or computer science job fairs. For more information, please visit our website: http://www.brandeis.edu/mathematics/graduate/resources/career-tips/index.html

1.4 Teaching. Teaching is an integral part of the doctoral program in mathematics, as it will be in the career of most mathematicians. All mathematics Ph.D. students are expected to teach a section of calculus or pre-calculus for at least four semesters, usually beginning in their second year of study. The department provides each student with extensive training before beginning to teach, and ongoing advice and support when the student is teaching. The valuable training and experience in teaching is an important asset in the academic job market (see 1.3.5). There is a departmental Teaching Prize awarded each year in appreciation for dedication and skill in teaching mathematics.

The Elementary Mathematics Coordinator is the faculty member who oversees graduate student teaching of calculus and pre-calculus.

Students interested in designing and teaching upper-level undergraduate courses are encouraged to apply for a University Prize Instructorship (see 3.6).

Students should consult the GSAS Handbook for Teaching Fellows https://www.brandeis.edu/gsas/current/tf-resources/handbook/index.html for general information about graduate student teaching at Brandeis.

A few students are hired by the university each summer to teach undergraduate courses. Among eligible students who wish to do this, priority is given to those who have taught least in previous summers. Summer teaching does not count towards the teaching requirement. Students who wish to teach outside Brandeis while supported by Brandeis must get approval from the department.

1.4.1 Teaching Apprenticeship Program. First-year students do not teach, but are expected to focus on the required courses and the adjustment to life as a graduate student. They are also required to grade for one undergraduate course per semester, and tutor one to two evenings per week in the department's drop-in tutoring program for students in pre-calculus or calculus. (They are paid for tutoring.)

In the spring of the first year, most first-year students participate in a three-week Teaching Apprenticeship Program. This program pairs each new student, the apprentice, with one who is currently teaching, the "coach"; the apprentice first visits several of the coach's classes, and then—working closely with the coach at each step—teaches three of his or her classes. The program is supervised by the Elementary Mathematics Coordinator.

Some students may not be ready for the Teaching Apprenticeship Program in their first year. Those whose native language is not English may need to focus on improving their English skills instead (see 1.4.5).

Students who complete the Teaching Apprenticeship Program may need to improve their teaching skills further before they are ready to teach their own section of pre-calculus or calculus. In that case, they participate in an extended apprenticeship program until they are ready.

1.4.2 Teaching responsibilities. Students usually begin teaching their own sections of calculus or pre-calculus in the fall of their second year. Graduate student instructors work closely with the faculty member overseeing the course (usually the Elementary Mathematics Coordinator), but nonetheless each graduate student has full responsibility for his or her section; this means preparing lectures, writing and grading quizzes, holding office hours, and participating in the writing and grading of common exams. The Elementary Mathematics Coordinator is available to graduate students who have questions about teaching or who are trying to improve their teaching skills.

Every attempt is made to equitably distribute teaching duties and provide all students with adequate training and experience. Most students will teach each semester during their second and third years, so that they will teach a total of four semesters. Students who are not ready to teach in the fall of their second year will end up doing more teaching in their final years of graduate school. There are typically fewer sections of calculus taught by graduate students each spring semester than there are graduate students who are eligible to teach. (Students are eligible to teach if they have successfully completed the Teaching Apprenticeship Program, are enrolled with Resident or Post-Resident status, and are not restricted from teaching by an outside funding agency.) Students who have already taught the most semesters are given the first opportunity to opt out of teaching that semester. Among those who have taught the same number of semesters, students enrolled the longest are given priority. Ties are then broken by drawing straws. Students who are not teaching assist by grading undergraduate courses that semester. Final decisions on teaching assignments are made by the Elementary Mathematics Coordinator and the Graduate Advising Head.

1.4.3 Teaching Practicum. During the fall semester of each year, all graduate student instructors enroll in a Teaching Practicum (204a) to work on their teaching skills. As part of the course, the practicum instructor observes the classes taught by graduate students, evaluates their teaching performance and provides advice to improve their teaching skills. The Teaching Practicum also provides a few mandatory workshops on teaching skills, pedagogy, innovations or concerns.

