Teaching Portfolio

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Contents

1 Introduction

This document describes my teaching and activities related to teaching while a graduate student at Indiana University. In these sections you will find:

2. Teaching Statement. My teaching statement concerns my philosophy, style, and goals to grow as a teacher.

3. Documentation of Teaching. This section includes descriptions of the classes which I have taught at Indiana University, primarily concerning content and format, as well as my responsibilities.

4. Evidence of Teaching Effectiveness. This section includes partial course evaluations, some unsolicited student feedback, and my remarks, organized by semester. This documentation demonstrates that the principles I describe in my teaching statement are something that students notice and appreciate.

5. Course Development. This section outlines my involvement with the development of the course *M106 The Mathematics of Decision and Beauty* at Indiana University, as well as my creation of the elective course *CLLC-L 230 The Mathematics of Voting* which will run in the Spring semester of 2022 .

6. Mentorship and Professional Development. In this section I describe some of the training I have received as a teacher, and how I have assisted with that training. I also describe my role in upper level undergraduate reading courses in math, and teaching awards I have received.

Appendix A: Department Syllabuses. These section includes some department syllabuses for classes I have taught, to better contextualize my teaching experience.

Appendix B: Documents Created by Me. This section includes samples of materials I created for classes, including assignments (with samples of student work), class notes, organizational materials, and the syllabus I created for a class in Voting Theory.

2 Teaching Statement

Mathematics is something we learn by doing and understand through context, and the journey is smoother and more enjoyable when made with companions. My teaching style reflects this belief by emphasizing students' collaboration, communication skills, and creativity. I focus on student success rather than my own expectations so that everyone in my classroom has the opportunity to succeed and feel they have learned something meaningful.

My students are active collaborators in the learning process, which helps me recognize and meet their needs. My lecturing style is very conversational, and my teaching style emphasizes groupwork and communication. On a typical day in a lecture hall I present a problem: "*How many ways are there to draw a hand of four face cards from a deck of cards?*" and I ask the class whether it is a combination or permutation problem. I get no response. In fairness, it is 8 am. I change my approach to a poll, and 70 hands go up, nearly the whole class. I quickly review the distinction between permutations and combinations and ask, "*Can someone who knew it was a combination problem tell me why*?" I receive several good answers worthy of discussion and (gentle) dissection. I ask the class to solve the next problem with the people around them. After their conversation wanes, the students walk me through their solutions, exhibiting both good ideas and some common mistakes, all of which are worth showing to the class. The discussion and groupwork take more time than it would for me to simply present solutions, but these methods involve students and drive them to discuss math in their own words and engage with the material at a level beyond memorizing algorithms.

I take advantage of the space in a smaller classroom to use more involved groupwork. When teaching about Euler circuits, I start by challenging students to form groups and solve the classic *Bridges of Königsberg* problem, presenting a map of Königsberg and a corresponding graph. Many of the teams discover for themselves a reason why the problem is impossible. By the time I define the terms *walk*, *Euler path*, and *Eulerian graph* the students already have strong intuition for what those things are, and I am simply providing names for their ideas. When I present a characterization of Eulerian graphs, I am affirming or refining their own theories. The students remember these specific ideas better, but they have also gained experience working on problems without an obvious approach.

I write assignments with this kind of high-level engagement in mind, designing them as teaching tools, rather than just evaluation tools, so that classwork and homework are part of a continuous learning process. That process starts with students practicing core skills in the classroom with my support, includes plenty of direct applications of those skills for students to try on their own, and continues with students tackling problems requiring creative solutions. For example, when I teach voting theory, I start by teaching students about the rules of various voting systems used in the world today. After students learn to determine the winners of elections according to those rules, I ask them to design their own voting system with the goal of making it as democratic as possible. Although one of my first groups insisted that the "hunger games" was their final answer, most others evaluate which principles of established voting systems they *like* in order to adopt the best and reject the worst aspects of the systems they have studied. They have to think about voting systems in terms of their underlying philosophy, rather than treating them as number-pushing algorithms. The philosophical perspective clarifies *why* we study each system, and it is also much easier to remember.

The reason I aim for high-level engagement is not simply that I have high expectations of my students; I believe it is easier to remember and understand math when one knows its broader context. I came to appreciate the importance of context when I was developing the materials for the Indiana University class *The Mathematics of Decision and Beauty*. I realized that at no point in the graph theory unit were we asking students to draw graphs, and I found that students were more successful in the unit once I added assignments of that kind. Being able to model a situation with a graph was important context for understanding what graphs are, and by adding this material I made the learning process smoother for students without lowering expectations. Providing context actually means asking more of students, but in a way that helps them to succeed.

I try to recognize the needs of students both as members of my classroom and as people, and to focus more on their success than my expectations. I make resources available to everyone, including rubrics shared online or described in class, old exams that set expectations for upcoming tests, and information about campus tutoring centers. I also work to grade equitably, with an understanding that my students lead complex lives outside the classroom and have diverse needs within it. For example, I try to have flexible policies about late homework and attendance. I make sure that class discussions are accessible to students with weaker math backgrounds, while creating rubrics in a way that does not needlessly emphasize their weaknesses (usually algebra). I strive to be kind, without being condescending, about the disparate skills and circumstances students may have in the same classroom.

My advice to any new teacher is to continually try to improve. I feel I have learned a lot this year as I designed a course from the ground up, entitled The Mathematics of Voting. As this is an elective class, I find my goals and teaching strategies are different than they might be in a traditional course for math graduation credit. For example, many of the activities I have planned are designed to be experienced rather than memorized or completely analyzed, and I am borrowing teaching and evaluation tools from different subject areas such as one-minute-reflections, roleplay, and small-group-in-large-group discussions. I am thinking about how and when these tools might benefit my more traditional math classes as well.

I became a mathematician because of the catharsis I feel when I finally solve a tough problem. Through teaching I get to help my students feel that too, as they discover that math is meaningful, and fascinating, and something they can excel at. They motivate me to continually improve, just as they have motivated my approach to teaching so far.

3 Documentation of Teaching

While a graduate student at Indiana University, I have been the instructor of record for six courses, over a total of ten semesters. These are:

- M118 *Finite Mathematics*; this course covers combinatorics, probability and linear algebra. It is the course most commonly taken by IU Bloomington students to satisfy their general education math requirement.

- D116 *Introduction to Finite Mathematics 1*; this course covers combinatorics and probability. It is the first half of a two semester alternative track to M118, which covers identical content to M118 at a slower pace.

- D117 *Introduction to Finite Mathematics 2*; this course covers linear algebra, including Markov chains. It is the second class in the two semester alternative track to M118.

- M018 *Basic Algebra for Finite Mathematics*; this course covers introductory probability and algebra. It is a half-semester preparatory course for students who will eventually use M118 or a similar course to satisfy their general education math requirement.

- M106 *The Mathematics of Decision and Beauty*; this course covers a number of topics presented independently, including music theory, voting theory, graph theory, game theory, 2-dimensional projection of 3-dimensional objects, and group theory in the context of symmetries of figures. It satisfies most majors' general education math requirement, and is mostly taken by students who have weak algebra backgrounds, and humanities students with a specific interest in one of the course topics.

- J113 *Introduction to Calculus with Applications*; this is a first course in calculus targeted at first-generation and low-income college students. The focus of the course is differentiation, though limits, antiderivatives, and the fundamental theorem of calculus are also covered.

My responsibilities for these classes always included lecturing, administrating of the class website (Canvas), assigning grades, holding office hours, and being the point of contact for my section. For most courses I also created assignments or selected problems, graded, proctored exams, and coordinated with other instructors.

3.1 M118 Finite Mathematics

I taught this course twice, once in 2016 to a section of about 15 students, and again in 2019 to a section of about 70 students.

M118 is a 3 credit hour coordinated course with many sections. The homework is online through a system called WeBWorK, and sample problem sets are available to instructors. Two out of four exams are written by the coordinator and graded by scantron. My responsibilities as the instructor of record for a section included:

- lecturing,
- selecting homework problem sets,
- holding office hours,
- writing and grading two out of four exams to be taken by my section,
- proctoring all exams,
- administrating the section website, which was a Canvas page,
- and being the point of contact for my section.

The topics of M118 include: introductory set theory and set theoretic notation; counting problems involving permutations, combinations, and inclusion-exclusion principles; counting problems in probability; conditional probability; Bayesian probability; Bernoulli trials; expectation of a random variable; matrix arithmetic; matrix row reduction to solve systems of linear equations; linear programming; and Markov chains. A department syllabus which states course policies and learning objectives has been included in the appendices.

