Duke Mathematics Professional Development Program for Mathematics Graduate Students

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Contents

1 Introduction **2**

2 Overview of Program **3**
2.1 Orientation Week . . . 3
2.2 Semester-long Teaching Assistantship . . . 3
2.3 Semester-long Pedagogy Course . . . 3
2.4 Teaching as Instructor of Record . . . 4
2.5 Goals of Professional Development . . . 4

3 History of the Program **4**

4 Sample Orientation Week Schedule **7**
4.1 Summary . . . 7
4.2 Goals . . . 7
4.3 Graduate Student Roles . . . 7
4.3.1 Lab TAs . . . 7
4.3.2 First-Time Instructor of Record . . . 8
4.3.3 Returning Instructor of Record . . . 8
4.4 Reflection and Revision . . . 8
4.4.1 Potential Additional Sessions . . . 8

5 Sample Pedagogy Course Plans **11**
5.1 A MW Plan Focused on Assignments and Reflection . . . 11
5.2 A TTr Plan Focused on Engaged Student Learning . . . 14
5.3 A MWF Plan Focused on Utilizing Guest Presenters . . . 17

6 Activities and support after the pedagogy course **19**
6.1 Practice teaching . . . 19
6.2 Subsequent orientation week sessions . . . 19
6.3 Teaching observations . . . 19
6.4 Continued mentorship and support . . . 20
6.5 Self evaluation . . . 20
6.6 Experimental spring workshops . . . 21

7 Discussion, Room for Improvement and Future Goals **21**

8 Lesson Descriptions **24**
8.1 Classroom Issues . . . 25
8.2 A discussion on equity in our classrooms . . . 27
8.3 Writing Exams, In Class, Discussion Guide . . . 29
8.4 Asking Good Questions . . . 31

9 Appendix **34**
9.1 Duties and pay for lab TA work 34
9.2 Sample Orientation Week Instructor Meeting 35
9.3 Observation Form 37
9.4 Lab Prep Document 39

1 Introduction

The purpose of this document is to share materials, in an organized way, from the graduate student professional development (PD) program in the Mathematics Department at Duke University. Our goal is to show how different program components come together to create a larger support system for graduate students as they prepare and begin to teach.

This document serves three different target audiences with distinct purposes. First, for the current PD providers in the Mathematics Department at Duke, this document records and saves the details of the program for reuse and revision in future years. Using this highly detailed resource, any faculty member in the Math Department at Duke can be easily introduced to the goals and structure of the program. Because there is natural turn over in the provider role at Duke, this document can also be used to on-board new providers. Second, for PD providers at other institutions, this document provides one sample template of PD for graduate student instructors. This document is a source of ideas on building, running, and sustaining a PD program according to the needs and available resources of a particular department. Although the content in this document is specific to a mathematics department, many ideas can be extended to any department that prepares new teachers for the classroom. The structure and details of the program outlined here can be used, edited, or expanded, and may be taken in pieces or as a whole. It could be use by an experienced PD provider looking for a new lesson on equity in the classroom, or by a provider who is starting a new program at their institution. Finally, for administrators and other individuals adjacent to the PD program, this document details the work, thought, and care involved in putting together a comprehensive plan for supporting graduate students as they begin to teach. This document intends to show administrators the intricacies of the program so that they will be better equipped to support PD efforts in the Mathematics and other departments.

The document is organized to give readers an overview of the program and a history of how it was developed over time before providing more detail specifically about program components. The document follows the chronological order of what a graduate student will experience after arriving to campus. Section 4 describes the orientation week that graduate students participate in during the week before the start of the Fall semester. In section 5, there are details about the pedagogy course that graduate students enroll in during their first semester. There are three sample course plans described with links to lesson details in section 8. In section 6, activities and support that follow the pedagogy course are described, including practice teaching, observations, and continued mentorship and support. Section 7 is still in progress. The appendix (section 9) contains documents that are used and updated year to year in the program.

2 Overview of Program

The Duke University graduate program in mathematics serves approximately ten new graduate students each year. The graduate student PD program at Duke has the following four main components, explored in more detail below.

1. **Orientation Week.** New graduate students attend a one-week orientation program before the start of their first semester.
2. **Semester-long Teaching Assistantship.** In their first semester, graduate students work as teaching assistants in a laboratory calculus course and a tutor in the Laboratory Calculus Help Room.
3. **Semester-long Pedagogy Course.** In their first year, graduate students complete a one-semester pedagogy course. The semester following their pedagogy course, graduate students guest lecture for one to two days in an introductory math course course.
4. **Teaching as Instructor of Record.** In their second year and following years, graduate students teach as instructor of record. Course coordinators in the calculus sequence meet weekly with instructors as part of continued mentorship and support.

2.1 Orientation Week

Before the start of their first semester, graduate students participate in a one-week orientation program. During this week, new graduate students prepare for their first semester responsibilities as teaching assistants. Orientation week includes sessions on the structure of lab calculus at Duke, duties of laboratory teaching assistants, grading, professionalism in the classroom, 15 minute practice lessons, and working the Laboratory Calculus Help Room. There are also offerings from the Graduate School during this week. In following years, graduate students continue to attend orientation week sessions on teaching to review and reinforce best practices. Some sessions are exclusively for new teachers, while others integrate both new and experienced graduate students. Graduate students have opportunities during this week to share ideas with faculty as well as each other. Details about the orientation week and a sample schedule can be found in section 4.

2.2 Semester-long Teaching Assistantship

During their first year, graduate students work as teaching assistants in one of Duke's laboratory calculus courses. For descriptions of these courses, visit https://math.duke.edu/courses. In their first year graduate students fulfill their teaching assistantships as Laboratory assistants. Laboratory assistants run once weekly course meetings for 75 minutes or 105 minutes, depending on the course. Lab assistants work in pairs, either with another graduate student or with an advanced undergraduate. Together, the lab assistant pairs introduce application problems related to lecture material. They facilitate group work, respond to questions, and grade assessments. They are not responsible for pacing content, writing assessments, or assigning grades. Instead, they help undergraduate students work through prepared active-learning materials. The graduate students are supported in weekly meetings with the course coordinator who helps frame the laboratory content in the greater storyline of the course.

2.3 Semester-long Pedagogy Course

While working as lab assistants, graduate students enroll in a one-semester, graded pedagogy course, run by the Math Department. This course meets twice weekly for 75 minutes. During class, graduate students reflect on their current work as laboratory assistants and prepare for their future work as instructors of record. Course topics include units on organizing lectures, writing and grading assessments, class logistics and resources, and addressing common but difficult teaching scenarios. At the end of the semester, graduate students present a 15 minute mini-lecture on the topic of their choice. In the semester following their pedagogy course, first-year graduate students guest teach for two class periods in an introductory math course. More details about the pedagogy course and three sample course plans can be found in section 5.

2.4 Teaching as Instructor of Record

Beginning in their second year and continuing throughout their graduate school career, graduate students teach as instructor of record in an introductory math course. They typically teach one section of single variable calculus, multivariable calculus, or linear algebra with approximately thirty students. These introductory courses are multi-section block courses serving hundreds of undergraduates and supervised by a course coordinator. Graduate student instructors meet once weekly with their course coordinator to discuss class content, pacing, exam writing, classroom management, and potential student interventions. At these meetings, new graduate students can exchange ideas with experienced graduate students as well as faculty members. At least one faculty member observes each first-time instructor and provides feedback. After their first time teaching as instructor of record, graduate students write a reflective summary of their experience and meet with a faculty member to discuss their self evaluation as well as their student evaluations.

2.5 Goals of Professional Development

The professional development program seeks to achieve the following three main goals.

1. Prepare graduate students to teach undergraduates during their graduate school career.
2. Provide graduate students with practical experience and skills that they can apply in future jobs.
3. Support a culture of teaching in the Math Department by inspiring graduate students to implement evidence-based teaching strategies, build active learning into their lesson plans, and foster inclusive learning environments.

In the semester-long pedagogy course, we are particularly interested in emphasizing active learning. We plan lessons in the pedagogy course to model activities that new instructors can borrow in their math classrooms. These activities include whole group discussions, think-pair-shares, peer presentations, and partner problem solving. By practicing active learning together, we hope to convince graduate students of the value of in-class work over passive lectures. A detailed course plan that highlights how active learning strategies can be used in the pedagogy course can be found in section 5.2.

Other goals include fostering camaraderie among the graduate student cohort, practicing public speaking, and building connections with teaching faculty. We hope that by the end of the program, the graduate students are both confident in and excited about their futures as teachers.

3 History of the Program

Before 1987, as was the case in most PhD programs at that time, it was assumed that all one needed to know in order to teach college mathematics was sufficient content knowledge of the course being taught. About that time, Michael Reed, chairman of Duke's math department, became concerned with the quality of teaching done by graduate students. At least part of this concern was brought on by poor student evaluations of teaching and an increase in complaints by students. An additional concern was that, at Duke (as well as nationally), there was an increase in the number of graduate students who were non-native speakers of English. Reed asked one of the term lecturers, Jack Bookman, to develop a program to better prepare graduate students to teach and to do so with the advice of Lewis Blake, another term lecturer and Supervisor of First Year Instruction. Bookman had been a high school teacher for four years and had a Masters of Arts in Teaching, a Master's degree program designed for students to receive a secondary school teaching certificate. In 1987, he was also a part time graduate student in Education. As the only person in the department with formal training in education, he was the natural choice to take on this responsibility.

At that time, the typical size of the entering class of mathematics graduate students was 5-10 students. Typically, in their first year, they conducted evening sessions where they helped first year Precalcus and Calculus students with their assigned homework. In their second and subsequent years they typically taught one or two 35 student sections of calculus as instructors of record.

Bookman, in consultation with Blake, proposed a teacher training plan where first year graduate students participated in a weekly seminar taught by Bookman who borrowed heavily from courses in Methods of Teaching Secondary Mathematics. The main emphasis of the seminar was on learning to prepare lessons,

making and grading tests and assigning grades. The graduate students also observed classes, taught by both faculty and graduate students, and discussed these observations in the seminar. There were discussions of administrative issues such as grading homework and holding office hours. Though the seminar structure has matured over the past 30 some years, many of the themes of the early years are still addressed. In addition to the seminar, graduate students "practice taught" in the spring semester of their first year of graduate study. They gave two "guest" lecturers in calculus classes. They were observed by a faculty member and were given feedback about their teaching.