1.4.4 Mandatory training. All new instructors and course assistants are required to attend the TF Orientation run by GSAS at the beginning of the fall semester. Most math graduate students will attend this at the beginning of their second year, right before they start teaching. All instructors, course assistants, graders and evening tutors are required to participate in Title IX training. Currently this might be fulfilled by attending the TF Orientation, but the University and/or GSAS may mandate additional training.

1.4.5 The ELP program. The university's English Language Program (or ELP) program helps one do this. All students from other countries (with the exception of students from or who have completed a degree in Australia, Canada, Ireland, New Zealand, South Africa, the US and the UK) will be required to take an English language exam during orientation. Based on these exam results from Brandeis's English Language Program, students may or may not be required to take ESL courses. If a student is required to take ESL courses, the Graduate Advising Head and Elementary Mathematics Coordinator may decide to postpone teaching while the student completes ESL courses. If you are asked to take an ELP class, then attendance and participation are required in order to maintain good academic standing, and a passing grade is a university requirement for graduation.

1.5 Grading. Students who are not teaching assist by grading one undergraduate course per semester. Graduate students graders are expected to grade homework for a class and may be

asked to grade midterm exams as well. In large classes, they may also help the instructor in grading the final exam or proctoring the midterms or final; however, the primary proctor (a TA or instructor) should be responsible for answering content questions during the exam. It is also expected that the students will hold two office hours per week. Students cannot be hired as graders for a course in which they are the TF.

1.6 Graduate Student Union. For more information on the services offered by the union and to read the union contract, please go here: https://www.brandeis.edu/gsas/current/union-information.html

1.7 Half Teaching Assistantships. The math department hires graduate students as half teaching assistants (half-TAs) for some large undergraduate courses. These jobs are in addition to usual responsibilities (e.g., teaching or grading) and are compensated separately (not included in the stipend). The current rate is $ 1775 per course for a half-TA, which has a work expectation of 5 hours per week over the semester. TA responsibilities vary based on the needs of the instructor and the course, but can include things like: attending class; holding office hours and/or recitations and/or review sessions outside of class; helping grade quizzes and exams; helping to proctor quizzes and exams; answering questions online; helping to write quizzes, exams, worksheets, review material (e.g., contributing problems). When half-TAing, you will receive a letter from the Graduate School outlining your pay and responsibilities.

1.8 Boston Area Graduate Consortium. It is possible for Brandeis graduate students to cross-register for mathematics courses at Boston University, Boston College, and Tufts. Graduate students should check with their advisor and the Graduate Advising Head before cross-registering for courses. For information on cross-registering, see http://www.brandeis.edu/gsas/students/cross.html. Graduate students sometimes sit in on courses at Harvard or MIT, but it is not possible to formally cross-register for these courses.

1. The Master's degree

The mathematics department also admits a few students working towards a Master of Arts degree in Mathematics in preparation for a non-academic career or for eventual admission to a Ph.D. program. A limited amount of financial support is available to Master's degree students through the Graduate School of Arts and Sciences (see 4.3).

In order to earn a Master's Degree, students must pass with a satisfactory grade (B- to A+) the seven required courses (see 1.1; syllabi are in Appendix B) and one math elective course numbered 130 or higher. With the permission of the graduate advisor, a student with superior preparation may omit one or more of these required courses and elect higher-level courses instead. In this case, the student must take an examination in the equivalent material during the first two weeks of the course. Master's students must also be in residence for at least one year.

These requirements are ordinarily fulfilled in 2–4 semesters, depending on the student's preparation and course-load. There is no teaching requirement for Master's degree candidates, but they may be hired to grade undergraduate courses, and they may be allowed to participate in the teaching apprenticeship program.

Brandeis undergraduates can enroll in the combined B.A./M.A. program in order to earn a Master's degree at the same time as their Bachelor's degree. Students must formally apply in the spring preceding their final year as an undergraduate. The requirements are then as described above. Ph.D. students who have fulfilled the above requirements are also eligible to

receive a Master's degree.

Students completing the requirements and wishing to receive the Master's degree need to file an Application to Graduate by the specified deadline.

2. Seminars and other activities

There are seminars and numerous other activities that graduate students benefit from, academically and otherwise. You are encouraged to take advantage of the opportunities available to you as a student in the department, at the university, and as part of the Boston area mathematical community.