3.1.1 M118 Test

I am including a test written by me in the fall 2019 semester, along with some remarks made by me in hindsight, in the appendices.

3.2 D116 Introduction to Finite Mathematics 1

I taught this course in the spring semester of 2018 to a section of about 70 students.

D116 is a 2 credit hour coordinated course with several sections. The homework is online through a system called WeBWorK, and sample problem sets are available to instructors. My responsibilities as the instructor of record for a section included:

- lecturing,
- writing quizzes for each lecture,
- working with an undergraduate grader,
- choosing homework problem sets,
- holding office hours,
- collaborating with other instructors to write exams;
- proctoring and grading exams,
- administrating the section website, which was a Canvas page,
- and being the point of contact for my section.

The topics of D116 include: introductory set theory and set theoretic notation; counting problems involving permutations, combinations, and inclusion-exclusion principles; counting problems in probability; conditional probability; Bayesian probability; Bernoulli trials; and expectation of a random variable.

3.2.1 D116 Quizzes

I was asked by the course coordinator to prepare quizzes for the beginning of each lecture with the intent of encouraging attendance. I've included some sample quizzes in the appendices, as well as comments on how I would write them differently today.

3.3 D117 Introduction to Finite Mathematics 2

I taught this course in the spring semester of 2021 to a section of about 50 students. This course was run entirely online.

D117 is a 2 credit hour coordinated course with several sections. The homework is online through a system called WeBWorK, and sample problem sets are available to instructors. My responsibilities as the instructor of record for a section included:

- lecturing online,

- holding office hours,
- collaborating with other instructors to develop the format of the class,
- grading written assignments,
- administrating the section website, which was a Canvas page,
- and being the point of contact for my section.

The topics of D117 include: matrix arithmetic; matrix row reduction to solve systems of linear equations; linear programming; and Markov chains.

3.4 M018 Basic Algebra for Finite Mathematics

I taught this course in Fall of 2016 to two sections of about 25 students each.

M018 is a 2 credit hour coordinated course with several sections. Each section meets daily for 8 weeks, and instructors typically teach two sections per semester. My responsibilities as the instructor of record for two sections included:

- lecturing,
- grading daily written homework,
- holding office hours,
- proctoring and grading exams,
- administrating the section website, which was a Canvas page,
- and being the point of contact for my section.

The topics of M018 include: introductory set theory and set theoretic notation; elementary counting problems involving permutations, combinations, and inclusion-exclusion principles; solving systems of linear equations; graphing systems of linear inequalities; and matrix row reduction.

3.5 M106 The Mathematics of Decision and Beauty

I have been the instructor of record for this course 4 times in Fall 2017, Fall 2018, Summer 2019, and Fall 2019, for classrooms of about 25 students.

M106 is a 3 credit hour course that has evolved in my time at Indiana University, but has generally had minimal coordination, with concurrent sections having the same exams and otherwise operating independently. My responsibilities as an instructor of record for this class have generally included:

- teaching for 50 minutes daily,
- holding office hours,
- writing exams (some semesters),
- proctoring and grading exams,
- grading written classwork and homework, (in some semesters I was instead assigned an undergraduate grader),
- administrating the section website, which was a Canvas page,
- and being the point of contact for my section.

Due to missing or inadequate course materials, I took on the additional responsibilities of

- creating and updating written worksheets and problem sets,
- and creating and updating course notes.

The math department responded to this work positively, and later hired me to collect and develop full materials for the course. I discuss this further in Section 5, and I have included samples of these materials in the appendices.

An M106 course is divided into 5 units which are taught independently. These are graph theory, voting theory, perspective, game theory, and either music theory or symmetry.

The topics covered in the graph theory unit include:

- modeling with graphs and digraphs,
- Eulerian circuits and Eulerization,
- Hamiltonian cycles,
- finding minimal spanning trees,
- proper colorings of graphs,
- and scheduling problems.

The topics covered in the voting theory unit include

- a survey of common voting systems,
- the Condorcet paradox,
- fairness principles,
- and Arrow's Theorem.

The topics covered in the game theory unit include:

- representing games with payoff matrices,
- identifying best responses and pure Nash equilibria,
- calculating mixed Nash equilibria,
- identifying and iteratively eliminating dominated strategies,
- and predicting rational play using the aforementioned principles.

The topics covered in the perspective unit include:

- graphing lines and figures,
- parallel projection,
- and central projection.

The topics covered in the music unit include:

- basic music literacy,
- calculating frequencies according to different tuning systems,
- calculating intervals between frequencies,
- and calculating beats between close frequencies.

The topics covered in the symmetry unit include:

- the symmetry groups of finite figures and objects,
- transformations of figures on the plane,
- and the symmetry groups of Frieze patterns.

3.5.1 M106 Online Co-Teaching

The structure of M106 was altered in the summer semester of 2020 to enable total online instruction, with the course coordinators producing video lectures and graduate student "co-instructors" essentially serving as recitation leaders. My responsibilities as a co-instructors of one section with 15 students included

- watching the lecture videos (about 50 minutes per day),
- leading a daily one hour recitation for my section on Zoom,
- grading homework assignments, which were formatted similarly to written worksheets but turned in electronically,
- grading exams, which were formatted similarly to the homework,
- holding office hours,
- attending a weekly meeting of co-instructors to discuss the course,
- administrating the course website, which was a Canvas page,
- and being the main point of contact for my section.

Solutions and rubrics were not provided for the assignments, or the first two exams. I organized some of the graduate student co-instructors to create these, and produced about a quarter of the solutions myself. I pushed for an agreement to publish solutions on the course websites, which was agreed to by the solution creators and course coordinators.

I experimented with the format of my recitation throughout the summer semester. By the end of the semester I was starting each recitation with an ungraded quiz on the content of the day's lecture videos. I would then field any questions about the homework. Generally there were few homework questions, so I would then work through prepared problems with the class. I would then give the students some prepared problems to work through in breakout rooms of 4-5 students. At the end of class, we discussed solutions to those problems.

I felt this approach worked well for this recitation, which was the first online course I taught during the pandemic. I found that for larger classes which I taught later that I had to alter this format somewhat, especially by deemphasizing the use of breakout rooms.

3.6 J113 Introduction to Calculus with Applications

I taught this class in the fall semester of 2021 to a section of about 15 students, alongside one other section. The course was taught in person.

J113 is a 3 credit hour coordinated course with written homework selected by the coordinator and instructors. It is the third course in a sequence for students in the Groups program, a program targeted at first-generation and low-income students, and meets students' general education math requirement. My responsibilities as the instructor of record for a section included:

- lecturing,
- selecting homework problem sets,
- creating solutions for some homework sets,
- grading some homework and all exams,
- creating and grading quizzes,
- holding office hours,
- administrating the section website, which was a Canvas page,
- and being the point of contact for my section.

Topics in J113 include: polynomial, rational, exponential, and logarithmic functions; limits; continuity; derivatives and techniques for differentiation; finding extrema to solve optimization problems; related rates; antiderivatives; and the fundamental theorem of calculus.

4 Evidence of Teaching Effectiveness

In this section I discuss evidence of my teaching effectiveness, organized chronologically by semester.

Included are partial course evaluations, where I give my average score for a question compared to the math department score. Questions added to the evaluation forms by the university were on a scale from 1-4, and department agree/disagree evaluations were on a scale from 1-5. I have also included selected student feedback from the course evaluations, unsolicited feedback from students, and some of my own comments.

I feel this documentation demonstrates that I teach in a way that engages students in a classroom across skill levels, that I prioritize student learning over my expectations, and that these and the other principles I describe in my Teaching Statement are something that students notice and appreciate.

4.1 Summer 2016, M118 (Finite Mathematics)

University Question (4 pts)	**Condon**	**Department**
How likely would you be to recommend this course with this instructor?	4.0	3.3
How much did the instructor motivate you to do your best work?	3.3	3.4
How much did the instructor emphasize student learning and development?	3.7	3.4
Department Eval. (5 pts)		
Overall, I would rate this instructor as outstanding.	4.7	4.2
My instructor is well prepared for class meetings.	4.7	4.4
My instructor explains the material clearly.	5.0	4.1

4.1.1 Course Evaluation Comments

What did you like most about this course and instructor?