During their first teaching experience, usually in the second year of graduate study, graduate students were observed twice by faculty members. This scheduling required a significant amount of work. Reed, as well as the next chairs of the department, felt strongly that this was a responsibility of the entire faculty. Faculty observers were sent the following instructions by Bookman:

> In order to improve the quality of instruction, all graduate students teaching for the first time will be observed by a member of the department two times at the beginning of the semester - once during the second week and once during the third week. It will be very much appreciated if you will be able to observe the graduate student listed below. After each observation, please arrange a time to discuss with the graduate student your reactions and suggestions. Please make some notes concerning the teacher's performance and give me a copy after you've had a chance to meet with the graduate student. I will put in your mailbox two copies of a form that you may want to use to facilitate your observations and note-taking. Your candor and cooperation will be very appreciated. If you have any questions, feel free to call me at any time. If you cannot do the observation, please let me know as soon as possible.

Prior to this message being sent, the chair would send a message to the faculty reminding them that these observations are important to the department and urging them to cooperate with Bookman in this effort. Although a few faculty members were not cooperative, by and large, most made the effort to perform this duty to the best of their ability.

Bookman coordinated the TA training efforts of the department from 1987 until his retirement in 2012. During that time, changes were made to the program, mostly incremental. However two external factors forced bigger changes to the preparation of graduate students for teaching – the introduction of calculus reform in the 90's with support from a grant from NSF (Award # 8953961) and the expansion of the graduate program in 2000 as a result of an NSF VIGRE program funding awarded to the Duke math department (Award # 9983320). These will be discussed below.

Financial support from the math department for the coordinator of the TA training activities was mostly consistent from 1987 – 2012. Initially, Bookman, whose teaching load was 12 credit hours (usually 3 or 4 classes) each semester received one month summer support (1/9 of his salary). However, the effort to coordinate this program and the implementation of some new aspects of the program were more time consuming than anticipated. Several years into this initiative Bookman requested, as was granted, a one course release per year to do this work instead of a month of summer support (in essence an increase from 1/9 to 1/8 of his salary.)

From 1987 until the mid 1990's several components were added to the program. The seminar began to meet twice a week for 75 minutes, a schedule that still exists today. Bookman videotaped each graduate student instructor's class on time during their time at Duke and met to discuss the tape with them. Topics were added to the seminar such as having a panel of current graduate instructors come talk to the first year grad students about their experiences teaching for the first time. Another added topic was a session where challenging scenarios were presented to graduate students and they were asked to discuss how they would address the problem. This session, developed by Lewis Blake from situations that he actually experienced, was done in a role playing format where he would play the role of an undergraduate meeting with his graduate student instructor. Graduate students were asked, after their first time teaching and after they read their student evaluations of teaching (SET's) to write a self-evaluation of their teaching. Once those were done and after Bookman finished reading the SET's he met with each of those first time instructors to discuss the SET's and self evaluations.

In the 1990's Duke mathematics professors, Lawrence Moore and David Smith, were award a major calculus reform grant. During that time, major changes were made in the way first year calculus was taught

at Duke (Bookman and Blake, 1996). First year graduate students were typically assigned to be lab TA's . Each week, in addition to three 50 minutes classes, the students had a 1 hour 45 minute lab period. In the math lab, students worked on problems, many based on real-world problems, using numerical, graphical and symbolic approaches. The role of the TA's was to guide the inquiry based learning. The labs were central to the content of the course. This necessitated adjustments in the way we prepared graduate students to teach, many of whom had little or no experience like this in the undergraduate education. To prepare graduate students to teach in the lab, we added two components to the program of graduate student teacher training: a week of training held during the week before classes started (a detailed description of the current orientation week sessions is given below in section 4) and weekly meetings with the course supervisor about what to expect and how to prepare for each lab. Initially, Lewis Blake, the Supervisor of First Year Instruction, conducted these meetings for both Calculus I and Calculus II each semester. Several years later, these sessions were led by the course supervisor for each of these courses. These course supervisors were regular rank, non-tenure track faculty.

Graduate students continued to typically be assigned to teach one section of the reformed calculus each semester, beginning in their second year. They taught the three 50 minute class periods each week, as instructors of record. They were not present during the lab period but were responsible for coordinating with the lab TA's. Because some of the content and pedagogy of these new courses were significantly different than what our graduate students may have seen in their calculus classes, we instituted weekly course meetings for teachers. As with the lab TA meeting, initially these were all conducted by Lewis Blake but eventually led by the course supervisors. A sample meeting plan that course coordinators use in a weekly meeting can be found in section 6.4. In 2000, the National Science Foundation announced a five year grant to Duke's math department under the program Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE). As a result of this program the size of the graduate program approximately doubled and the amount of teaching done, during the funding period of the grant, by an individual graduate student decreased and the time they started teaching their own sections was delayed sometimes to the third year of graduate study. After the grant, the size of the graduate program stabilized at 10-12 new students per year which was more than before the VIGRE grant started. These increased numbers of graduate students caused two minor changes to the TA training program. There were an increased number of classroom observations needed to be done and increased scheduling and coordination, without an increase in resources devoted to TA training. In order to somewhat compensate for the increased time commitment required, we no longer videotaped each of the graduate students teach. This was a regrettable but necessary adjustment.

Beginning in 2008, responding to requests from the graduate students, the seminar was offered as a for credit course, offered on a pass/fail basis. This did not reflect any change in the content of the program. Prior to this the seminar met twice a week for 75 minutes, with some minimal homework or reading assignments. What changed is that it now appeared on their transcript.

Since Bookman's retirement in 2012, a succession of non tenure track regular rank faculty have undertaken the supervision of the TA training, including the co-authors of this document, Akin and Braley. Some of those times the seminar has been team taught, once with an experienced graduate student. This requires that department devote more resources to this effort but providing the graduate students with more than one perspective has been helpful.

4 Sample Orientation Week Schedule

4.1 Summary

The pre-semester orientation week provides professional development for three connected graduate student populations: incoming first-year graduate students who will serve as teaching assistants for lab calculus courses, first-time instructors of record, and experienced graduate student instructors. The roles that graduate students play are defined more carefully below. Some activities during orientation week target one specific experience level/role, while other activities combine these levels so that everyone can share their expertise. Orientation week serves as a refresher course for instructors of record, because these graduate students have prepared for their role throughout the previous school year(s). Importantly, orientation week serves as the primary preparation for incoming graduates students, most of whom have never before run their own classroom, to lead lab sessions as teaching assistants just one week later. For that reason, the focus of orientation week is on the fundamental skills and materials needed to run a classroom.

4.2 Goals

- Prepare first-year graduate students to lead a lab session the following week as lab TAs.
- Provide basic logistical/procedural information needed to run a classroom (copier codes, websites, where to find chalk, what to do in case of an emergency, FERPA, etc.)
- Connect experienced graduate students and faculty members with new instructors and TAs to start building a community of teachers within the calculus courses.
- Remind graduate students at all levels of the diversity of students in their classrooms and the importance of viewing students as whole individuals.
- Promote a culture of engaged student learning.

4.3 Graduate Student Roles

First time instructors of record and returning instructors of record may end up managing first year graduate students in the role of Lab TAs. We encourage interaction between these groups of graduate student at various sessions throughout the week.

4.3.1 Lab TAs

Lab TAs work in pairs to lead discovery-based lessons in Calculus I and II courses. These lab sessions meet once per week and last either 75 or 105 minutes, depending on the course. The instructor of record for the course in most cases is not present during the lab meeting.

Many lab activities apply calculus concepts in settings such as physics, economics, chemistry, biology, and probability. Some lab activities focus on theoretical understanding of major calculus theorems, and some are practice problems closely related to material students have already seen. Students may be assessed on lab content by writing up a lab report, taking a quiz, or answering a worksheet of questions.

Lab TAs are expected to divide the students into groups, introduce the main goal of the activity, review relevant calculus material, and sometimes demonstrate new examples. After the introductory mini-lecture, TAs then facilitate group work, answer questions, troubleshoot issues, and probe students with deeper questions as they progress through the lab activity. TAs administer quizzes and assist with grading lab material. Outside of lab, TAs meet with the course coordinator each week to prepare for the lab. In these 30 minute meetings, the coordinator reviews some of the mathematics that will arise during the lab, connects the lab material to the rest of the course, highlights areas where students may get stuck, and provides solutions to the TAs. A sample outline of Lab TA duties and a sample lab prep document can both be found in the Appendix.

Lab TAs communicate weekly with the instructor of record for their course either via email or in-person. Instructors should provide rubrics, set due dates, and highlight any deviations from the course schedule. Lab TAs should return graded papers, and give feedback to instructors about any difficulties that arise in lab.

4.3.2 First-Time Instructor of Record

First-time instructors of record will teach in a coordinated course, typically calculus I or II. The syllabus for each of these courses is common across all sections and set before the start of the term by the course coordinator. Homework problems from the textbook are common, although the instructor of record may decide how to assess homework and may choose to assign additional problems. The course coordinator determines the weighting of assignments in final grade calculations. Instructors of record decide their own class policies on late work, attendance, and homework collection. Instructors write and grade their own midterms with editing from course coordinators. The common final exam given to all sections in the course, is written and graded collectively by instructors from all sections of a course. Course grades are assigned by the instructor of record, but reviewed by the course coordinator and supervisor of first-year instruction. First-time instructors meet weekly with the course coordinator to stay on pace with material, identify tricky concepts for students, and stay connected to the lab material. Instructors of record teach between 150 and 175 minutes each week, depending on the course. Instructors of record also staff the Math Help Room for two hours per week in lieu of traditional office hours.

4.3.3 Returning Instructor of Record

Returning instructors of record have the same responsibilities as first-time instructors. They take on an additional leadership role in weekly course meetings by sharing materials and helping to troubleshoot problems.