3.1 Seminars. The department has a variety of (usually) weekly seminars. Some are intended to be accessible to all graduate students, while others require more background. *The Everytopic Seminar* is intended to expose graduate students and undergraduates to research topics in mathematics and occasionally related areas, such as physics and computer science. The Graduate Student Seminar, organized by the graduate students, is one in which the students lecture to each other on topics of interest and eat pizza.

The Joint Brandeis-Harvard-MIT-Northeastern Colloquium is a weekly event that rotates among the four universities and meets at Brandeis 2 or 3 times a semester. The speakers are leading mathematicians from around the world, and the talks are often accessible to graduate students. The department takes the speaker to dinner afterwards and subsidizes dinners for graduate students.

The New Directions Lecture Series, also known as the *NOSY (for Not Only Second Year) Seminar*, is a series of lectures or mini-courses offered in the fall semester of each year. They are given by faculty members and are designed to introduce students to a current area of research in more depth than is possible in a single seminar lecture. Second-year students are especially encouraged to attend this seminar, as it offers them an opportunity to learn about the research interests of faculty members.

The Topology Seminar tends to choose a theme for the semester and works as a learning seminar with participants taking turns giving talks. Outside speakers sometimes give talks as well.

The Combinatorics Seminar is an introductory seminar for combinatorics. The talk should be accessible to first year graduate students.

There are a number of informal learning seminars on topics of interest to students in a particular area. In the past academic year this included working seminars on dynamics and number theory, modular and automorphic forms, and other topics.

The Undergraduate Math Club sometimes organizes interesting and accessible interdisciplinary lectures.

There are many other seminars in the Boston area that are regularly attended by Brandeis faculty and students—MIT's Combinatorics Seminar, Harvard's Number Theory Seminar, the Harvard-MIT Algebraic Geometry seminar, Harvard's Gauge Theory and Topology Seminar, the Boston College Geometry and Topology Seminar, and the Boston University Algebra Seminar, to name a few. Students also sometimes informally attend classes given at other

universities. Check with the instructor when doing this to make sure he or she doesn't mind.

3.2 Travel funds. Attending workshops and conferences is a useful way to learn mathematics, meet others in the field and let people know about your work. Ph.D. students who have settled on an area of research are encouraged to go to at least one during their graduate career. The Mathematics Department makes $500/year available to each Ph.D. student for this purpose. Use of the funds requires permission of your thesis advisor or the Graduate Advising Head.

3.3 The Jerome Levine Outstanding Thesis Award. Every year the Jerome Levine Outstanding Thesis Award is given to the student who, in the opinion of the faculty, has written the best Ph.D. thesis in the past year.

3.4 Summer support. Though quieter than during the school year, the department still has a fair amount of activity during the summer, with many faculty and students still coming in regularly.

While everyone needs a break, we hope that you'll spend most of the summer pursuing your studies. However, the department cannot guarantee financial support to students during the summer months. It is therefore understandable that some of you will seek employment during the summer, and some of you will take the opportunity to travel home.

A few students are hired each summer to teach undergraduate mathematics courses (see 1.4). A few others sometimes find jobs on-campus that leave them time for mathematics. The department also has some funding to support students working on their research during the summer. We will support a limited number of students for up to a month each. To be eligible, you must have taken all the required courses and you must be in residence and not otherwise employed during the period of support. To apply, you need to write a brief proposal describing your summer research plans. Awards will be based on merit, with priority given to those students who are not teaching in the summer and have not received summer support before. The two best proposals each year will be funded from the *Harold L. Levine Endowed Fellowship Fund.* This award is similar to the regular summer research fellowships that are funded by grants and other department funds, but has a somewhat higher amount.

3.5 Social events. The department's friendly and informal atmosphere fosters interaction among faculty and students and enhances the environment for learning and research. A variety of social events contribute to this atmosphere. There is an afternoon tea in the department lounge two days each week when classes are in session. Two or three Thursdays each semester, the Joint Colloquium (see 3.1) is held at Brandeis; it is preceded by a tea in the department and followed by dinner at a local restaurant. In addition, there are several annual events, usually including a fall barbecue and a holiday party.