Mr. Daniel Condon was an excellent instructor. He was approachable when we had questions and was knowledgeable and passionate about the subject matter. This style of teaching was excellent for those who are not mathematically inclined, and he never ran out of patience or manners.

4.2 Fall A. 2016, M018 (Basic Algebra for Finite Mathematics)

University Question (4 pts)	**Condon**	**Department**
How likely would you be to recommend this course with this instructor?	3.8	3.3
How much did the instructor motivate you to do your best work?	3.4	3.3
How much did the instructor emphasize student learning and development?	3.7	3.3
Department Eval. (5 pts)		
Overall, I would rate this instructor as outstanding.	4.6	4.2
My instructor is well prepared for class meetings.	4.7	4.5
My instructor explains the material clearly	4.6	4.2

4.2.1 Course Evaluation Comments

What did you like most about this course and instructor?
His personality and connection he formed with his students.

What did you like most about this course and instructor?
The pace of this course and Daniel made sure the class had some fun and really understood the material well.

What did you like most about this course and instructor?
Daniel explains things very clearly and simply. This was good when learning something new, but frustrating when I already had a good understanding of the topic.

What did you like most about this course and instructor?
The pace was perfect and the instructor was fantastic at explaining course material and keeping students engaged.

4.2.2 Remarks

The student who was frustrated when their class was too slow is surely not unusual, and I believe I have improved on this matter. When teaching a topic that I think a lot of students will already be familiar with, I explain why it is important for us to still discuss that topic with care so that everyone in the classroom can be on the same page. I am also careful to explain when the familiar topic is being explored as an analogy or jumping off point for something that is likely unfamiliar.

4.3 Fall B. 2016, M018 (Basic Algebra for Finite Mathematics)

University Question (4 pts)	**Condon**	**Department**
How likely would you be to recommend this course with this instructor?	2.8	3.3
How much did the instructor motivate you to do your best work?	3.1	3.5
How much did the instructor emphasize student learning and development?	3.1	3.6
Department Eval. (5 pts)		
Overall, I would rate this instructor as outstanding.	3.9	4.2
My instructor is well prepared for class meetings.	4.3	4.5
My instructor explains the material clearly	4.1	4.2

4.3.1 Course Evaluation Comments

Because my evaluation scores were low for this course, but the comments were generally positive, I am disclosing all comments made by students on the course evaluations.

What did you like most about this course and instructor?
That we were able to get extra credit and get more outside help

What did you like most about this course and instructor?
He was very knowledgeable on the topics.

What did you like most about this course and instructor?
The material was taught in a way that was very easy to understand. Also, graded papers were returned really fast.

What did you like most about this course and instructor?
How everything is very forward and the instructor is very decisive in his teaching

What did you like most about this course and instructor?

He was very nice and very helpful

What did you like most about this course and instructor?

Introduction useful for Finite math next semester

What did you like most about this course and instructor?

He was very understanding of the level of students and was even humorous.

What did you like most about this course and instructor?

The material we covered was well explained by the instructor which made it easy to learn which improved my interest in the class.

What did you like least about this course and instructor?

The confusion between the different possibilities of help

What did you like least about this course and instructor?

There was nothing not to like.

What did you like least about this course and instructor?

How the class is everyday

What did you like least about this course and instructor?

No complaints

What did you like least about this course and instructor?

Some topics were overly simple for my level

What did you like least about this course and instructor?

I worry that I will still not be prepared enough for finite.

What did you like least about this course and instructor?

Nothing.

4.4 Fall 2017, M106 (The Mathematics of Decision and Beauty)

University Question (4 pts)	**Condon**	**Department**
How likely would you be to recommend this course with this instructor?	3.2	2.9
How much did the instructor motivate you to do your best work?	3.4	3.1
How much did the instructor emphasize student learning and development?	3.5	3.2
Department Eval. (5 pts)		
Overall, I would rate this instructor as outstanding.	3.7	3.7
My instructor is well prepared for class meetings.	4.2	4.2
My instructor explains the material clearly	4.4	4.5

4.4.1 Course Evaluation Comments

What did you like most about this course and instructor?

Patient. Always checked with students for comprehension, offered office hours daily, sense of humor.

What did you like most about this course and instructor?

I liked how Daniel was always willing to help our students. When we would come to class with questions on the homework that day he would suggest we push back the due date because we didn't understand it enough and that understanding he material was the main goal not forcing us to turn things when we didn't know what we were doing.

What did you like most about this course and instructor?

He's the most relatable, understanding, caring, and "real" math professor that I've had at IU. A lot of complaints are always made towards the instructors in more math related courses that regard their ability to connect to students. Daniel is one of the few that had no issue with this, and made each meeting for class a helpful and informative time.

What did you like most about this course and instructor?

This class offered the opportunity to use math in a unique way. I thought that Daniel was an excellent instructor who had patience when it came to students who did not understand certain topics and was always willing to spend extra time making sure everyone understood what he was teaching. He was also funny!

What did you like most about this course and instructor?
I couldn't pass finite so I'm happy this course was an option. Daniel was always willing to help me during office hours and even when he didn't have office hours. He was never condescending and always patient with his students.

What did you like most about this course and instructor?
Daniel was so helpful and available if we needed anything. He was the perfect instructor for this course and I'm so happy I took it with him! ... Daniel was absolutely one of the most helpful instructors I have had in college.

4.4.2 Unsolicited Feedback

Daniel, Thank you for an awesome semester. The OCQs are anonymous, but you are honestly one of the most hardworking, caring & supportive instructors I have ever had. Thank you!!

4.5 Spring 2018, D116 (Introduction to Finite Mathematics 1)

University Question (4 pts)	**Condon**	**Department**
How likely would you be to recommend this course with this instructor?	2.3	2.9
How much did the instructor motivate you to do your best work?	3.1	3.2
How much did the instructor emphasize student learning and development?	3.1	3.2
Department Eval. (5 pts)		
Overall, I would rate this instructor as outstanding.	3.4	3.7
My instructor is well prepared for class meetings.	3.7	4.2
My instructor explains the material clearly	3.9	3.7

4.5.1 Course Evaluation Comments

What did you like most about this course and instructor?

This instructor was patient with the class and always asked the students if the taught material was understood by everyone. He always allowed students to comment and ask questions of clarification or better explanation.

4.5.2 Remarks

This course was a low point for me as a teacher. I had a lot of issues with technology and format for several weeks at the beginning of the semester while trying to meet the needs of student who was hard of hearing. I don't think the tone of the class recovered even once I improved on those issues.

I think I have learned from this semester, and would be better prepared to teach a student who is hard of hearing in the future. On the more general subject of technology, I was much more proactive in considering the format of my teaching in Summer 2020, which was the next time that I prepared for a course knowing that technology would be a major consideration.

4.6 Fall 2018, M106 (The Mathematics of Decision and Beauty)

University Question (4 pts)	**Condon**	**Department**
How likely would you be to recommend this course with this instructor?	3.2	2.9
How much did the instructor motivate you to do your best work?	3.5	3.1
How much did the instructor emphasize student learning and development?	3.4	3.1
Department Eval. (5 pts)		
Overall, I would rate this instructor as outstanding.	4.0	3.7
My instructor is well prepared for class meetings.	4.6	4.2
My instructor explains the material clearly	4.1	3.7

4.6.1 Course Evaluation Comments

What did you like most about this course and instructor?

Daniel was very approachable and very patient when I was lost on a topic.

What did you like most about this course and instructor?

He was really interested in the topics and really accommodating. Whenever the class at large had issues with homework or topics he'd give us extra time and go back over things to make sure we understood what we were doing. He changed his office hours to better suit the class and he was really available to help us.

What did you like most about this course and instructor?

I felt like our professor was very helpful in making sure the topic was understood. The has been by far the best math class I have had in my educational career. Thank you!

What did you like most about this course and instructor?

I loved Daniel. He was a great professor, so available, so smart, so willing to help. He was great.

What did you like most about this course and instructor?

Daniel is kind, reasonable, and very available to help students in need.

What did you like most about this course and instructor?

I liked that Daniel really wanted us to understand the reason why we were learning this material, to begin with. I think that often times we find ourselves wondering why we are taking this math course if we aren't even entering a field where math is involved besides the basics you learn in high school. His office hours and pre–review for the exams were EXTREMELY useful. Great thing to add to the course, especially for those who are shy about raising their hand when they don't understand something.