4.4 Reflection and Revision

To promote a culture of engaged student learning, the teaching faculty are revising activities from orientation week to model active learning techniques. The teaching faculty are also looking to add opportunities for graduate students at all levels to contribute their ideas and knowledge during orientation week. Future orientation weeks could include several new sessions listed below.

4.4.1 Potential Additional Sessions

- Visit your classroom (for first-time TAs and instructors to get the feel of standing in front of a classroom prior to the first day of class)
- First day plans: setting the tone for active learning
- Troubleshooting active-learning models
- Setting class policies and drafting policy documents
- Previously used materials and how to access them

In order to include some of these new sessions while also remaining within reasonable time limits, the orientation week sessions listed in the sample schedule could be condensed, combined and reorganized. Given the time constraints, it may be necessary to treat these additional topics only briefly during orientation week, but revisit them in greater detail during the semester-long pedagogy class and weekly instructor meetings.

Sample Schedule of Activities

Day 1

Payroll Setup and Other Business Matters (45 min)
Facilitator: Math business office
Participants: New graduate students
Description: Introduction to payroll, account setup, issue textbooks and lab manuals

Welcome (45 min)
Facilitator: Supervisor of First-year Instruction and an experienced graduate student instructor
Participants: New graduate students
Description: Overview of the coming week. From experienced graduate student: What most heavily influenced the development of your teaching? What have you come to think are the most important things for a good teacher's process? What advice can you offer to new graduate students as they begin to develop these skills themselves?

GTA at Duke (2 hr)
Facilitator: PoP/lecturer team who will lead the semester-long graduate student teaching seminar
Participants: New graduate students
*Description:*Community builder, overview of syllabus for semester-long teaching course, pair teaching exercise (Lorenz curve), description of practice teaching assignment

Day 2

Lab Logistics (2 hr)
Facilitator: Lab manager
Participants: New graduate students
Description: Overview of Duke's calculus courses. Role of graduate assistants. How labs work, undergraduate assistants, managing with two lab instructors, facilitating group work, possible problems. Lab run-through. Evaluating student's lab work: reports, quizzes, and short report forms. Question and answer session.

Classroom Issues (1 hr 30 min)
Facilitator: PoP team
Participants: All graduate student instructors
Description: Collaborative discussion of a variety of teaching scenarios (classroom management, student meetings, grades, balance)

Day 3

Block grading (1 hr 30 min)
Facilitator: Supervisor of first-year instruction
Participants: All graduate student instructors and post-docs
Description: Detailed discussion of the practices and procedures for assigning final grades in a block course.

Help Room (1 hr)
Facilitator: Lab manager
Participants: All graduate student instructors and lab assistants
Description: Duties, best practices, challenging scenarios, sign up

Day 4

Practice Lab Presentations (2 hr)
Facilitator: All PoPs and lecturers
Participants: New graduate students
Description: 10 minute practice presentations. New graduate students practice giving the same content introduction that they will provide during their first lab class the following week

Learning Management Systems: Sakai and Duke Hub (2 hr)
Facilitator: SFI
Participants: First-time instructors (faculty and graduate students)
Description: Using an online gradebook, posting assignments and other resources, finding photo roster, giving permission numbers, sending class emails

Meeting with Director of Graduate Studies (1 hr)
Facilitator: DGS
Participants: New graduate students
Description:

Lab Calculus at Duke (45 min)
Facilitator: Chair of the Calculus Committee
Participants: New graduate students
Description: History of the lab calculus program at Duke

Grading Exams (2 hr)
Facilitator: All PoPs and lecturers
Participants: New graduate students and first-time graduate student instructors
Description: Practice grading student responses. Project range of grades to emphasize the subjective nature of grading.

Day 5

Handling Office Hours (2 hr 30 min)
Facilitator: SFI
Participants: First-time graduate student instructors and post-docs
Description: Improvised student conversations

Course Instructor Meetings (1 hr 30 min)
Facilitator: Course coordinators
Participants: All lab calculus instructors
Description: Each course coordinator meets with the instructors teaching their course. The discuss updates to the syllabus, course polices, connections to other classes, specific content that should be emphasized or is tricky, grades, overview of instructor manual

Day 6

Lab TA and Instructor Meeting (2 hr)
Facilitator: Lab manager
Participants: All lab assistants (undergraduate and graduate) and all lab calculus instructors
Description: All lab assistants meet the instructor they will work with in the upcoming semester. Discuss grades, communication, forming groups, class rosters. Work through case study[4] on facilitating group work in course staff teams. One of the goals of this activity is to build community and lines of communication between course staff around pedagogical choices and establish a culture of reflection.

Lab Meeting (1 hr)
Facilitator: Course coordinators
Participants: All lab assistants (undergraduate and graduate)
Description: Preparation for the first lab. Discuss content, introduction, class connections, expectations

5 Sample Pedagogy Course Plans

In this section we will provide three sample plans for the teaching preparation seminar for first year graduate students in the Mathematics Department at Duke University. These plans each have a slightly different flavor and were each co-facilitated by a pair of faculty members or a faculty and graduate student team.

The subsection A MW plan describes a seminar that met two days per week. It describes a system, using Google drive folders, to help graduate students share and organize their teaching resources; the system hosts a record of the work done by the students. This plan also includes a list of assignments that were completed by the students outside of class.

The subsection A TTr Plan describes a seminar that met two days per week. It highlights how different pedagogical strategies are used in the facilitation of the seminar to give the graduate students different ideas for promoting student engagement.

The subsection A MWF plan is a condensed course plan that highlights how providers can leverage resources that already exist at their institution by inviting visitors from offices that partner in supporting instructors and partner in helping students develop as independent and productive learners.

The text that is highlighted in blue will navigate you to sample lesson plans in Chapter 11.

5.1 A MW Plan Focused on Assignments and Reflection

This course plan was used in Fall 2015. The seminar was co-facilitated by faculty members Emily Braley and Rann Bar-On. The seminar was for credit, graded on an A-F scale and mandatory for all first year graduate students in Mathematics.

In this iteration of the seminar, the students were asked to use a nest of Google Drive folders to coordinate with one another outside of class, post reflections, sample lessons and more. This was an easy way for the students to share their work with facilitators and each other. The main folder contained readings, sample quizzes and tests, surveys, observation forms and other materials used in the course. Then each graduate student had their own sub-folder where they frequently uploaded or posted content. In the schedule below, when it says post or upload to "your folder," it is referring to the individual sub-folder for each student.

The students could access all of the folders during the seminar which allowed them to go into each others folders to give each other feedback on lesson plans or test questions. At the end of the semester the access was restricted so that only the individual graduate students and the teaching faculty could access individual folders. One of the goals of the seminar is to help build a sense of professional community around teaching for the graduate students and help the graduate students build an identity around teaching.

We created this space for the graduate students to start building their own library of teaching materials and resources as an example of an organization strategy. The set of materials produced by each graduate student has the potential to form the basis of a teaching portfolio; this is a place where the graduate student could continue to collect teaching materials including observation notes and evaluations.

This plan includes descriptions of readings and homework assignments for graduate students taking the seminar.

Math 771

Orientation week: 8/17-8/21.
For the first seminar meeting, We need from you an information sheet that includes:

- your name
- your mentor's name
- your duke email
- a secondary email (if preferred)
- your semester schedule
- a brief summary of any previous teaching experience
- two teaching related goals for your first year in the program

For Monday of week 1, you should prepare a 10 minute lesson introduction on a topic of your choice from first semester calculus. Each of you will present your intro in the first week of class (Presentations 1-6 and Presentations 7-12 on the schedule that follows.)

Week	**Monday**	**Wednesday**
1, Ideas	Presentations 1-6	Presentations 7-13
1, HW	*You will prepare a 20 minute presentation on a topic of your choosing that is accessible to undergraduate. Date TBD.*	*Read "Learning Math Meaningfully." Write a one paragraph reflection and post to your folder.*
2, Ideas	Qualities of a "good" teacher, teaching traps to avoid, professionalism in the classroom	Who will you be teaching? AP Trends, student misconceptions, diversity. Teaching Observation assignments given.
2, HW	*Read "All in a Day's Work" by Richard M. Felder and Rebecca Brent. Write a 1 paragraph reflection and post to your folder.*	*Make classroom observation of a peer and of a faculty member.*
3, Ideas	Undergraduate panel, discussion of lab feedback and the lab feedback forms.	Difference in calc courses at Duke including placement, expectations of instructor, what happens in teacher meetings, etc.
3, HW	*From labs covered so far, pick one and make suggestions for improvement including why changes should be made from a pedagogical standpoint and the standpoint of the students.*	*Write a new "lab question" based on your proposed changes.*
4, Ideas	Lecturing styles (what to look for in observations), handout on Good Questions by Terrel. Presentation #1	Discussion of labs including observations, suggested changes, assessment and group work. Current state of lab calculus courses. Presentation #2
4, HW	*Read "Seven Years of Project Calc at Duke – Approaching a steady state" by Bookman and Blake. Write a 1 paragraph reflection and post to your folder.*	*Create a rubric for grading a long lab assignment that connects to the Student Learning Objectives of the calculus courses and upload to your folder.*
5, Ideas	Roll over of lab conversations and discussion of rubrics. Grading of lab reports, visit from Dr. Ben Cooke (Academic Resource Center)	Discussion of classroom observations. Presentation #3
5, HW	*Grade sample lab report from this term using the rubric you created and grade sample test problems.*	

Week	Monday	Wednesday
6, Ideas	Discussion of grading samples. Visit from Dr. Paul Bendich for discussion on lab writing "contest."	Writing quizzes and tests. Presentation #4
6, HW	*Lab writing "contest" assignment. Write reflection on the implementation of your rubric for grading the lab report and upload to your folder.*	*Write a sample Quiz and upload it to your folder.*
7, Ideas	Academic dishonesty, balancing teaching responsibilities with research and other obligations. Visit from Prof. Richard MacPhail	FALL BREAK - no seminar meeting
7, HW	*Read and write feedback on quizzes you are assigned to. Post your feedback to your folder.*	
8, Ideas	Writing lesson plans, resources. Presentation #6	Discussion of quizzes and feedback mechanisms. Peer observations. Presentation #7
8, HW	*Write a 50 minute lesson plan on your assigned topic. Upload lesson plan to your folder.*	*Revise and repost quiz based on feedback.*
9, Ideas	Course evaluations, LDOC, heading into finals. Presentation #8	Discussion of lesson plans. Presentation #9
9, HW	*Draft of lab/projects submitted*	*Final presentation assignment and slot assignment*
10, Ideas	Opportunities for professional development at Duke, peer observations, reflecting on your teaching. Presentation #10	Challenging classroom scenarios and campus resources.
10, HW	*Read "Teaching Math graduate students how to teach" by Sol Freidberg and prepare 1 paragraph reflection*	*Final presentation preparation*
11, Ideas	Graduate student panel	Implicit bias and classroom diversity. Visit from Dr. Nyote Calixte.
11, HW	*Final presentation preparation*	*Final presentation preparation*
12, Ideas	Equity	Final presentations
13, Ideas	Final presentations	Final presentations
14, Ideas	Final presentations	Final presentations
15, Ideas	Giving and collecting feedback	Revisiting teaching goals and next steps.