3.6 GSAS, GSA and ISSO. The mathematics graduate program is one of many that comprise Brandeis University's Graduate School of Arts and Sciences. GSAS is responsible for overseeing these programs. GSAS provides a variety of support services for graduate students. These include an orientation program, foreign language courses, and workshops throughout the year on topics such as dissertation preparation and the job search. GSAS handbooks and newsletters provide information on a variety of topics such as academic policy, teaching and funding opportunities. These funding opportunities include the graduate school's own Dissertation Year Fellowships and University Prize Instructorships. Mellon Dissertation Year Fellowships are intended mainly for non-science students, but mathematics students may be interested in applying for a University Prize Instructorship. These are competitive awards made

to exceptional students to design and teach upper-level undergraduate courses. Mathematics students have won these awards in the recent years.

The Graduate Student Association is a student organization devoted to enhancing graduate student life and representing graduate student concerns at Brandeis. There are also many other student groups, including but not limited to: Brandeis Queer Grad Student Union, Brandeis Graduate Science Social Committee, Diverse Brandeis Scholars, Career Development for the Sciences, Science Policy Initiative and Women in Science Initiative.

International students will also certainly avail themselves of the services of the International Students and Scholars Office, which assists with visa and immigration issues and helps international students adjust to life at Brandeis.

3. Administration

The Graduate Advising Head is responsible for overseeing the instruction and advising of graduate students in the mathematics department. This responsibility includes making recommendations to the university concerning admission, readmission, and funding of graduate students and the granting of graduate degrees. If the Graduate Advising Head is unavailable, or unable to address a particular concern, then the matter should be taken care of by the Department Chair. Academic grievance and petition procedures are described in the GSAS Student Handbook: https://www.brandeis.edu/gsas/current/gsas-student-guide/index.html.

4.1 Advising. All students should meet with the Graduate Advising Head at the beginning of each semester to discuss courses and plans for the semester and progress towards the degree.

The Graduate Advising Head serves as the primary advisor for all incoming Ph.D. students. When a student begins working on major and minor exams, this role is assumed by the examiners (see 1.2.3), and then by the thesis advisor once one is chosen (see 1.3.3).

The Elementary Mathematics Coordinator advises students on matters related to teaching.

All other graduate students are advised primarily by the Graduate Advising Head, in conjunction with the undergraduate advisor for joint B.A./M.A. students.

4.2 Evaluation. The mathematics faculty meets at the end of each semester to evaluate the graduate students and a progress letter is sent to students in May. The academic performance and teaching performance of each student is reviewed. Each faculty member who has had significant contact with the student, in either a class, a reading course, dissertation work, or through undergraduate teaching, reports on the student's performance. Minor problems are handled informally by the Graduate Advising Head or the student's advisor. Major problems result in a letter to the student and a meeting with the Graduate Advising Head. These letters are usually quite serious and warn of the student's possible required withdrawal from the program if performance does not improve.

The following is a summary of requirements for Ph.D. students to maintain good academic standing. Failure to complete them in the suggested time frame can result in a warning to complete them by a specific date or risk withdrawal. See the relevant section of the handbook for more details (also, please see Appendix D: "Summary of Ph.D. Program Requirements")

- **Required courses:** Pass or place out of at least two per semester during first year.

Complete during second year. (See 1.1.)Second Year Seminar: Pass during second year. (See 1.2.1.)

- **Other courses:** Pass all courses with at least a B- grade. (See 1.2.1.)
- **Qualifying exams**: Make significant progress on the major or minor exam by the end of the second year. Complete major exam by third year and minor exam by fourth year. (See 1.2.2.)
- **Language exam:** Complete by the end of the third year. (See 1.2.3.)
- **Teaching:** Take and pass an ELP course if required. Complete the Teaching Apprenticeship Program. Teach when required (at least four semesters). Take the Teaching Practicum each fall when you are teaching. (See 1.4.)
- **Dissertation:** Select an advisor and start a project in third year. Make significant progress by the end of the fourth year. (See 1.3.3.)

4.3 Funding. All students accepted in the Ph.D. program and in good academic standing receive a stipend for all five years (in the annual amount of $25,000 for the 2019-2020 academic year) as well as health insurance and tuition coverage. Students who are TFs as part of their teaching requirement receive an additional $1,600 per semester (for the 2019-2020 academic year). For more information on union negotiated rates, please go here: https://www.brandeis.edu/gsas/current/union-information.html

4.3.1 Funding Beyond the 5th Year. Unless they are on a grant from their advisor, students beyond their fifth year do not receive funding and are responsible for tuition costs. Additionally, students must pay for University health insurance ($2,999 for 2019-2020) unless they enroll in a qualifying alternative plan and complete the waiver form on the University Health Plans website.