4.7 Spring 2019, M106 (The Mathematics of Decision and Beauty)

University Question (4 pts)	**Condon**	**Department**
How likely would you be to recommend this course with this instructor?	2.8	2.9
How much did the instructor motivate you to do your best work?	3.1	3.1
How much did the instructor emphasize student learning and development?	3.2	3.2
Department Eval. (5 pts)		
Overall, I would rate this instructor as outstanding.	3.4	3.8
My instructor is well prepared for class meetings.	4.2	4.3
My instructor explains the material clearly	3.9	3.8

4.7.1 Course Evaluation Comments

What did you like most about this course and instructor?

Daniel was one of the best instructors I've had at IU. He was well organized, set clear standards and expectations, and was reasonable in everything he did. As to the course, it was so much more enjoyable than any math class I've ever taken. I'm "not a math person", but I actually liked being in the class, which surprised me. I found the concepts interesting. I wish that there were more classes like this one.

What did you like most about this course and instructor?

I used to hate and DREAD math (I failed Finite 3 times) but this class was my favorite course in my 5 years of college. It was challenging but also interesting and even fun. Daniel is super knowledgeable and kind. He goes above and beyond for his students...

What did you like most about this course and instructor?

I appreciated Daniel's availability and willingness to go above and beyond to help me when I started to fall back. I went through some trying times which threw some huge curve–balls during this semester and Daniel was willing to work with me and did his best to keep me motivated.

4.8 Summer 2019, M106 (The Mathematics of Decision and Beauty)

University Question (4 pts)	**Condon**	**Department**
How likely would you be to recommend this course with this instructor?	3.2	2.9
How much did the instructor motivate you to do your best work?	3	3.1
How much did the instructor emphasize student learning and development?	3.2	3
Department Eval. (5 pts)		
Overall, I would rate this instructor as outstanding.	3.8	3.8
My instructor is well prepared for class meetings.	4.0	4.0
My instructor explains the material clearly	4.2	3.7

4.8.1 Course Evaluation Comments

What did you like most about this course and instructor?

As someone who has taken a lot of my classes over the years (only 1 at IU), I can honestly say that Daniel is the best instructor I've ever had. He's very personable and reasonable and explains everything in a way that's easy to understand.

4.8.2 Unsolicited Comments

Thank you for being the best math instructor I've ever had. I've always loved math, but I usually end up having to teach the lessons to myself, but I was able to learn just from class/your notes. Thank you.

4.9 Fall 2019, M118 (Finite Mathematics)

University Question (4 pts)	Condon	Department
How likely would you be to recommend this course with this instructor?	3.2	2.8
How much did the instructor motivate you to do your best work?	3.3	3.1
How much did the instructor emphasize student learning and development?	3.4	3.1
Department Eval. (5 pts)		
Overall, I would rate this instructor as outstanding.	4.1	3.7
My instructor is well prepared for class meetings.	4.6	4.3
My instructor explains the material clearly	4.2	3.7

4.9.1 Course Evaluation Comments

What did you like most about this course and instructor?

Daniel makes the lecture portion of the class not boring. It's hard to focus and be engaged at 8 am but I find that with Daniel as the teacher I don't hate getting up early for class...

What did you like most about this course and instructor?

Out of all the other instructors for this class I liked him the best, he's very approachable and the small class size helps...

What did you like most about this course and instructor?

I don't really have a favorite part of the course, but Prof Condon was always funny and kept the room light. It made it a little easier to go to 8 am Finite.

What did you like most about this course and instructor?

Mr. Condon gave in depth explanations of each topic, giving us the what and why of each and every step, in such a helpful manner that I myself was able to help many of my friends who's instructors were not so helpful. I feel very lucky to have had Mr. Condon as my instructor.

What did you like most about this course and instructor?

Professor Condon always brought energy and enthusiasm to class which made a dreary subject light and comparatively better than what I imagine the class could have been. Also, he always arrives early to class to answer any student questions in addition to his typical office hours!

What did you like most about this course and instructor?

Daniel Condon was a great instructor who thoroughly went through each step of all of the content this semester. Even though some of his steps between how to solve problems were obvious sometimes, I appreciate that he took the time to do them anyway for the sake of clarity.

4.10 Spring 2021, D117 (Intro. to Finite Mathematics 2)

University Question (4 pts)	**Condon**	**Department**
How likely would you be to recommend this course with this instructor?	3.3	2.9
How much did the instructor motivate you to do your best work?	3.6	3.1
How much did the instructor emphasize student learning and development?	3.5	3.2
Department Eval. (5 pts)		
Overall, I would rate this instructor as outstanding.	4.2	3.7
My instructor is well prepared for class meetings.	4.7	4.2
My instructor explains the material clearly	4.4	3.8

4.10.1 Course Evaluation Comments

What did you like most about this course and instructor?

Daniel was always willing to answer any and all questions, as many times as it took for you to understand. He was very understanding with us in terms of timelines for stuff and would push back due dates if needed. He also asked for our input on a number of issues which was nice. Additionally, his office hours were super helpful. You could go and tell him what you needed help with and he would go through examples until you had a better understanding. He always encouraged us to attend office hours, PASS, and other tutoring services. He also advocated for the use of CAPS when recognizing a number of us may have been feeling down/stressed.

What did you like most about this course and instructor?

Daniel explained things very well and even explained them in multiple ways for us to understand.

What did you like most about this course and instructor?

I like how the course was recorded for future references.

4.10.2 Remarks

The student who referred to PASS is referring to a free tutoring service offered by the university. They also refer to CAPS, which is the university's **C**ounseling **a**nd **P**sychological **S**ervices. I'm not sure when I first started advertising the university's mental health services, but it seemed particularly important during that semester (Spring 2021) and I continue to advertise those and other university services in my classes.

5 Course Development

In this section I discuss my experience with course development, which goes beyond ordinary experiences for graduate students. I developed nearly full materials for the course M106 *The Mathematics of Decision and Beauty* over several semesters when I was teaching it, and as my summer assignment in 2018.

I also wrote a proposal for an interdisciplinary course in voting theory, for Indiana University students living in the Collins Living-Learning Center; the second version of that proposal was accepted, and the course is scheduled to run in Spring 2022.

5.1 M106 The Mathematics of Decision and Beauty

When I became involved with M106 as a grader, and later as an instructor, I found that the materials available for the course were wanting. The course was originally planned to run for one semester, and its design reflected that. Each unit had notes written by a different person, some of which were probably only intended for personal use. An electronic homework system had been set up for the course, but it was plagued by bugs and questions were not always designed optimally for teaching.

During my first semester as an instructor of record for the course, I created written homework assignments to replace electronic homework. Because my students were unable to follow the course notes, I created new notes for one of the later units, graph theory; I chose this unit based on the time I had to prepare materials and my knowledge of the subject. I improved on these materials when I taught the course again the following semester.

Members of the math department recognized that the materials I was creating were helping students to succeed in the course, and I was asked to spend the following summer semester developing full materials for the class. I used that time to create course notes for voting theory, game theory, and music theory, as well as class activities, worksheets, sample tests, problem banks, and modular course schedules. In later semesters, I integrated the worksheets and some activities into the notes as exercises and created an instructor version of the notes with comments about the content and exercises, and solutions to those exercises.

5.1.1 On Coordination Between Sections

When I first became involved in M106, the “full” curriculum was actually longer than could be taught in a semester, with instructors each semester choosing 5 out of the 6 units (game theory, graph theory, music theory, voting theory, projection, symmetry) to teach. There was also variation in which topics were included in the instruction of each unit. The one uniform factor between sections was that all sections in each semester took identical tests, but this was actually detrimental given the lack of uniformity in teaching.

When I was hired specifically to develop the materials of the course, one of my primary goals was to make the instruction uniform. For this reason, I created course materials for the 5 subjects that had been taught most often, and omitted symmetry. For these subjects, I included notes and worksheets for all topics that I knew previous instructors had covered, and I added topics that I felt provided necessary context for each unit. I also created a guide to coordinating sections of the course, which was meant to help concurrent instructors teach in a uniform way. That guide included:

- recommended course schedules for spring/fall and summer semesters;
- a description of which topics were fundamental for students to understand each unit, and a chart of how topics related to each other;
- and the tools to quickly draft exams. These included sample exams and extensive LaTeXed problem banks. The relevance to uniformity is that instructors were advised to draft exams before teaching each unit, as a goalpost for what they would cover.

A sample from this guide is included in the appendices.