5.2 A TTr Plan Focused on Engaged Student Learning

This course plan was used in Fall 2018. The seminar was facilitated by Jack Bookman and Tori Akin. The seminar was for credit, graded on an A-F scale and mandatory for all first-year graduate students in Mathematics.

The following syllabus emphasizes engaged student learning by modeling various active-learning techniques with the GTAs. Italicized text in the syllabus provides suggested in-class activities for the corresponding lesson plan. Research by Hannah Sturtevant and Lindsay Wheeler at the University of Virginia suggests that many teachers want to have a more engaged classroom but fail to implement active-learning techniques because of the time required to plan effective 3 activities [8]. This syllabus strives to provide a grab-bag of techniques ranging from simple methods that are limited in time and scope to more flexible activities that could require an entire class period. Below, the active-learning strategies in the syllabus are briefly described:

1. Think-pair-share: Students consider a problem individually for a fixed amount of time (30 seconds to 5 minutes). Then, students discuss their thoughts in pairs. Pairs share with the whole group.

2. Think-pair-square: Students consider a problem individually, then in pairs, then in fours. Small groups share with the whole group.

3. Whole-group discussion: Members of the class share competing ideas. Together, the class develops arguments in support of various viewpoints. In whole group discussions, it can be useful to have a record keeper documenting ideas at the board. Randomizing participation with student name cards can help ensure all voices have a chance to be heard.

4. Systematic share-out: Small group representatives report thoughts to the whole group.

5. Exit ticket/reflection card: Students take 5 minutes at the end of class to individually answer a question or ask a question. Students write down their answer/question on a note card and submit as they exit the class.

6. Groups work at the board : Small groups get board space to write down their ideas. By physically restricting the location of written ideas to a common space, this can help groups work collaboratively and exchange thoughts.

7. Polling: Students vote on multiple choice questions. This can be done with hand signals, clickers, slips of paper, or online polling software (e.g. TopHat). This type of active-learning can be useful for large classes because it gives everyone a chance to share an opinion. Contentious questions may spur think-pair-squares/think-pair-shares.

8. Presentation/workshop: Students prepare material outside of class. During class, students present their work. During presentations, other students in the class are responsible for finding mistakes and refining ideas. Instructors try to direct discussion without providing the "correct answer."

9. Brainlist: Students generate ideas by creating multiple lists. Each student begins a list with a single item. Each Student passes their list to a neighbor. Each time a student must add an idea that is not already on the list and that they have not yet already added to different list.

Week	Tuesday	Thursday
8/28/2018	**What makes a good teacher?** Qualities of Good (or Bad) Teaching from teacher and student perspectives. What makes a good teacher? *Think-pair-share: what makes a good teacher?*	**Lab Reflections & Micro-teaching** Discuss challenges from labs from Tuesday; "Micro-teaching" 5-10 min for upcoming lab *Whole group discussion/reflection: takeaways from the first week as TAs; Presentations + anonymous feedback forms*
9/4/2018	**Prepare for classroom observations** Develop an observation form started as a homework assignment *Work in groups of three at the board; Systematic share-out*	Student Beliefs and Mathematics Before class, read "Student Attitudes and Calculus Reform" and "Beliefs and Their Influence on Mathematical Performance," Garofalo. Presentations on readings. *Presentations: randomize order by drawing names from a deck; Exit ticket: ask one question you still have about student beliefs.*
9/11/2018	**Foundations of Math Education** Discuss e.g. Freeman et al report, research on why students leave math *Poll GTAs on what they believe are the most reported reasons for leaving math*	**The Duke Courses** How do the various calculus courses differ? Who enrolls in each course? What kind of content is covered. *GTAs meet in pairs with instructors from one calculus course prior to class. Presentations: pairs report on course details*
9/18/2018	**The Duke Courses, continued**	**Help Room and Lab Situations** Students report on their observations of undergraduate (UG) student behavior in Help Room or lab; Discuss different approaches to explaining an interesting problem or questions *Presentations: one student presents a problem at the board while the whole group offers suggestions; Randomize order by drawing names from deck;*
9/25/2018	**Goals of Calc Course** Comparing our courses with goals of calculus course expressed in research literature *Pairs are assigned one goal from McCallum paper. Systematic share-out: compare/contrast our calculus course goals with the McCallum goal*	**How to plan lessons** Pros and cons of lecture versus discovery learning, and alternatives in between *Brainlist: pros/cons; Systematic share-out*
10/2/2018	**Class observations, No class meetings** Using rubric developed during first week observe both a GTA and a faculty member	**Professionalism** Guest speaker
10/9/2018	**Fall Break**	**Discussion of classroom observations:** Submit observation forms before class *Presentations: randomized order*

10/16/2018	**Asking good questions** Discussion of variety of active-learning techniques and the importance of posing the right kinds of questions to promote student thinking *Work in pairs at the board to develop good questions*	**Present Lesson plans** Presenters project their plans at the front of the room *Workshop to improve presented plans; Systematic share-out: GTAs offer in-person critiques*
10/23/2018	**Presentations: lesson plans**	**University resources** Academic resource center, office of student conduct, academic advising, etc. *Reflection ticket: What questions do you have about resources at Duke?*
10/30/2018	**Making up tests** How to create better in class tests and quizzes and to better explain to UGs how and why tests are used to assess student learning *Presentations: key definitions/concepts that GTAs prepared for homework e.g. formative/summative assessments*	**Critiquing instructor test** Using ideas from previous lesson discuss three example tests; Talk about how to deliver constructive feedback to peers and mentors *Whole-group discussion*
11/6/2018	**Present test/quiz** Presenters project their assessments at the front of the room *Workshop to improve presented assessments*	**Grading tests** Students discuss how they would a grade some sample student exams from an instructor's class *Poll GTAs and display spread of grades for each question*
11/13/2018	**Challenging scenarios** Visit from another faculty member *Role play some common challenging student interactions*	**Assessing your own teaching** Discussion of student evaluations of teaching, how to interpret these evaluations, and other ways to gauge your success *Think-pair-share activity with evaluations from previous semesters*
11/20/2018	**Graduate student panel** An invited team of experienced GTAs discusses common classroom issues. The GTA panel will be given a few prompts in advance, but need not prepare material. Seminar instructors are not present during the panel.	**Thanksgiving break**
11/27/2018	**Course organization** What to tell students before day of class in class policy sheet, ideas for first day activities to set tone for active learning, etc. *Pairs work at the board: what to include in a policies sheet*	**Final Presentations** Each student makes a 15 minute presentation on an undergraduate topic of their choice *Anonymous feedback forms*
12/4/2018	**Final Presentations**	**Final Presentations**

5.3 A MWF Plan Focused on Utilizing Guest Presenters

This brief sample plan emphasizes how guest presenters from across the institution can enrich the seminar. It also illustrates a reorganization of the seminar into three 50-minute meetings weekly.

Fall 2016, Math 771, Teaching College Mathematics:

https://www.overleaf.com/1613464887zwszjjnmcxcj

Emily Braley braley@math.duke.edu, Chester Lian lian@math.duke.edu

Each of you will give a 50 minute lesson on a calculus topic of your choice during the term. These are the lessons starting in the fifth week of the semester.

Week	**Monday**	**Wednesday**	**Friday**
08/29/16	Introductions and classroom norms. Presentation 1-3	Presentation 4-5	Presentation 6-8
09/05/16	Lesson 9. Qualities of a "good" teacher. Watch and discuss video clips.	Lesson 10-11. Observation Protocol.	Lesson 12. Discussion of the reading assignments.
09/12/16	Difference in calculus courses at Duke including placement, PCA, how to access course info online.	Who will you be teaching? AP Trends, student misconceptions, diversity. Data on STEM majors in the US.	Writing lesson plans, resources.
09/19/16	Discussion of grading lab reports. **Visit** from Rann Bar On.	Discussion of lesson plans.	Implicit Bias Training: **Visit** from Ben Reese, Vice President of the Office of Institutional Equity
09/26/16	Lesson #1	Discussion of observations.	Lesson #2
10/03/16	Discussion of grading samples.	Writing quizzes and tests.	Lesson #3
10/10/16	FALL BREAK	Discussion of quiz questions. What are we testing?	Lesson #4
10/17/16	Professionalism in teaching roles: **Visit** from Clark Bray, Supervisor of first year instruction	Challenging scenarios II – interactions with peers and faculty.	Lesson #5
10/24/16	"Asking Good Questions" adapted from a worksheet by Maria Terrel.	Discussion of revised quizzes.	Lesson #6
10/31/16	Discuss Grading of Sample Final Exam Questions	Mid-semester feedback and reflection. How is lab going? Where do you need more support? Where do your students need more support?	Lesson #7
11/07/16	Panel of graduate student **visitors**.	Challenging Scenarios Part III	Lesson #8
11/14/16	Campus resources, **visit** from Ben Cooke of the Academic Resource Center	Heading into finals, LDOC, end of semester business.	Opportunities for professional development at Duke, peer observations, reflecting on your teaching. **Visit** from Hugh Crumley of the Graduate School.
11/22/16	Lesson #9	Thanksgiving Break	Thanksgiving Break

11/28/16	Grading in the L-courses and the block grading system. **Visit** from Sarah Schott.	Reflection on teaching goals	Lesson #10
12/05/16	Lesson #11	Lesson #12	Lesson Make up (if necessary)

6 Activities and support after the pedagogy course

6.1 Practice teaching

In the spring semester of the graduate students' first year, each of them is assigned to present two guest lessons to a class of first year undergraduate calculus students. During these two teaching experiences, the graduate student is observed by at least one faculty member who will meet with him or her after the class to provide feedback and suggestions. Having more than one experience teaching a class allows the graduate student an opportunity to apply the feedback from the observations. The observer is provided with our standard observation instrument (see 9.3) and sends his or her observation notes to the coordinator of TA training.