Most 6th year students have completed all program requirements (with the exception of their dissertation/defense) and are considered "continuation" students by the Graduate School. Continuation students are charged $812 for each fall and spring semester (for 2019-2020). However, 6th year students who have NOT completed all program requirements (with the exception of the dissertation/defense) are counted as "post-resident" students by the Graduate School, which means that the 6th year tuition rate for each fall/spring semester would be $1,624 (for 2019-2020). (Students in years 1-5 are NOT responsible for their tuition and health insurance costs).

Ph.D. students no longer on funding who are hired as Graders or 1/2 Teaching Assistants through the Graduate School are typically eligible for tuition scholarships for the semester in which they are performing these duties. Graders can receive a tuition scholarship up to the cost of the post-resident fee (not to exceed the cost of tuition) and 1/2 Teaching Assistants can receive a tuition scholarship up to the cost of the continuation fee.

4.3.2 Other Funding Opportunities. Ph.D. students are strongly encouraged to apply for fellowships for which they may be eligible. Students from the U.S. may be eligible for graduate fellowships from the NSF and other government agencies offering very generous stipends. Some foreign countries also offer fellowships to nationals for graduate study in the U.S.

Ph.D. students interested in teaching upper-level undergraduate courses should consider applying for a University Prize Instructorship (see 3.6).

4.3.3 M.A. Scholarships. M.A. students may be eligible for merit-based or need-based

financial aid from Brandeis in the form of reduced tuition. Students should contact GSAS regarding this and other financial aid opportunities, such as student loans. More information can be found here: https://www.brandeis.edu/gsas/financing/masters/index.html

Financial aid opportunities for B.A./M.A. students are the same as for other undergraduates.

4.4 Rights and Responsibilities. The university's Rights and Responsibilities Handbook sets forth policies governing rules of conduct that apply to all Brandeis students. The Rights and Responsibilities Handbook also explains university policies, including those of Equal Opportunity and Affirmative Action. Brandeis is also committed to providing reasonable accommodations to community members with disabilities, as described in its publication on Disability Resources. For more information, students should contact the GSAS Disability Coordinator.

Within Brandeis, the Mathematics Department forms a strong community which values research and learning and cultivates an atmosphere of respect and support for fellow students, faculty and staff. As a graduate student in the department, it is part of your responsibility to help maintain that environment.

One aspect of this worth stressing is our dedication to teaching. The graduate students in mathematics have a reputation for sharing their enthusiasm for the subject and providing quality instruction to the undergraduates. We expect you to do your part to maintain that reputation and the strong teaching culture in the department.

On a less lofty note, we have to remember to take care of the physical environment as well as the intellectual one, and keep the shared offices, lounge, and kitchen reasonably clean.

At the end of each academic year, the graduate students elect three or four Graduate Student Representatives for the following year. These representatives have the additional responsibility of looking after graduate student interests within the department. This includes expressing the opinion of graduate students on matters such as hiring, course offerings and teaching assignment policies. There is also the opportunity for students to voice their opinions and concerns during an annual Town Hall.

Appendix A: Contact Information

Administration:

- Department Chair: Joel Bellaiche (jbellaic@brandeis.edu) (Dmitry Kleinbock, kleinboc@, is currently acting as DC)
- Graduate Advising Head: Olivier Bernardi (bernardi@), Dmitry Kleinbock (Spring/Summer 2019)
- Elementary Mathematics Coordinator: Rebecca Torrey (rtorrey@)
- Math Department Administrator: Catherine Broderick (cbroderi@)
- Academic Administrator: Emily Palmer (emilydpalmer@) / (scigradoffice@)
- Grad Student Representatives: Shujian Chen (shujianchen@), Eric Hanson (ehanson4@), Kewen Wang (swterry@), and Job Rock (jobrock@)

Language Examiners:

- French: Bellaiche or Daniel Ruberman (Ruberman@)
- German: Omer Offen (offen@)
- Russian: Kleinbock

Placement Examiners:

- Algebra I (131a): Bernardi
- Algebra II (131b): Kiyoshi Igusa (igusa@)
- Geometric Analysis (140a): Alan Mayer (mayer@)
- Real Analysis (141a): Kleinbock
- Complex Analysis (141b): Mayer
- Topology I (151a): Ruth Charney (charney@)
- Topology II (151b): Corey Bregman (cbregman@)
- Advanced Bifurcation Analysis (161a): Jonathan Touboul (jtouboul@)
- Numerical Methods (162a): Thomas Fai (tfai@)

Important Offices:

- Math Department: Goldsmith 218, 781-736-3050
- Graduate Affairs Office: Ros-Kos Connector Room 3-RK02, 781-736-2369 (Emily)/ 781-736-2352 (main line), scigradoffice@brandeis.edu
- Graduate School: Kutz Hall (2nd floor), 781-736-3410, GSAS@brandeis.edu
- Registrar: Kutz 121, 781-736-2010, registrar@brandeis.edu

Appendix B: Syllabi for Required Courses

Math 131a: Algebra I

Core topics (ALWAYS covered): Please use this checklist as you go through the course.

1) **Group theory:**
- ☐ Quick review of the basic theory (subgroups, homomorphisms, etc.).
- ☐ Group actions
- ☐ Conjugacy classes
- ☐ Sylow theorems.
- ☐ Solvable and nilpotent groups.
- ☐ Free groups, presentations.
- ☐ Categories: Basic notions of categories, functors and natural transformations are introduced and used as a language during the course.

2) **Rings and Modules:**
- ☐ Review of basic theory (subrings, ideals, fields, homomorphisms, etc.)
- ☐ UFD's
- ☐ PID's
- ☐ Polynomial rings.
- ☐ Linear algebra over rings (free modules, tensor products, exterior and symmetric powers, determinants).
- ☐ Finitely generated modules over a PID and applications.

3) **Field theory:**
- ☐ Field extensions, splitting fields, finite fields.
- ☐ Separable and inseparable extensions, algebraic closure.
- ☐ Fundamental theorem of Galois theory, solvability by radicals.

Additional topics (if time permits):
- Field theory (trace and norm, transcendental extensions, purely inseparable extensions, infinite Galois extensions, Kummer theory).
- Category theory (adjoint functors, Yoneda's lemma, limits).

Possible Texts:
- Lang: Algebra
- Jacobson: Basic Algebra

Appendix B: Syllabi for Required Courses

Math 131b: Algebra II

Core topics (ALWAYS covered): Please use this checklist as you go through the course.

1) **Homological algebra:**
- Exact sequences
- Complexes and homology
- Projective and injective modules
- Ext and Tor

2) **Commutative algebra:**
- Chain conditions
- Hilbert basis theorem
- Nullstellensatz
- Localization

3) **Representation theory (of finite groups):**
- Maschke's theorem
- Schur's Lemma
- Frobenius reciprocity
- Characters

Additional topics (if time permits):
- Non-commutative algebra (Semisimple rings, Wedderburn's theorem).
- Additional representation theory (representations of Sn, Brauer's theorem, representations in finite characteristic, representations of Lie algebras and Lie groups).
- Commutative algebra/number theory (integrality, completion, DVR's, Dedekind domains).
- Commutative algebra/algebraic geometry (dimension theory, Noether normalization, the ideal-variety correspondence, primary decomposition).

Possible Texts:
- Lang: Algebra
- Jacobson: Basic Algebra

Appendix B: Syllabi for Required Courses

140a: Geometric Analysis

Core topics (ALWAYS covered): Please use this checklist as you go through the course.

1) **Manifolds:**
- Change of coordinates
- Differential structure

2)
- Tangent bundle
- Derivations
- Vector fields
- Lie bracket
- Tensors

3) Basics of vector bundles:
- Normal bundles
- Pullback construction

4)
- Transversality
- Implicit function theorems

5)
- Picard theorem
- Frobenius Theorem

6) **Differential forms:**
- Closed and exact
- Poincar´e Lemma
- Frobenius Theorem in differential form version

7)
- Integration
- Stokes Theorem
- Orientations and volume elements
- de Rham cohomology and theorem

Additional topics (if time permits).

- Basic Lie Groups: Lie algebra, one parameter subgroups, structural equations, left and right invariant vector fields.