5.1.2 Teaching Philosophy and Course Development

As the person creating course notes, schedules, and assignments, my pedagogy had a heavy influence on how other people would teach the course. I value class activities and student driven discussions, and this is reflected in the course materials. Examples of this are in the appendices, including:

- A sample of one section of course notes. These include a number of “comprehension checks” which are examples of problems one can ask the class. Some comprehension checks merit groupwork. The notes in the appendices are actually from the instructor edition, which includes comments in the margins to aid the instructor. The notes also include problems that can be given as classwork or homework, including starred problems that are a good basis for longer class activities.

- An example of a voting theory assignment, given as a starred problem in the notes, in which students were asked to design a voting system. Also included are solutions from students whom I was able to contact and who gave me permission to share their work. This activity is described briefly in my Teaching Statement.

- A sample exam, as well as reflections on that exam and how I would write it differently now.

5.2 CLLC-L 130 The Mathematics of Voting

At Indiana University, advanced graduate students can propose courses to be taken by undergraduates who live in the Collins Living-Learning Center. I have submitted a proposal for a course in voting theory twice, and the second proposal was accepted.

A syllabus for the course is included in the appendices. This was written partly with feedback from Collins students, who have my thanks. The course will be a 3 credit hour 100-level course open to students from any major.

The mathematical topics of the course include: a survey of voting systems, covering how they work and how voters might strategize, with diversions into fairness principles highlighted by individual systems; fairness principles for voting systems and Arrow's theorem; apportionment methods; fairness principles for apportionment methods, and apportionment paradoxes; geometric methods of districting; tests for gerrymandering; and applications of voting theory to computer science and animal behavior.

Course objectives include:

- Students will apply common democratic procedures to determine election winners and apportion voting districts according to those procedures.

- Students will apply strategic voting methods to affect elections in their favor.

- Students will analyze notions of fairness and understand their relationships with each other and strategic voting methods.

- Students will evaluate common democratic procedures in terms of fairness criteria.

- Students will evaluate common arguments in the discourse on election reform.
- Students will create new democratic procedures and evaluate the ways in which they are fair/unfair, and how they may be susceptible to strategic manipulation.
- Students will communicate unambiguously about the rules of elections and fairness criteria.

In short, students will gain familiarity with some procedural aspects of elections in their democracy, as well as some alternatives, and be able to evaluate these and the discourse around them, as well as contribute to that discourse.

Some activities are typical of a traditional math class. Students will compute winners of elections, apportion districts, and draw districts according to algorithms discussed in class, and these activities will revolve around worksheets. There is an exam on these topics, but it is a small part of students' final grades. For other topics, such as exploring strategic voting, roleplay and written reflections take a more important role. When covering topics pertaining to fairness, the class will revolve around group discussions. Students will also work on creative group projects, such as designing a voting system and giving presentations.

5.2.1 Variations

I am cognizant that I may have the opportunity to teach a voting theory class at another institution in the future, and that the goals of that institution may lead me to alter this course.

I believe that this course could be adapted to emphasize topics related to social justice. For example, one can study how certain voting systems were proposed to better represent marginalized groups, and the degree to which that goal is actually achieved by those systems. The history of democratic thought, gerrymandering, and election reform are topics that could be discussed at greater length. If possible, I would like to work with another instructor from an appropriate field to teach this version of the course.

Alternatively, this course could be reorganized to focus on voting theory in computer science, as much of the modern research is in that field. The second half of the course would be at least partially about that research, and its context, though presented at a level appropriate for undergraduates.

6 Mentorship and Professional Development

6.1 The Directed Reading Program

In the Directed Reading Program, advanced undergraduates studying math are paired with graduate student mentors to participate in a reading course for one semester. Students read a math book not covering the content of a class regularly offered at IU. They meet with their mentors for at least one hour a week to discuss the topics of that book, and they give a presentation on a topic from their book at the end of the semester.

I was a mentor for this program in the Fall 2018 semester and Spring 2019 semester with two different students. Both students read Volume 1 of *Winning Ways for your Mathematical Plays* by Berlekamp, Conway, and Guy, a seminal but fairly accessible text on combinatorial game theory.

Our discussions were mostly about the text, but not restricted to it. For example, we analyzed a number of games not discussed in the text. We also discussed related topics regarding math and being a math major, such as non-combinatorial game theory and how to write a proof. We also workshopped their math talks for the end of the semester.

6.2 The Peer Mentoring Program

In 2020 I helped found a peer mentoring program for graduate students at Indiana University. Our primary goal was to help incoming students make connections within the department, with the purpose of making the department more inclusive.

I helped organize the program in its first year, and in the 2021-2022 academic year I am serving as a peer mentor for one incoming student.

6.3 Teacher Training Courses

The Indiana University math department offers two teacher training courses. The first (M595) is about teaching undergraduate college math, which I took in my first year at IU. The second (M596) focuses specifically on teaching *M106 The Mathematics of Teaching and Beauty*; I have assisted in teaching this course by giving a talk about teaching voting theory.

6.4 TYRIT

The Transforming-Your-Research-Into-Teaching workshop is a national seminar through the CIRTL network that runs for 6 weeks. I participated in the seminar in order to better develop the Mathematics of Voting course I was designing. I was surprised by the diversity in teaching methods employed by other fields, and I have done my best to incorporate these into my voting theory course, as appropriate.

6.5 2020 Summer Teaching Workshop

In the summer semester of 2020 I reached out to IU's Center for Innovative Teaching and Learning to request help organizing a teaching workshop on inclusive teaching methods. This one hour workshop was ultimately led by a member of CITL, was available to all math graduate students, and discussed inclusion, justice, and equity in teaching.

6.6 Awards

I was awarded the **David A. Rothrock Teaching Award** in the spring semester of 2018, and the **David A. Rothrock Teaching Fellowship** in the spring semesters of 2020 and 2021, for "excellence [in] teaching of mathematics."

7 Appendix A: Department Syllabuses

M118 Finite Mathematics Syllabus

The following four pages contain an M118 department syllabus, which outlines course policies and learning objectives for *M118 Finite Mathematics*.

M118 – Departmental Syllabus for Fall 2019

Required Materials:
Text Book: ***Finite Mathematics*** by Maki, Thompson, and McKinley ***6th edition***.

Students are expected to have access to the textbook and to study the sections of the textbook indicated in the suggested schedule found at the end of this document. It is essential that students study the textbook, in addition to attending lecture, in order to succeed with homework assignments and to be prepared for exams.

Calculators are not allowed on exams in M118.

GRADE BREAKDOWN

Assignment	Percentage of overall grade
Homework/Quizzes	15% (total)
Instructor Exams (Exams 1 and 3)	35% (total)
Midterm Exam	22%
Final Exam	28%

DEPARTMENTAL EXAMS

Midterm Examination

The midterm examination will be held Saturday, October 12, 2019, from 9:00 – 10:30 am. All students will take the test at that time.

The midterm will be a comprehensive and cumulative departmental exam, covering chapters 1-4, written by the course coordinator. All students will take the test at that time.

Final Examination
The final examination will be held Friday, December 20, 2019, from 2:45–4:45 pm. All students will take the test at that time.

The final will be a comprehensive and cumulative departmental exam, covering chapters 1-8. It will be written by the course coordinator. All students will take the test at that time.

Most students will take the departmental exams at locations different from where they meet for lecture. Room assignments for the departmental exams will be announced in class about a week before exam time.

Calculators are not allowed on exams in M118. (It bears repeating.)

General Education requirements satisfied by M118 – Finite Mathematics:
Indiana University General Education: This course is considered as both a Mathematical Modeling and a Natural and Mathematical Sciences course. Learning outcomes for such courses are available at https://gened.indiana.edu/requirements/index.html.

Learning Objectives for M118 – Finite Mathematics

1. Students should become proficient in using combinatorics and probability to model problems in a variety of applied areas. This includes identifying which problems can be solved using such methods, solving the resulting mathematical problems, and drawing qualitative conclusions from the numerical solutions.

2. Students should become proficient in modeling using systems of linear equations in a variety of applied areas. This includes creating variables, translating information about the relationships among these variables into linear equations, incorporating other given data, solving the resulting mathematical problems, and drawing qualitative conclusions from the numerical solutions.

3. Students should become proficient in modeling linear decision-making problems in settings drawn both from business and from everyday experience. This includes creating variables, translating given constraint information into linear inequalities, incorporating given data, solving the resulting linear optimization problem, and deducing optimal decision choices by analysis and by graphical representation of the constraints.