- The purpose of this practice teaching is twofold. The main reason is that, although the first year graduate students have had multiple opportunities to do microteaching in front of their peers and have been lab TA's, they have not had to design a full one hour lesson and deliver it to a class of undergraduates. Without having the opportunity to do this before they start teaching, their first time doing this would be on their, and their undergraduates', first day of class. Having this early practice teaching experience may reduce some of that anxiety. Furthermore, it would not be practical to observe all new graduate student instructors on their first day of teaching.
- A secondary reason for having the graduate students do this practice teaching is so that we can assess whether the graduate students are minimally able to teach. If they are not, we will provide other opportunities for the graduate students to improve their teaching and they will be assigned other responsibilities to meet their teaching assistantship requirements.

6.2 Subsequent orientation week sessions

After the first year, graduate students attend a more tailored set of sessions during Orientation Week. The focus of their time during that week becomes more specific to their teaching assignment. For example, they do not attend sessions for NEW graduate students (e.g. payroll set up), but do participate in course instructor meetings, Lab TA and Instructor Meeting, the Classroom Issues sessions. In the coordinated courses, we encourage the idea that all instructors and graduate students bring expertise of some kind to the course. Leveraging the expertise and experience of the seasoned graduate student instructors in these sessions is important for building community around teaching within the course and within the Department. One of the meetings during Orientation Week that most helps build the kind of culture we want around teaching is the Lab TA and Instructor Meeting on Day 6. This meeting brings all of the Lab Calculus TAs and instructors into the same space to work through a case study, such as what to do on the first day of class or how to handle group work[4]. The main goal of this session is to establish a culture of reflection that focuses on student learning and sets the tone for the collaboration that will take place on the teaching teams within each course during the semester.

6.3 Teaching observations

During their first semester as instructor of record, each first-time teacher is observed twice by a regular rank faculty member. After each observation, the faculty member and graduate student meet to discuss the lesson that was observed and reflect on what went well and where there is room for improvement. During the second observation, the observer looks to see whether the GTA incorporated suggestions from the first observation. Typically, teaching faculty conduct the classroom observations, but research faculty sometimes assist. A written record of the observation is kept on file for each GTA in order to track progress over time. These written records help inform future recommendation letters. A current version of an observation form can be found in the appendix.

Reflection/discussion questions post-observation:

1. What is one thing you think went well?

2. What is one thing you think you should have done differently?
3. What were the students doing during class?
4. What were the main student misconceptions, if any? What did students learn/understand? How do you know?

6.4 Continued mentorship and support

Most of the continued support to graduate student instructors is delivered during weekly teaching meetings in the coordinated courses that the graduate students teach in. These meetings are intended to support the graduate student instructors by cutting down on their individual preparation time and keep consistent the messaging across all of the sections in the course. A typical 60 minute teaching meeting will usually break down like this:

- **Recap of last week - 10 minutes:** How were the last three lessons? What are the students struggling with? Did any of the worksheets we used work very well this week? Is there anything we should spend more time on?
- **Administrative items - 5 minutes:** What are the administrative items we need to be on top of in the next week or two? This might include writing exam questions, grading lab reports, returning exams in a timely matter, following up with students who need extra support, and so on. There are also major University wide events that instructors need to be informed about, like add-drop period closing, mid-term grade submission deadline, etc. It is very helpful for novice instructors to have a short list of reminders for the upcoming weeks.
- **Upcoming lessons - 30 minutes:** What is happening in the next three lessons? How do these lessons fit into the overarching story line of the course? What is the content that the students will be challenged by? Where are there BIG opportunities for an active component in each lesson? What are the homework problems to look out for in the help room? How should we communicate about these lessons with the other course staff (TAs and help room staff.)
- **Connecting to the lab - 10 minutes:** What is happening in lab next week? Where does the lab content fit into the story line of the course? When and how can we weave the lab content into the other lessons of the week?
- **Reminders and follow-up - 5 minutes:** Wrap up the meeting by reinforcing the reminders for the next couple of weeks and plan any follow up conversations that might be necessary regarding specific issues that have come up or specific students. Examples of this might be:
  - A graduate student instructor needs help figuring out how to support a student who failed an exam and then missed a scheduled meeting with the instructor.
  - A graduate student instructor wrote an exam that was too easy or too hard and the course coordinator wants to schedule a meeting to look at it together and make changes.
  - The graduate student instructor is concerned with the grading of the homework and wants to look at the grades with the course coordinator and make a plan for how to discuss the grading issue with the grader assigned to the section.

6.5 Self evaluation

Student evaluations of teaching (called Teacher Course Evaluations, TCEs, at Duke) are an important but problematic way of evaluating teaching. Philip B. Stark and Richard Freishtat (University of California, Berkeley, statistics department and the Center for Teaching and Learning, respectively) report

> *"The common practice of relying on averages of student teaching evaluation scores as the primary measure of teaching effectiveness for promotion and tenure decisions should be abandoned for substantive and statistical reasons: There is strong evidence that student responses to questions of 'effectiveness' do not measure teaching effectiveness."*[10]

There are also multiple studies documenting the gender and racial bias in these instruments. This does not mean that there isn't value in student evaluations of teaching (SET). Taken together with classroom observations and other assessment methods, these SET's can provide productive feedback to college instructors. In particular, they provide a good window in to how students think about how they learn and what they believe is good teaching. As with other preconceived notions about learning and mathematics, understanding these attitudes is an important part of improving our teaching. However, one must be judicious in the of use these instruments and avoid using them as the only method of evaluating teaching performance. In order to help first time teachers better understand and benefit from their student evaluations we ask them to complete a self-evaluation after they have received copies of the student evaluations. They are given the following instructions:

Once your teacher-course evaluations are available for you to read (sometime in January) and after you've read them, I'd like you to **write** a self-evaluation addressing the following questions:

1. What are your greatest strengths as a teacher?
2. What are your greatest weaknesses as a teacher?
3. What is the aspect of your teaching you would most like to improve and how do you plan to do that?
4. Think about an important idea from the course that you tried to get the students to understand. What was that idea? Why was it important? How did you present it? To what extent did the students learn this idea? How do you know?

After I've finished reading your teacher-course evaluations and after I've read your self-evaluations, we will schedule a conference to discuss your TCEs.

6.6 Experimental spring workshops

In the past, the teaching faculty in the math department have occasionally joined with other offices on campus to provide supplemental spring workshops for all faculty in the Department, including graduate student instructors and junior faculty. These workshops were aligned with the changing needs and different teaching initiatives taking place in the Department. For example, teaching faculty together with the Office of Assessment at Duke conducted a session on backwards design for new courses and for supplemental course projects that could be proposed by graduate student instructors. The goal of that session was to help novice instructors, who were about to design a course or component of a course, think about how to be use data gathered from various kinds of assessments to determine whether the students were meeting the course's learning objectives. Another spring workshop partnered with the Office of Institutional Equity where participants were invited to examine and reflect on implicit bias.

7 Discussion, Room for Improvement and Future Goals

When the seminar was first developed in 1987, the ideas for the seminar were adapted from Bookman's preservice training as a prospective high school teacher and from his experience in teaching secondary and post-secondary mathematics. At the time he was a graduate student in Education and he also drew some ideas from his course work in that program. The seminar was, and continues to be, somewhat informal. There are assignments to be done outside of class but the time demand is significantly less than that of their first year graduate mathematics content courses. This was a conscious decision based on an attempt to minimize resistance from some of the graduate faculty who were concerned that the time graduate students spent thinking and working on teaching would come at the expense of their preparation for research.

During the 1990's, discussions about calculus reform informed much of the content of seminar, largely because the graduate students were assigned to teach these new labs and new courses. The content, pedagogy, philosophy and intellectual basis of these reformed calculus courses were radically different than what most of the graduate students experienced in their own calculus classes, even the graduate students who had been educated in the US. Duke University was the site of one of the first large-scale calculus reform projects

funded by the National Science Foundation (NSF award #8953961). The developers, Lawrence Moore and David Smith of Duke University, designed a course whose key features were real-world problems, hands-on activities, discovery learning, writing and revision of writing, cooperative learning, and using technology as an integral part of this process of formulation, solution, and communication[11]. As program evaluator for the grant, Bookman was able to collect lots of data - both quantitative and qualitative - and share the insights gained with the graduate students in the seminar. The grant also provided funding for conference travel and this enabled Bookman for the first time in his career to attend conferences and meet and learn from other mathematics educators. In addition, at these national meetings, Bookman met other faculty (notably Pat Shure at University of Michigan and Dorothy Wallace at Dartmouth College) who were beginning to develop programs for preparing graduate students to teach undergraduate mathematics. This was an important opportunity to learn from others and to cross-pollinate ideas; until then the intellectual basis for the Duke's TAPD program came only from Bookman's experience and his conversations within Duke University.

In the early 2000's, the National Academy of Science published How People Learn: Brain, Mind, Experience, and School: Expanded Edition[9]. This book summarized current research in cognitive and development psychology and discussed how this research could inform how educators could construct more effective learning environments for students. In particular, it explained how people learn by constructing new knowledge and understandings based on what their prior knowledge and beliefs. The ideas were introduced to the graduate students in the teaching seminar and became the intellectual basis for how we wanted graduate students to think about their teaching. At the same time, there was much research being conducted and published on the benefits of cooperative learning and this research informed some of the discussions in the seminar.