Possible Texts:

- Warner: Foundations of Differentiable Manifolds and Lie groups
- Spivak: A Comprehensive Introduction to Differential Geometry, vol. I
- Milnor: Topology from the Differentiable Viewpoint
- Bott and Tu: Differential Forms in Algebraic Topology
- Lee: Introduction to Smooth Manifolds

Appendix B: Syllabi for Required Courses

Math 141a: Real Analysis

Core topics (ALWAYS covered): Please use this checklist as you go through the course.

1) **Measure theory:**
- ☐ Measure spaces
- ☐ Measurable functions
- ☐ Integration and convergence theorems
- ☐ Lebesgue measure
- ☐ Lp-spaces.
- ☐ Egorov Theorem
- ☐ Lusin Theorem
- ☐ Fubini Theorem

2) **Metric spaces, general topology:**
- ☐ Complete and compact spaces
- ☐ Baire category theorem
- ☐ Arzela-Ascoli theorem
- ☐ Application to Peano existence theorem

3) **Banach spaces:**
- ☐ Normed linear spaces
- ☐ Banach spaces
- ☐ Hilbert spaces (basic theory)
- ☐ Dual spaces
- ☐ Hahn-Banach theorem
- ☐ Riesz representation theorem.
- ☐ Open mapping theorem
- ☐ Closed graph theorem

4)
- ☐ Fourier transforms
- ☐ Inversion

Additional topics (if time permits):
- Derivatives of measures, Radon-Nikodym theorem. Bounded variation, Lebesgue-Stieltjes integral, signed and complex measures, Hahn and Jordan decompositions, Helly's theorems. Fejer's theorem. Probability theory. Basic ergodic theory.

Possible Texts:
- Kolmogorov/Fomin: Introductory Real Analysis
- Lang: Real and Functional Analysis
- Royden: Real Analysis
- Rudin: Real and Complex Analysis

Appendix B: Syllabi for Required Courses

Math 141b: Complex Analysis

Core topics (ALWAYS covered): Please use this checklist as you go through the course.

1)
- ☐ Holomorphic functions in one variable (basic theory)

2)
- ☐ Integration
- ☐ Cauchy's theorem
- ☐ Cauchy's formula

3)
- ☐ Open mapping
- ☐ Maximum principle

4)
- ☐ Power series
- ☐ Weierstrass theorem
- ☐ Mittag-Leffler theorem

5)
- ☐ Linear transformations
- ☐ Conformal maps
- ☐ Riemann mapping theorem

6)
- ☐ Elliptic functions
- ☐ Weierstrass $\wp$-function

7)
- ☐ Harmonic functions
- ☐ Subharmonic functions
- ☐ Dirichlet problem

Additional topics (if time permits):
- Introduction to Riemann surfaces. Connections with the theory of covering spaces and cohomology. Gamma and zeta functions. Picard's theorem. Runge's theorem. Inhomogeneous Cauchy-Riemann equation. Several complex variables (Hartog's theorem). Phragmen-Lindelof theorem.

Possible Texts:
- Ahlfors: Complex Analysis
- Conway: Functions of One Complex Variable
- Narasimhan/Nievergelt: Complex Analysis in One Variable

Appendix B: Syllabi for Required Courses

Math 151a: Topology I

Core topics (ALWAYS covered): Please use this checklist as you go through the course.

1) **Covering Spaces and Fundamental Group** (depending on class background, some or all may be skipped):
- ☐ Basic Definitions (homotopy, fundamental group)
- ☐ Existence and classification of covering spaces
- ☐ Correspondence between subgroups and covering spaces
- ☐ Van Kampen's theorem

2) **Homology Theory:**
- ☐ Basic definitions of singular and simplicial homology
- ☐ Long exact sequence, excision, Mayer-Vietoris
- ☐ Homology of cell complexes and/or CW complexes
- ☐ Homology of basic spaces: sphere, projective spaces

3) **Applications of homology:**
- ☐ Maps between spheres; degree of map
- ☐ Vector fields
- ☐ Fixed point theorems
- ☐ Separation theorems (Jordan Curve theorem)

Additional topics (if time permits):
- Cohomology theory: Basic properties, cup and cap products.