Academic Dishonesty:
Academic misconduct will be dealt with as described in the http://www.iu.edu/~code/. Exams are not collaborative. Keep your eyes on your own exam and protect your work from those sitting near you. Smart phones, smart watches, calculators, cameras, and such are not allowed and are to be removed from your desk before your instructor begins passing out the exam materials. Use of any such devices during an exam will be considered as academic dishonesty and will result in a grade of F for that exam. Do not share pencils, erasers, and such during exams. All exam materials that your instructor distributes must be returned to your instructor before you leave the room. In all instances of academic dishonesty, a formal report of the incident will be made to the Office of Student Ethics.

Religious Observation:
Students with conflicts between course requirements (e.g. examinations) and religious observances must contact the instructor during the first two weeks of the term and follow the procedures outlined by campus policy, available at:
http://enrollmentbulletin.indiana.edu/pages/relo.php.

Help resources:
There will be free math help available in a variety of times/places on campus:

Sunday through Thursday, 7:00-11:00 pm, at the Academic Support Centers (ASC), located in Briscoe, Teter and Forest; signup is required. [Closed 9/1 and 9/2 for Labor Day]

Monday through Thursday, 4:00-6:00 pm at the departmental M118 help sessions, located in Swain East 340 (Math Learning Center). [Closed 9/2 for Labor Day]

PASS tutoring: Times and locations to be announced (usually early evening)

SUGGESTED SCHEDULE

The Midterm and Final Exams are the same date and time for all sections.

Dates	Sections
26 Aug-30 Aug	1.1, 1.2, 1.3
2 Sep-6 Sep	(Labor Day 9/2) 1.4, 2.1
9 Sep-13 Sep	2.2, 2.3, 2.4
16 Sep-20 Sep	2.4, Review, Exam 1
23 Sep-27 Sep	3.1, 3.2, 3.3
30 Sep-4 Oct	3.4, 4.1, 4.2
7 Oct-11 Oct	4.3, Review
Saturday, October 12	Midterm Exam from 9:00-11:30 am Covers Ch 1-4 Rooms TBA
14 Oct-18 Oct	5.1, 5.2 (Fall Break 10/18)
21 Oct-25 Oct	5.3, 6.1
28 Oct-1 Nov	6.2, 6.3
4 Nov-8 Nov	Review, Exam 3
11 Nov-15 Nov	7.1, 7.2, 7.3
18 Nov-22 Nov	7.3, 8.1, 8.2
25 Nov-29 Nov	Thanksgiving Break
2 Dec-6 Dec	8.2, 8.3
9 Dec-13 Dec	Review
Friday, December 20	Final Exam from 2:45-4:45 pm Covers Ch 1-8 Rooms TBA

Below is a suggested schedule of topics along with a listing of good homework problems from each section of our text book which you can study when preparing for exams.

Suggested Problems (from 6th edition)

Section	**Starting page**	**Problems**
1.1	9	1, 5, 7, 9, 11, 15, 17, 19, 21, 25, 27, 29
1.2	17	1, 5, 7, 9, 10, 11, 13, 15, 19, 23, 25, 27, 29, 31
1.3	25	1, 2, 3, 5, 7, 9, 11, 12, 13, 15, 16, 17, 23, 25, 27, 28, 29
1.4	37	1, 2, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 23, 24, 25, 29, 31
Ch 1 Rev	41	3, 5, 8, 9, 10, 11, 15, 16, 17, 19, 25, 28, 29, 32, 33
2.1	54	1, 3, 5, 7, 9, 11, 12, 13, 15, 21, 25, 26, 27, 29, 32
2.2	64	1-5, 7, 9, 11, 13, 14, 15, 17, 18, 19, 22, 24, 25, 27, 29, 31, 37
2.3	74	1, 2, 3, 5, 7, 9, 11, 13, 15, 19, 21, 23, 25, 27, 30, 36
2.4	80	1, 2, 3, 5, 7, 9, 11, 12, 13, 15, 17, 19, 23, 27, 31
Ch 2 Rev	84	1, 3, 5, 7, 11, 12, 13, 15-19, 25, 29-31, 33, 35, 39
3.1	96	1-7, 9, 10, 11, 13, 14, 15, 17, 19, 21, 25, 26, 27, 29
3.2	106	1-9, 11, 13, 15, 17, 19, 21, 23, 25, 26, 27, 29
3.3	116	1-4, 7, 10, 11, 13-18, 21, 23, 27, 29, 33
3.4	125	1-9, 11, 12, 13, 15, 17, 19, 21, 23-25, 29, 31
Ch 3 Rev	131	1-7, 9, 11-14, 17, 18, 19, 21, 23-27, 29, 31, 33
4.1	146	1-7, 9, 11, 13, 15, 19, 21, 23, 25, 26, 27, 31, 33
4.2	156	1, 3-5, 7, 9, 10, 11, 13, 15, 17, 19-21, 23, 25, 26, 27
4.3	168	1, 3, 5, 7, 11, 13-17, 19, 21, 25, 27, 29, 31
Ch 4 Rev	173	1, 3, 4, 5, 7-9, 11, 13, 14, 15, 17a, 31, 34
5.1	192	3, 5, 6, 9, 11, 12, 13, 15-18, 21, 23, 26
5.2	205	3, 5, 7-10, 13, 15, 17, 18, 19, 21-23, 25, 28
5.3	225	1-5, 7, 9, 11, 13, 15-19, 21-23, 27, 29
Ch 5 Rev	229	1-5, 8, 11, 15, 16, 17, 19-21, 25-29, 30, 33
6.1	246	1-11, 13-20, 23, 27, 30, 31
6.2	259	1-5, 7-9, 11, 12, 13, 15, 17, 20, 21, 25, 31
6.3	274	1–4, 7-13, 15, 17, 19, 21, 23, 24, 29
Ch 6 Rev	278	1, 2, 3, 5, 7, 9, 11, 13, 16, 17, 19, 21, 23, 25, 26
7.1	294	1, 2, 3, 5, 6, 7, 9-12, 17, 18, 19, 21, 23, 25, 26, 27
7.2	307	1-5, 7, 9-12, 15, 16, 17, 19, 21-23, 25
7.3	322	1, 3, 5, 6, 7, 9, 11, 13, 14, 15, 17, 18, 19, 23, 24, 29, 31, 35
Ch 7 Rev	325	1, 3, 5, 7, 9, 11, 13, 15, 17, 18, 19, 21, 23, 25, 26, 27, 29, 31
8.1	338	1-9, 11, 13, 15, 17, 18, 19, 21, 23, 25, 27
8.2	352	1, 3, 5, 7, 9, 11, 13, 15, 16, 21-23, 29
8.3	367	1, 3, 7, 9-15, 17, 19, 21, 24, 31
Ch 8 Rev	390	1, 3, 5, 7, 9, 11

M106 The Mathematics of Decision and Beauty Syllabus

The following four pages contain a syllabus for *M106 The Mathematics of Decision and Beauty*, which outlines course content and policies.

MATH-M 106 SECTION 10318
THE MATHEMATICS OF DECISION AND BEAUTY
SPRING 2019

Instructor:	Daniel Condon	dmcondon@indiana.edu
Also featuring:	Rebeka Man	rjman@indiana.edu

Office hours: My office is located at 1103 Atwater Avenue, on the second floor. This is the white house on the northeast corner of Atwater and Hawthorne. I encourage you to attend my office hours as needed, and you can schedule to meet me outside of office hours if needed.

The other instructors will also be holding office hours in their own offices, and you are welcome to attend those as well:

Instructor	**Office**	M	T	W	R	F
Daniel Condon	1103 Atwater Ave.	11-12	12-1	11-12		
Hayley Bertrand	Swain East 045	9:30-11, 1-1:30				10:30-11:30
Kai Smith	Swain East 045	1:30-2:20		1:30-2:20		1:30-2:20
Andrew Dabrowski	Swain East 117		1:30-3:30		1:30-3:30	

Course web page: `https://canvas.iu.edu`

Course description: Math M-106 is an exploration of mathematical structure in art, music, and decision-making. It aims to reveal some of the hidden relationships that animate human experiences and activities like perspective drawing, voting systems, packing, scheduling, and musical rhythm. During Spring 2019, we plan to cover:

Music
- Pitches and scales
- The physics of sound
- Tuning problems
- Harmonics

Voting Theory
- Voting systems
- Strategic voting
- Fairness principles
- Arrow's theorem

Game Theory
- What is a game?
- Optimal strategies
- Nash equilibria
- Pure and mixed strategies

Perspective
- 2D and 3D coordinates
- Parallel projection
- Overlapping cues
- Similar triangles and proportionality
- Central Projection

Graph theory
- Graphs as models
- Euler circuits
- The traveling salesman
- Spanning trees
- Graph coloring
- Scheduling and bin packing

Unlike most math courses, coverage of each topic will be largely self-contained, so that difficulty in one area shouldn't impede a student's potential to excel in others. The course meets daily and will emphasize group-and activity-based learning. For this reason, attendance is expected. Specific General Education learning outcomes are listed at the end of this syllabus.