Since Bookman's semi-retirement in 2012, new faculty have led the program and this has provided an opportunity to revitalize and rethink the goals and content of the program. To provide continuity, Bookman has served as an advisor and mentor to the new faculty leading the program. The involvement of faculty in CoMInDS, including attending workshops and participating in the CoMInDS Community of Practice, has brought new ideas to the work of providing professional development to graduate student instructors and TAs. In particular, we have tried to emphasize, and model, in each seminar meeting the importance of inquiry based teaching practices[5].

Much of the intellectual basis discussed above has focused on the content of our TAPD program. As we move forward, our work would be improved if we became more informed about how graduate students learn to teach. Although there is less research done in this area than in how K-12 teachers learn to teach, we should learn more about what is known and advocate for more such research. Furthermore, there has been little work done, or understanding about, evaluating the extent to which TAPD programs are effectively preparing graduate students to teach. This is a national problem and a need that is universally identified as important by providers of TAPD. Another need the national TAPD community has identified is for high quality observation tools for graduated student teaching. We have developed an observation instrument at Duke which we have used for many years. Although it has face validity, its validity and reliability ought to be more formally evaluated.

The Duke Math teaching faculty have become more connected to the Math Education research community. The Progress through Calculus research team (NSF grant DUE I-USE #1430540) reviewed Duke's introductory-level math program in 2017 and 2018. In their review, they recommended extending Duke's semester-long pedagogy course to include an additional course for instructors teaching for the first time. In order to offer even more support to graduate students as they first begin their role as instructor of record, the Department has also considered hiring a "teaching coach." The teaching coach would complete classroom observations; workshop lesson plans, homework problems, and test problems; and help troubleshoot any tricky situations with undergraduate students. Shira Viel and Tori Akin will take the lead on assessment of the Math Department's current courses. They plan to begin a systematic evaluation of the semester-long pedagogy course, described in detail in this document, for first-year graduate students. We recognize that this is a difficult task and are going to take first steps to better understand the extent to which our efforts are successful.

We have identified some other areas where we would like to improve our program:

- using peer observations and building on the work of Rogers and Yee (Collaborative Research: Implementing a Peer-Mentorship Model for Mathematics Graduate Student Instructors, Award Ids #1544342, #1544346)

- making better connections with the ESL faculty in the graduate school
- learning more about how to incorporate research about knowledge of student thinking into the orientation week activities, the seminar and weekly course meetings
- earlier intervention, with midsemester student surveys together with faculty observations, to help identify and correct any problems
- As we make changes in the undergraduate program (e.g. a move toward standards based grading, see [12]) this will require additional professional development for the graduate students who will need to implement and explain new systems to the undergraduates.

8 Lesson Descriptions

This section describes lessons that are used either in the Orientation Week sessions or the semester long Pedagogy Course for professional development for graduate students in Mathematics. All of these lessons are linked to the sample schedules for the Pedagogy course or Orientation Week, where they have been used. All of the lessons are organized in a similar format where we give a synopsis of the lesson and identify the goals of the lesson. We also include the rationale behind the lesson that reveals some of the motivation for why things are taught in a particular way at Duke. We also list the preparatory homework and materials that may be required for the activity and then give an overview of how the lesson is implemented in the session. Some of these lessons will work well as stand-alone sessions, while others are strongly tied to the arch of the pedagogy course.

8.1 Classroom Issues

Synopsis

This activity has become a staple in the Orientation Week schedule and is a mandatory session for all graduate student instructors (both new and experienced.) The scenarios are tweaked from year to year because there is substantial repeat participation each Fall. One nice aspect to having more experienced graduate student instructors participate, is that they can give appropriate responses based on their experience that help generate buy-in among the new graduate student instructors.

Goals

The goals of this activity are to deliver a substantial list of do's and don'ts while empowering the experienced graduate student instructors to share their knowledge and experiences. A secondary goal is to reinforce to all of the graduate student instructors that the course supervisors are a resource for anything that might come up with students both in and out of the classroom. This is a point that is typically echoed by the seasoned graduate student instructors.

Rationale

The list of scenarios included below are not intended to stretch or challenge the participants, but are intended to deliver do's and don'ts in a collaborative way. Some of them are to get the graduate students thinking about planning (should they make up groups for students ahead of time) and some have a correct answer (if the tornado sirens go off, stop teaching and take your class to the basement of the building.)

Preparatory Homework

There is no preparation required for this session for graduate student instructors.

Materials

We typically don't hand out a list of prompts but rather project the prompts on slides.

Introduction

We usually introduce this activity by asking graduate student instructors to actively participate and welcome them to take notes during the session.

Directions for use

Summary activity

Scenario prompts that are projected during the session:

- You have students working in pairs on a problem and there is a student who has not found a partner or group and is using their phone instead of attempting the problem.
- You ask your class to break up into pairs or small groups to work on a problem.
- There is one student in the middle of the room whom everyone turns away from. As they start working, this student is looking around but cannot find a partner. You have a student that sits in the front row every day and challenges you as you lecture.
- At first you handled the constant interruption by turning the students questions back to the class but as the semester wears on you (and the rest of the class) are losing patience with what has become a disruption.

- It's become abundantly clear to you that two students in your class has a falling out. They used to sit beside each other every day and now are on opposite sides of the room and don't make eye contact with one another. You know they are also assigned to the same lab group. They both failed the last homework quiz. You notice that a student has not been in class or lab for over a week.
- A student approaches you after class and tells you that one of their lab group members didn't contribute to the preparation of the lab assignment and didn't respond when the group reached out to set up a group meeting. The rest of the group feels that this student shouldn't get the same grade on the assignment.
- A student approaches you after class and tells you that their lab group got together without them and they didn't get to look over the lab report before it was submitted. Now this student is dissatisfied with the group grade that was given and doesn't think it is fair.
- You have a student that has failed three consecutive homework quizzes and just got a D on the first midterm exam. They ask you if they should withdraw. You have a student who has consistently doing work in the B range. You haven't talked to this students outside of class very much, but you have seen them in the help room several times. They approach you before class with a withdrawal form and ask for your signature.
- A large poster advertising student presentations on "teaching for racial equity" is defaced on campus prompting a student protest. Protesters march around the campus and past your classroom window. All of the students look out of the window to see that two of the students in your class are skipping to participate in the march. Your class tells you that only one of your lab TAs showed up for lab on Tuesday and the other lab TA was clueless and couldn't help them.
- You are in the help room and hear a student really bad mouthing their teacher, who is one of your grad student colleagues.
- You get to class early and a student comes up to argue about his midterm grade. He gets more and more heated. By the time class is set to begin, he is yelling at you in a threatening way.
- Every time you pose a question to the class, the same student immediately calls out the correct answer. The other students become intimidated, and are not participating.
- You are grading your midterm exams, when you become certain that two students were copying off of one another. You know that they are friends and were seated next to one another during the exam.
- While lecturing, you hear students in the back row talking. At first, you let it slide, but it has continued, and is clearly bothering other students nearby.
- A student in your class faints during lecture.
- With 20 minutes left in class everyone's phones start beeping loudly. There is a tornado warning where campus is threatened. The warning message states "Everyone should take cover immediately."
- You hand back the first midterm exam and one of your students in the back of the classroom is crying and loudly sniffling as you begin the lecture.

Assessment

Follow-up/Extension activities/Other versions of this activity

There are a lot of context specific prompts in this session that can be updated and changed to address specific challenges at individual institutions.

8.2 A discussion on equity in our classrooms

Synopsis

This lesson starts with a hands-on activity for participants. The task is simple: create a mobile with any theme you would like using only the materials provided in the brown paper bag provided. The activity grounds the conversation that follows in a shared experience.

Goals

The goal of this activity is to reflect on the student population in our classrooms. What resources do the students have access to? What ways do the students differ? How might these differences impact how the students are able to access the course and course resources? How can we design and structure classes to serve all of the students in our classroom?

Rationale

By starting with this hand-on activity GTAs have an opportunity to reflect on how it feels to be in a "diverse" classroom. Do they notice that there are other groups with more/fewer materials to work with? Do they ask each other for help or to share? Do they accept help/materials from another group? How does it feel to be in a group with little to no supplies while making the mobile? How does it feel when everyone is showing their mobile to the class and it becomes clear that there were groups with very different sets of resources? This grounds the conversation about our own classrooms in a concrete experience of inequity in the room.

Preparatory Homework

There is no preparation necessary for this activity.

Materials

Each group with be provided a brown paper bag with supplies. The key idea to successfully setting up the activity is that the bags contain varying "levels" of supplies. For example, one group may get a coat hanger and a brown paper bag with brown construction paper, a black magic marker, and yarn, but without tape/glue or scissors. Then another group might have a coat hanger and a brown bag with different colored paper, glue, tape, scissors and a hole punch, a variety of colored pencil colors, stickers, and glitter gel pens.

Brown paper bags (1 per group)
Coat hangers (1 per group)
Markers, colored pencils, crayons
Stickers
Paper: white paper, construction paper and/or other craft paper
Yarn or string
Scissors and hole punchers
Glue stick
Tape
Any other craft supplies that could "enhance" a mobile

Introduction

All groups should be given identical instructions: Using only the materials in the paper bag and the coat hanger provided, create a mobile.

Directions for use

I like to set up the classroom ahead of time by putting the desks or tables into clusters for group work if they are not arranged that way already and put materials for each group on the tables.

Once class starts, I give the single instruction "Using only the materials in the paper bag and the coat hanger provided, create a mobile." The students typically chat as they build the mobile and I take the opportunity to check in with them. I let them work for 10-15 minutes.

I invite the groups to tell the class about their mobile. What theme is it based on (if any)? Did they have fun making it? (5 minutes) I prompt the class with the following questions to drive the conversation moving forward: *What did you notice as we shared the mobiles?*

Did anyone notice the difference in the supplies before the show and tell session? How did you feel?

For the next few questions, it is nice to have a record of the resources and best practices generated from the conversation. I have an idea of the list of these ahead of time (which is institution specific) and try to make sure they all come up in the conversation. This list includes things like the mental health services, how to borrow a laptop from the library, student organized affinity groups on campus that are known for supporting academic work, the women's center, the academic resource center (for advising/tutoring and study habit coaching) and more. The graduate students don't need to memorize this list, but it is nice to have an internally generated resource list.

What differences in resources/access will the students in our classes have from one another?