Possible Texts:
- Hatcher: Algebraic Topology
- Greenberg and Harper: Algebraic Topology: A First Course
- Munkres: Elements of Algebraic Topology

Appendix B: Syllabi for Required Courses

Math 151b: Topology II

Core topics (ALWAYS covered): Please use this checklist as you go through the course.

1) **Cohomology theory** (continuing from 151a if begun):
- ☐ Basic properties
- ☐ Cup and cap products

2) Universal coefficients:
- ☐ Tor and homology
- ☐ Ext and cohomology
- ☐ Kunneth theorems

3)
- ☐ Poincare duality

Additional topics (if time permits):
- Homotopy theory: Basic properties, Hurewicz theorem, path spaces, fibrations, Eilenberg-MacLane spaces and cohomology.

Possible Texts:
- Hatcher: Algebraic Topology
- Greenberg and Harper: Algebraic Topology: A First Course
- Munkres: Elements of Algebraic Topology

Appendix B: Syllabi for Required Courses

Math 162: Numerical Methods for Scientific Computing

Core topics (ALWAYS covered): Please use this checklist as you go through the course.

4) Numerical linear algebra:

- Floating point arithmetic
- Polynomial interpolation
- Linear systems and LU factorization
- Least squares and QR factorization
- Singular Value Decomposition

5) Numerical differential equations:

- Quadrature methods
- Euler and Runge-Kutta methods
- Accuracy and stability of timestepping schemes

Additional topics (if time permits):

- Optimization, eigenvalue problems, finite difference methods for PDE's, Lax Equivalence Theorem

Possible Texts:

- Heath: Scientific Computing: An Introductory Survey
- Trefethen and Bau: Numerical Linear Algebra

Appendix D: Summary of Ph.D. Program Requirements

****NOTE**: ALL Students MUST be enrolled in at least 12 credits to be considered a full-time student.**

1) **First Year Program**:
- Four core courses: 131a (Algebra I), 141a (Real Analysis), 141b (Complex Analysis), 151a (Topology I)
- One or two of the remaining three required courses*

2) **Second Year Program**:
- Remaining Required Courses*
- 204a Teaching Practicum (taken in the fall when teaching; the 4 semester teaching requirement may be filled starting in the second year onwards)
- 200a Graduate Seminar (spring semester)
- Select advisor
- Foreign Language Exam (may also be completed in 3rd year)
- Division of Science Responsible Conduct of Research (RCR) Workshop

3) **Third Year Program**:
- Minor Exam (may also be completed in 4^{th} year)
- Major Exam
- NOTE: if taking 401D Dissertation Research, it is recommended to take one additional elective course.

4) Fourth Year Program:
- 401D Dissertation Research (12 Credits)
- It is recommended to take one additional elective course.

5) **Fifth Year Program**: 401D Dissertation Research (12 Credits)

* In addition to the four core courses, students are required to take at least three of the following seven courses: 131b (Algebra II), 151b (Topology II), 140a (Geometric Analysis), Math 161a (Advanced Bifurcation Analysis), Math 16XX (Numerical Methods), Math 16XX (Probability), and Math 16XX (Partial Differential Equations). The three courses marked with XX are in the process of being approved or developed; the department plans to start offering them on a regular basis within the next two academic years from now.

Appendix E: Summary of Graduation Procedures

1) Application to graduate: https://www.brandeis.edu/registrar/forms/graddegree.html

2) Schedule defense and reserve a room: email scigradaffairs@brandeis.edu

3) Complete and submit a DEC form (DUE two weeks before defense): http://www.brandeis.edu/gsas/current/dissertation-guide/pdfs/dec-form.pdf

4) Signature page (DUE day of defense) : http://www.brandeis.edu/gsas/current/dissertation-guide/pdfs/signature-page.pdf

5) Dissertation defense form (DUE day of defense): http://www.brandeis.edu/registrar/forms/docs/forms/graduate/Ph.D._Dissertation_Defense_Form.pdf

6) Revisions Form (if necessary, due date depends on type of revisions): http://www.brandeis.edu/registrar/forms/docs/forms/graduate/PH.D._REVISIONS.pdf

7) Submit dissertation: http://www.brandeis.edu/gsas/completing/dissertation-guide.html

If you have any questions related to this checklist and graduation requirements, please contact Emily Palmer in the Grad Affairs Office (Emilydpalmer@brandeis.edu / scigradoffice@brandeis.edu / 781-736-236