Attendance: Class meetings are fundamental to the curriculum of this course, and your participation in daily class activities is important not just for your own learning, but for your fellow students as well. Attendance is therefore expected, and students are responsible for everything discussed in class, including changes to the schedule or course syllabus.

Calculator: Students should have a basic scientific calculator like the TI-30. The use of more sophisticated devices (e.g., with text memory) is not permitted on quizzes or tests.

Assignments and Quizzes: Homework, in-class assignments, and quizzes will constitute 20% of your grade. Each day you should expect to have a homework assignment due the next day. Makeups for homework and in-class assignments are generally not given unless a student has an excused absence, and homework is not accepted late.

Exams: There will be six exams, one at the end of each unit as well as a cumulative final exam. Each student must bring their IU photo ID to every exam. Our Final is Thursday, May 2, from 12:30 pm to 2:30 pm.

Missed exams: Makeups are almost never allowed. Makeups will not be given barring truly exceptional circumstances. If you think you will miss an exam due to conditions not under your control, you should notify the instructors at least one week in advance to discuss your options. If you must miss an exam due to documented illness, you must inform the instructor earlier the same day. In this case, you must visit the Health Center or your personal physician for documentation to allow for a makeup.

Grading. The grading, exam dates, and letter grade assessment is as follows:

Assignments	daily	20%
Music Theory Exam	Jan 25	12%
Voting Theory Exam	Feb 15	12%
Game Theory Exam	Mar 1	12%
Perspective Exam	Mar 29	12%
Graph Theory Exam	Apr 19	12%
Cumulative Final	May 2	20%

A+	Above 97%
A	Above 93%
A-	Above 90%
B+	Above 87%
B	Above 83%
B-	Above 80%
C+	Above 77%
C	Above 73%
C-	Above 70%
D+	Above 67%
D	Above 63%
D-	Above 60%
F	Below 60%

Students disputing a grade must do so within a week of its being posted in the gradebook.

Withdrawal: The last date to withdraw from the course with an automatic grade of W is Sunday, March 10.

Learning outcomes: The official Gen Ed learning outcomes for Math-M 106 are listed below. Also see `https://gened.indiana.edu/about/gened-learning-outcomes.html`.

- Ability to solve simple scaling problems by using relative sizes in perspective to calculate actual sizes in 3D space.
- Ability to use perspective drawing techniques to create realistic 2D images of simple 3D geometric objects.
- Ability to calculate social ordering of candidates based on voter profiles and voting systems.
- Given a voter profile, ability to determine successful strategies for insincere voting.
- Ability to solve simple scheduling problems.
- Ability to use graphs (e.g., trees) for modeling relationships within a data set.
- Ability to identify pure-and mixed-strategy Nash equilibria.
- Ability to use payoff matrices to model simple conflict dynamics, find best responses, dominant strategies, and Nash equilibria.
- Ability to explain the difference between Pythagorean tuning vs. even temperament.
- Given one pitch frequency, ability to find others at perfect intervals above or below it, and to determine tonal intervals between given pitch frequencies.

General education: This course may be used to satisfy either the campus General Education Mathematical Modeling requirement, or the campus General Education Natural and Mathematical Sciences requirement, but not both simultaneously. Mathematical Modeling courses provide rigorous instruction in fundamental mathematical concepts and skills presented in the context of real-world applications. The modeling skills provide analytical methods for approaching problems students encounter in their future endeavors. Learning Outcomes addressed in Math-M 106 include but are not limited to:

- Create mathematical models of empirical or theoretical phenomena in domains such as the physical, natural, or social sciences.
- Create variables and other abstractions to solve college-level mathematical problems in conjunction with previously-learned fundamental mathematical skills such as algebra.
- Draw inferences from models using college-level mathematical techniques including problem solving, quantitative reasoning, and exploration using multiple representations such as equations, tables, and graphs.

A passing grade in an approved course is required to show proficiency in mathematical modeling under the General Education curriculum.

Natural and Mathematical Sciences: Learning Outcomes addressed in Math-M 106 include but are not limited to

- Model and understand the physical and natural world.
- Ability to solve problems.
- Analytical and/or quantitative skills.

Academic integrity: As a student at IU, you are expected to adhere to the standards and policies detailed in the Code of Student Rights, Responsibilities, and Conduct. When you submit an assignment with your name on it, you are signifying that the work contained therein is yours, unless otherwise cited or referenced. Any ideas or materials taken from another source for either written or oral use must be fully acknowledged. All suspected violations of the Code will be reported to the Dean of Students and handled according to University policies. If you are unsure about the expectations for completing an assignment or taking an exam, be sure to seek clarification beforehand.

Disability services: Every attempt will be made to accommodate qualified students with disabilities (e.g. mental health, learning, chronic health, physical, hearing, vision, neurological, etc.). You must have established your eligibility for support services through the appropriate office that services students with disabilities. Note that services are confidential, may take time to put into place and are not retroactive; captions and alternate media for print materials may take three or more weeks to get produced. Please contact Disability Services for Students at

`http://disabilityservices.indiana.edu`

or 812-855-7578 as soon as possible if accommodations are needed. The office is located on the third floor, west tower, of the Wells Library, Room W302. Walk-ins are welcome 8AM to 5PM, Monday through Friday. You can also locate a variety of campus resources for students and visitors that need assistance at:

`http://www.iu.edu/~ada/index.shtml`.

Religious observances: Students with conflicts between course requirements (e.g. exams) and religious observances must contact their instructors during the first week of the term and follow the procedures outlined by campus policy, available at:

`http://enrollmentbulletin.indiana.edu/pages/relo.php`

Sexual misconduct: As your instructors, one of our responsibilities is to help create a safe learning environment on our campus. Title IX and our own Sexual Misconduct policy prohibit sexual misconduct. If you have experienced sexual misconduct, or know someone who has, the University can help. If you are seeking help and would like to speak to someone confidentially, support resources for individuals who have experienced sexual assault are available 24 hours a day. Call (812) 855-8900. More information about available resources can be found here:

`http://stopsexualviolence.iu.edu/help/index.html`.

It is also important that you know that federal regulations and University policy require us to promptly convey any information about potential sexual misconduct known to us to our campus' Deputy Title IX Coordinator or IU's Title IX Coordinator. In that event, they will work with a small number of others on campus to ensure that appropriate measures are taken and resources are made available to the student who may have been harmed. Protecting a student's privacy is of utmost concern, and all involved will only share information with those that need to know to ensure the University can respond and assist. To learn more, we encourage you to visit

`http://stopsexualviolence.iu.edu`.

J113 Introduction to Calculus with Applications

The following page is from a syllabus for *J113 Introduction to Calculus with Applications*, which outlines course content and policies. The rest of the original document was simply a schedule for the semester, which I have omitted.

Fall 2021 **MATH J113 - Brief Calculus** **Syllabus**

Text: *Calculus with Applications*, Brief Version, 11th Ed. by Lial, Greenwell and Ritchey

COAS J113 is a 3 - credit brief calculus course equivalent to Math M119. It satisfies the calculus requirement for the School of Business, School of Public Health and SPEA. It also carries IUB Gen Ed Math Modeling credit and Gen Ed N&M credit.

Students in J113 must have completed J112 with a grade of C- or better. If you received a C or C- in J112, it is **strongly recommended** that you go to the Groups Tutorial Office right away to sign up for J113 tutoring. If it has been more than two semesters since you took J112, it would be wise to sit in a J112 or M014 class to review algebra before attempting J113. Talk to the instructor about sitting in an algebra class.