This is usually where we spend the bulk of our time discussing and the graduate students typically share stories from their own experience.

What can we do and what can we be thoughtful about as we prepare to meet the needs of all students in our classrooms?

This conversation can often lead to understanding the network of resources available to students and how to help them navigate that network. This is an important time to make sure you talk about access to technology.

The main takeaway here should be that more structure in the classroom is better! This leads to a conversation about the principles of universal design for the class. I like this short article *** REF *** that describes universal design and provides resources to learn more.

Summary activity

To close, I give the graduate students a "minute paper" described below.

Assessment

Ask the graduate students to do a "minute paper" at the end of the session with a prompt: What was the theme the activity meant for us to reflect on today? What was one new thing you learned? I like this prompt because it gives the facilitator a good idea of whether or not they achieved their goal in the session. It can also help inform future sessions.

Follow-up/Extension activities/Other versions of this activity

I like the linked article about universal design for the classroom as a follow up reading to this activity. You could come up with many different artifacts that you ask the class to build other than a mobile.

8.3 Writing Exams, In Class, Discussion Guide

Synopsis

This document outlines a list of topics a Provider of TA PD might want to consider discussing in leading a one class period seminar class about creating in class tests and quizzes. For each sub-topic (e.g. setting or purposes) seminar participants are asked to brainstorm about what issues need to be considered in making up a test. Some parts of this activity (e.g. the difference between norm reference and criterion referenced tests) may require students to do some work in advance or require the facilitator to make a short didactic presentation. Some facilitators may choose not to address all the issues raised in this activity and others may want to include other things. The parts of this activity that I spend the most time on and are of most important to my students are the sections about content selection and issues in item selection. The discussion of communicating the results of the tests is also critical especially when communicating these test results to first year college students fresh out of high school who bring expectations about what mathematics tests and grading is supposed to be like.

Goals

TA's will learn to write less terrible tests and quizzes and to better explain to their students how and why the tests are used to assess student learning. TA's will also learn about the limitations and sources of measurement error in using tests to assess student learning.

Rationale

Undergraduates take grading and testing very seriously and it is important that instructors understand how to make effective tests. Most of the concerns and complaints raised by undergraduates are related to their perception of the quality and fairness of the tests and the grading of those tests. Understanding the purposes of testing and aligning assessment with the goals of the course are minimally essential concepts for teaching at the undergraduate level.

Preparatory Homework

It is not necessary to have an assignment that participants complete before the class where this activity is done, but I assign subgroups of students to read something about one of the following ideas and to prepare a two-minute presentation to the class explaining the meaning of the idea:

What is the difference between norm-referenced tests and criterion tests? To what extent are in class tests like either of these?

In terms of educational or psychological testing and measurement, what is meant by validity? what is meant by reliability? What factors will affect the validity and reliability of class tests?

What is standard based grading or mastery grading? What are the pros and cons?

What is our institution's academic integrity policy? What should you do if you think someone is cheating?

What does "alignment" mean in terms of testing?

What do we mean by "discriminating" in terms of test questions?

Materials

None

Introduction

Ask seminar participants to brainstorm about what they think are some of the purposes of tests and quizzes. The handout provides some things the provider may want to add to the discussion if not mentioned by TA's.

Directions for use

I usually discuss things in the order presented in the attached document,Creating In Class Tests, (also given below) though I often will skip, postpone or just briefly mention some things (usually test security) if there is a productive discussion of other things and time becomes a factor. If the facilitator desires to do so, he or she can hand out a checklist of questions the instructor needs to answer while constructing test (i.e. questions in setting, content and item selection, and communication).

8.4 Asking Good Questions

Synopsis

In this lesson, we discuss developing good questions to ask during class. We consider how different classroom structures are conducive to particular types of questions. Students look through a list of curated questions and rate the questions based on clarity, difficulty, conceptual content, and appropriateness. Then, students have an opportunity to write their own lesson-specific questions and present them to the rest of the class. The lesson uses material from Maria Terrell's Asking Good Questions project [6].

Goals

The primary goal of this lesson is to help GTAs develop questions that challenge students at the right level and promote active learning. The secondary goal is to provide GTAs with ideas for how good questions can be implemented in various active learning models that include peer discussion.

Rationale

As reported by Maria Terrell, (Miller, Robyn L., Everilis Santana-Vega, and Maria S. Terrell. "Can good questions and peer discussion improve calculus instruction?" Problems, Resources, and Issues in Mathematics Undergraduate Studies 16.3 (2006): 193-203.), instructors often ask low-level questions that reinforce mechanics but are not conducive to active learning because they do not require discussion. Peer discussion of conceptual questions improves learning outcomes. By asking good questions and using strategies for peer instruction, GTAs can spark classroom conversations that support learning.

Preparatory Homework

Optional
Read: "Can good questions and peer discussion improve calculus instruction?" by Terrell et. al.
Written reflection:

- Give an example of a "less than ideal" question. What does the question lack? How could you improve the question?
- Is the key to a successful classroom asking the right questions?

Materials

- Slides of good questions (from various sources)
- Copies of textbook pages from a GTA-lead course

Introduction

What is a good question? What are some qualities of good questions? Have pairs brainstorm and share their list with the whole group. A list might include:

- Related to in-class material
- Accessible
- Challenging
- Conceptual (?) or are mechanical questions also good (?)
- Clearly defined (?) or is is nice to be open-ended (?)

While many different types of questions can be "good," We want to inspire active thought and lively discussion. It is not enough to ask the right questions; as instructors we need to stimulate peer-to-peer discussions and encourage students to develop arguments. What are some ways that you can ask a question and engage students? A list might include:

- Think-pair-share
- Polling/clickers/holding up a number
- Whole group discussion: The instructor collects multiple perspectives from students. Several students offer and refine ideas while the instructor records at the board but does not necessarily weigh in on correctness.
- Group quizzes: Possible model in which students first take the quiz individually and then retake the same quiz as a group.

What is the relationship between asking good questions and promoting active learning?

Directions for use

The activity can begin with an overview of what makes "good" teaching. (If this activity is used as part of a semester-long course, that may mean reminding GTAs of a previous lesson. Or, if this activity is used in isolation, this can be a quick listing of ideas.) Instructors typically agree that part of a "good" classroom is having engaged students, and one way to engage students is by having them ask and answer questions. In this activity we will

1. Look at research that suggests that questions help students learn and that the structure used for asking questions impacts learning outcomes.
2. Consider example questions and evaluate them on their strengths/weaknesses.
3. Practice writing our own questions to inspire students to think critically and deeply.

Provide GTAs with a brief overview of Maria Terrell's good questions project. Emphasize that peer discussion has the biggest impact on performance.
Provide GTAs with several examples of questions from Maria Terrell's project, and other types of good questions. The calculus questions developed for use at Cornell may be more theoretical than good questions for different courses at other institutions. Evaluate the strengths and weaknesses of the questions you present. Come up with a running list of qualities for good questions. (Qualities may include: open ended, low floor/high ceiling, demonstrates a key concept, demonstrates a typical misconception, inspires debate, etc.)
Assign pairs of GTAs a particular mathematics topic. Have them spend 15 minutes creating questions at the board. Groups present their ideas to each other.

Assessment

Assignment: Write 5 good questions at different levels (at least one low floor-high ceiling) on a given topic

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9 Appendix

9.1 Duties and pay for lab TA work

This is a sample of the duties and expectations that is handed out to undergraduate and graduate students working in the introductory calculus classes.

- Duties:
  1. Work through the lab yourself to prepare.
  2. Attend a meeting of about 30 with the course supervisor to discuss the lab and material before the lab meets. It may be the preference of some instructors that you also meet with them separately.
  3. Be to your assigned lab early to organize students into groups. You will work with the teacher to assign students into lab groups.
  4. Give introduction to the lab including (in some cases) a review of prerequisite materials.
  5. Walk around the room throughout the lab answering questions, talking with students, and facilitating group discussion about the lab material.
  6. Follow up with your instructor after the lab. This includes submitting a lab feedback form if it is required by your course supervisor.
  7. Help with grading of reports and quizzes from lab. You cannot grade exams or any other course material.
  8. Work at least one hour a week in the math help room.
  9. Notify the course coordinator and your instructor if you will not be in lab. You are responsible for finding a substitute for yourself if you cannot be in lab or the help room.
- Organization:
  The instructor for each section is in charge of the lab attached to their class, even if the teacher does not attend lab. Each lab will be run by two lab staff members. These pairs could include the class instructor, an undergraduate TA, or a graduate TA. Both staff members are responsible for helping in the lab and one TA will be assigned as the "lead TA" and is responsible for follow up with the class instructor. Grading may be shared by both staff members.
- Total time:
  Your time commitment on a week to week basis will vary as the difficulty of the labs and grading assignments vary. You can expect to work roughly 1-8 hours per week. The department estimates for one lab assignment you will spend (and therefore bill to the department) an average of 4-5 hours per week.
- Pay:
  For undergraduate students, the pay rate for this position is $10.50 per hour. This rate applies to all of the work, whether it's participation in weekly meetings, individual preparation for the lab, working in the lab itself, grading papers, or helproom work. Please be sure to submit your time cards in a timely fashion else you will not receive pay. For graduate students, this time is contracted in your stipend letter.
- Materials:
  You can check out a course pack in Physics 117. Any solutions, notes, or guides will be provided at weekly meetings by the course coordinator. Solutions for grading will be provided by the course instructor or course coordinator.

9.2 Sample Orientation Week Instructor Meeting

This is a sample agenda for a first meeting of the semester during orientation week for all teachers in Calc 1. This list of topics is intended to be a review for seasoned teachers and help new instructors navigate the resources most commonly used during the term.

Math 111L Teacher Meeting Agenda
Fall 2016 Training Week

- Instructor's Handbook
- Course Syllabus
  - Final Exam
  - Thursday, December 15
  - 9:00 am - 12:00 pm
- Instructor's Syllabus
- Course Policies
  - Supervisor of First Year Instruction approved discussion on grading
  - NEW: no calculator on midterms or final exam
- Class Policies and Consistency
  Please include:
  - your contact information
  - your help room hours
  - homework information
  - Office Hours and Help Room
  - Student privacy (FERPA)
  - Reporting

  May include:
  - classroom policies
  - communication guidelines
  - best practices
  - lab report guidelines
- Joint Sakai Site has information for all sections
  - Post semester midterms after they are given
  - No practice exams
  - No previous exams
- Individual Sites
  - Class Policies
  - Gradebook
- Lab Meetings and working with TA's
  - Communication is key
  - Labs are an integral part of the course that will be tested on the final
  - Roles of TA's and Instructors outlined in Instructor Handbook
- Tests
  - 3 midterms per the syllabus
  - Students requiring accommodation – 25Live, Physics 123, Help Room
  - Final Exam
- Gateways
- Resources
  - Resources for your students:
    * you
    * the help room
    * Academic Resource Center (ARC)
    * Peer Tutors from ARC (they can also hire private tutors)
    * Counseling and Psychological Services
    * Neighborhood Deans
  - Resources for teachers:
    * Emily - braley@math.duke.edu, (—) ——— (cell)
    * Clark - cbray@math.duke.edu
    * TRAP: https://www.math.duke.edu/trap/, this is a resource suite with lesson plans and worksheets
    * Experienced teachers in the course with us: Rome, Pan, Brian
    * Neighborhood Deans - you should feel free to reach out with student concerns
    * 25Live: http://events.duke.edu/facility/25Live/, this is the website where you can book classroom space as needed

- Professionalism
  - In the classroom
  - In email and other correspondence
  - Outside of the classroom
    - students
    - help room
    - with each other
- Pre-calculus Assessment Test
  - Each teacher finds their section number in column A of the 'Raw' sheet
  - Under that section number, paste in the names of your students
  - For each student, put the letter answer that student chose in the correct column.
  - If a student skipped an answer, put 'n' (this is important!)
  - Once a row is filled in, the score appears in column AB.
- **Important Dates**:
  - August 29 – Classes start
  - August 30 – PCA given and student responses input
  - September 2 – Waitlists erased
  - September 9 – Drop/add ends
  - September 27 – Test 1
  - October 7 – Midterm grades due
  - October 10 – Fall break
  - October 11 – Fall break
  - October 12 - Classes resume
  - November 1 – Test 2
  - November 23 – Thanksgiving break
  - November 24 – Thanksgiving break
  - November 25 – Thanksgiving break
  - November 28 - Classes resume
  - December 6 – Test 3
  - December 9 – Classes end – All students must complete Gateway
  - December 15 – Final Exam 9am-12pm, teachers proctor and grade the final

9.3 Observation Form

Classroom Observation

Instructor's Name: _____ Evaluator: _____

Class: _____ Location: _____ Date: _____

Number of student's present: _____

Start Time: _____ End Time: _____

Brief description of topic(s):

1. **Lesson Plan**
   Please describe the form of presentation: (e.g. lecture, group work, etc.). Please comment on: the degree of preparation and organization; whether the plan was appropriate for the topic being taught; whether the lesson plan included or should have included appropriate use of technology or other instructional devices; and anything else you feel is important.

2. **Classroom Activities and Atmosphere**
   Please describe what the students were doing during the class. Please comment on: the attentiveness of the students; the degree to which students felt free to ask questions; the interaction of the teacher with the class as a whole and with individual students; the interaction of students with other students; and anything else you noticed about the classroom atmosphere. Is the teacher friendly, patient, and approachable?

3. **Teaching**
   Please comment on: how well the lesson was delivered; the clarity of exposition; any effort on the part of the instructor to assess students' learning; whether the instructor had difficulty with the use of or whether the instructor effectively used instructional devices (e.g. the blackboard, calculators, classroom computers, overhead projectors, hands-on props, etc.); and anything else you feel is important.

4. **Checklist**

A. *Lecture Component, if applicable*

speaking:	clear	- - - - -	not clear
	faces class	- - - - -	faces board
	too loud	- - - - -	too soft
eye contact:	good	- - - - -	needs improvement
preparation:	knowledgeable	- - - - - -	needs improvement
	organized	- - - - - -	disorganized
reliance on notes:	too much	- - - - -	too little
explanation:	clear	- - - - -	not clear
board work:	orderly	- - - - -	messy
interaction with class:	polite	- - - - -	impolite
level of questions asked:	too high	- - - - -	too low
lecture helped students learn:	yes	- - - - -	no

B. *Active Learning Component, if applicable*

preparation:	organized	- - - - - -	disorganized
level of questions:	too high	- - - - -	too low
moved around room:	too much	- - - - -	too little
time spent:	too much	- - - - -	too little
activity helped students learn:	yes	- - - - -	no

5. **General Comments**
Suggestions for improvement:

Other comments:

9.4 Lab Prep Document

Log Plots Lab

OVERVIEW

Students will plot datasets and determine the relationship between the independent and dependent variables. Plots will look curved in the x-y plane. Then students will translate the datasets onto a log scale where the data may look linear. Students can use the equation of the line in a semi-log plot or a log-log plot to recover the equation of the original curve.

GOALS

- Determine whether a data set has a linear, exponential, or power relationship.
- Write down the equation for the line of a semi-log plot or a log-log plot, depending on the data.
- Use $\ln(x)$ as the inverse of e^x.
- Review properties of logarithms and exponentials, equation for a line.
- Use spreadsheets to visualize data.

BEFORE CLASS

- Coordinate with instructor:
  - Assessment: Log plots quiz next week, or lab report. Check on due date of lab report.
- Work through the lab
- Write on the board:
  - **Parts of the lab to omit:** Exercise I of Part II
  - Log and exponential rules table

Logarithms	Exponentials
$\ln(AB) = \ln(A) + \ln(B)$	$e^a e^b = e^{a+b}$
$\ln(A/B) = \ln(A) - \ln(B)$	$e^a / e^b = e^{a-b}$
$\ln(A^p) = p\ln(A)$	$(e^a)^p = e^{ap}$
$\ln(e^x) = x$	$e^{\ln(x)} = x$

  - Open spreadsheet in Sakai under Resources→ Lab Material F18→Log Plots Lab
  - Solution equations for Ex 2a and Ex page 15.

INTRODUCTION

- Time: 15 minutes
- Discuss:
  - How will students be assessed on the lab?
  - Exercise I of Part II can be used to study.
  - Give overview of lab
  - Review the idea that $\ln(x)$ and e^x are inverses.
    Draw plots x vs. e^x and x vs. $\ln(e^x)$.
    If you have time, draw plots x vs. x^2 and $\ln(x)$ vs. $\ln(x^2)$

CHECKPOINTS

- Exercise 2a: The original plot and semi-log plot will both look almost linear, but the original plot will have a slight curve. Ask students how they can test to see if a dataset has a slight curve?
  One thing they can check is whether or not the Δy are increasing. They should create a spreadsheet column that computes differences in the y values.

- Before students leave: Two data points in a semi-log plot are (1, ln(2)) and (2, ln(5)). If the semi-log plot is linear, give the equation of the curve formed by the data points (in the original plot). If the log-log plot is linear, give the equation of the curve formed by the data points (in the original plot).

NOTES

- In class the students will have covered:
  - Functions and Inverses: $\ln(x)$ is the inverse of e^x.
  - Exponential equations/growth/decay
  - We will (in future classes) talk about how "curved" the graph of a function appears in the context of first and second derivatives. This lab gives us a different way of identifying when data has an exponential curve (all derivatives positive) or polynomial (eventually derivatives are 0) without talking about derivatives.
- Common errors:
  - Some students will have trouble seeing $\ln(y) = \ln(3) + t\ln(2)$ as $\ln(y) = mt + b$. If they get stuck, be ready to show them that if them exponentiate $\ln(y) = mt + b$ they will get $y = Ce^{mt}$. Show them a picture of the line and the exponential curve.
- In Exercise 2 (b), the conclusion will be that the semi-log plot produces a graph that is concave up. This means that the values are growing *faster* than exponentially. (So the relation ship among the data is neither exponential nor polynomial. If students are interested, you can tell them this is called "super-exponential".)
- A main idea of this lab is that it is easy to compute the equation for a line and we can leverage this easy computation to make more complicated models. In particular, we can use lines from semi-log plots or log-log plots produce an exponential or power model.

  Students should not produce an exponential or power best-fit curve from spreadsheet functions without knowing the underlying mechanisms. They should produce the equation for the power or exponential curve themselves. They should use the ideas about logs/exp/inverses that we covered in class.
- Students need to be able to do two conversions:
  1. If they have the equation for the line in a semi-log plot or a log-log plot, they should be able to find the exponential or power equation of the original function.
  2. If they have an exponential or power function they should be able to convert to the equation of the line in the semi-log plot or log-log plot.

SOLUTIONS

Part II

- In Part II of the lab you will need to remind students that the y-intercept of $\ln(y) = mt + b$, dictates the initial value of the exponential model: $y = e^b e^{mt}$. (That is, the initial value at time 0 is e^b.)
- Students may omit Exercise 1.
- In Exercise 2, encourage the students to use spreadsheets to practice manipulating the data!
- In Exercise 2 (a), A possible model (answers will vary based on rounding and the points from the semilog plot the students use to get an equation for the line):

  $$y = 4.2e^{-.14t}$$

  This equation means the slope of the semi-log plot is approximately $-.14$.

- In Exercise 2 (b), the conclusion will be that the semi-log plot produces a graph that is concave up. This means that the values are growing *faster* than exponentially. (So the relation ship among the data is neither exponential nor polynomial. If students are interested, you can tell them this is called "super-exponential".)
- In Exercise on page 15, the log-log plot should have a slope of approximately .25 and and the original function should be close to

  $$y = 3t^{.25}.$$

Investigations

- In Investigation #1 the students are given a data set and asked to find an expression that gives the distance fallen as a function of velocity. Then test the function by graphing it over a plot of the data points listed in the table. You may need to remind them how to show that the distance fallen is not proportional to the velocity (i.e. v/d is not constant). The log-log plot will be linear with slope of about 4.427. The log-log model of the data should be close to

  $$y = 4.427d^{1/2}.$$

- In Investigation #2, the semi-log plot is linear with a slope of approximately $-.347$. The function to model the data should be close to

  $$12e^{-.347t} mg/mL.$$