There will be four exams and a cumulative final exam. Homework will be assigned daily, and quizzes will be given at the discretion of your instructor. Your grade in J113 will be determined by the number of points you accumulate from:

4 Exams	400 points
Homework	100 points
Quizzes	100 points
Final Exam	200 points
Total	800 points

The grading scale is approximately: 90 - 100% = A - . . . A+, 80 - 89% = B – . . . B+, 70 - 79% = C - . . . C+, 60 - 69% = D - . . . D+, and below 60% is failing. In keeping with the policies of the Groups Mathematics Program, **daily attendance is required.**

The sections in the text that will be covered are outlined below. You should read each section in the text *before* it is discussed in class.

Date	**Section to be Covered**
Monday, Aug. 23	R.1, R2
Tuesday, Aug. 24	R.3, R.4
Wednesday, Aug. 25	R.5
Thursday, Aug. 26	R.6
Friday, Aug. 27	R.7

— **Continued** —

8 Appendix B: Documents created by me

M118 Test

The following 5 pages include the problems from a test written by me for my section taking M118 Finite Mathematics. Some of the stylistic choices in this test are simply in keeping with standard test design for this class in the department: a multiple choice test; wrong answers are based on expected mistakes; the answer choice "none of the above" is never intended to be the correct answer, which is explained to students; the difficulty is typical of the third exam in this class; some of the terminology, if a little informal, is typical of the course. If I rewrote this test, I would not deviate from the department style.

I do think there were some missed opportunities for teaching. For example, problem 1 is a linear programming problem typical of the course, whereas problem 9 is an atypical linear programming problem. Juxtaposing these problems could clarify the writer's intent so that students who were lost in the original version of the test might instead have learned something new with the proposed change.

Problems 12 and 18 have a similar relationship of escalating abstraction and difficulty, and might also benefit from juxtaposition, though I think the effect with these problems would be less dramatic.

1. Chuck's Dog Chow comes in two varieties: Good Doggo and Healthy Pupper. Each ounce of Good Doggo chow contains 2 gram of proteins and 12 grams of filler. Each ounce of Healthy Pupper chow contains 5 grams of protein and 10 grams of filler. How many ounces of each type of chow can be made in order to use up 500 grams of Protein and 1400 grams of Filler?

   (a) no Good Doggo, and 100 oz of Healthy Pupper
   (b) 100 oz of Good Doggo, and 60 oz of Healthy Pupper
   (c) 60 oz of Good Doggo, and 50 oz of Healthy Pupper
   (d) 50 oz of Good Doggo, and 80 oz of Healthy Pupper
   (e) 150 oz of Good Doggo, and no Healthy Pupper
   (f) None of the Above

2. Solve for A:

$$A + \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \begin{pmatrix} 2 & 1 \\ 1 & -1 \end{pmatrix}$$

   (a) $A = \begin{pmatrix} 2 & 1 \\ 1 & -1 \end{pmatrix}$
   (b) $A = \begin{pmatrix} 1 & 1 \\ 1 & -2 \end{pmatrix}$
   (c) $A = \begin{pmatrix} 0 & -1 \\ 2 & 0 \end{pmatrix}$
   (d) $A = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$
   (e) $A = \begin{pmatrix} 1 & -1 \\ 2 & 1 \end{pmatrix}$
   (f) None of the Above

3. The following is an augmented matrix for a system of equations with variables w, x, y, z.

$$\left(\begin{array}{cccc|c} 1 & 0 & 2 & 0 & 2 \\ 0 & 1 & 1 & 0 & 3 \\ 0 & 0 & 0 & 1 & -3 \end{array}\right)$$

   Which of the options below are the solution set for this system?

   (a) $w = 2,\quad x = 3,\quad y = y,\quad z = -3$
   (b) $w = 1 - y,\quad x = 1 - \frac{y}{3},\quad y = y,\quad z = -3$
   (c) $w = 2 - 2y,\quad x = 3 - y,\quad y = y,\quad z = -3$
   (d) $w = 2,\quad x = 3,\quad y = 0,\quad z = -3$
   (e) $w = 2,\quad x = 3,\quad y = \{2, 3\},\quad z = -3$
   (f) None of the Above

4. Solve for X in the matrix equation

$$AX + BX = C$$

   where $A = \begin{pmatrix} 4 & 6 \\ -3 & 6 \end{pmatrix}$ and $B = \begin{pmatrix} 1 & -6 \\ 3 & -1 \end{pmatrix}$ and $C = \begin{pmatrix} 5 & 0 \\ 10 & -5 \end{pmatrix}$.

   (a) $A = \begin{pmatrix} 1 & 2 \\ 0 & 1 \end{pmatrix}$
   (b) $A = \begin{pmatrix} 10 & 5 \\ 15 & 0 \end{pmatrix}$
   (c) $A = \begin{pmatrix} 0 & -5 \\ 5 & -10 \end{pmatrix}$
   (d) $A = \begin{pmatrix} 2 & 2 \\ 1 & 1 \end{pmatrix}$
   (e) $A = \begin{pmatrix} 1 & 0 \\ 2 & -1 \end{pmatrix}$
   (f) None of the Above

5. Find a value of k so that the matrix below has no inverse:

$$\begin{pmatrix} 1 & 2 & k \\ 0 & 1 & 1 \\ 1 & 1 & 3 \end{pmatrix}$$

(a) $k = 0$
(b) $k = 1$
(c) $k = 4$
(d) There are multiple values of k for which this matrix is not invertible.
(e) This matrix is invertible for any value of k
(f) None of the Above

6. Find the inverse of the matrix $A = \begin{pmatrix} 2 & 1 \\ 8 & 3 \end{pmatrix}$.

(a) $A^{-1} = \begin{pmatrix} 3 & 1 \\ 8 & 2 \end{pmatrix}$
(b) $A^{-1} = \begin{pmatrix} -1.5 & .5 \\ 4 & -1 \end{pmatrix}$
(c) $A^{-1} = \begin{pmatrix} -3 & 1 \\ 8 & -2 \end{pmatrix}$
(d) $A^{-1} = \begin{pmatrix} 1.5 & -.5 \\ -4 & 1 \end{pmatrix}$
(e) $A^{-1} = \begin{pmatrix} 3 & -1 \\ -8 & 2 \end{pmatrix}$
(f) None of the Above

7. A small economy has the following technology matrix, where the first row corresponds to petroleum, and the second row corresponds to cheese.

$$A = \begin{pmatrix} .8 & .9 \\ .1 & .5 \end{pmatrix}$$

How many units of petroleum are necessary to fill an external demand for 5 units of cheese?

(a) 0

(b) 50

(c) 100

(d) 250

(e) 450

(f) None of the Above

8. What is the y-intercept of the line that is parallel to the line $y = \frac{3}{2}x + 7$ and contains the point $(8, 2)$?

(a) -14
(b) -10
(c) -5
(d) -2
(e) 7
(f) None of the Above

9. Melf's Muffins makes peanut-crunch muffins and double-chocolate muffins. A peanut-crunch muffin contains an ounce of peanuts and a tablespoon of chocolate chips. A double-chocolate muffin contains no peanuts, but does contain three tablespoons of chocolate chips. Melf plans to cook 100 muffins, using 1 gallon (256 tablespoons) of chocolate chips. How many ounces of peanuts will he need?

   (a) 22
   (b) 64
   (c) 78
   (d) 100
   (e) 156
   (f) None of the Above

10. What are the dimensions of the matrix resulting from the calculation below:

$$\begin{pmatrix} 1 & 1 & 0 \\ 0 & -1 & 1 \\ 1 & 0 & 1 \\ 2 & 0 & 0 \end{pmatrix} \begin{pmatrix} 1 & 2 & 2 & 2 \\ -1 & 3 & 1 & 3 \\ -1 & 2 & 1 & -4 \end{pmatrix} - \begin{pmatrix} 1 & 2 & 2 & 2 \\ -1 & 3 & 1 & 3 \\ -1 & 2 & 1 & -4 \end{pmatrix} \begin{pmatrix} 1 & 1 & 0 \\ 0 & -1 & 1 \\ 1 & 0 & 1 \\ 2 & 0 & 0 \end{pmatrix}$$

   (a) 3×4
   (b) 3×3
   (c) 4×4
   (d) 4×3
   (e) This calculation is not well defined
   (f) None of the Above

11. Solve the following matrix equation:

$$\begin{pmatrix} 1 & 2 & 0 \\ 0 & 1 & 1 \\ 1 & 4 & 2 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} 3 \\ 4 \\ 10 \end{pmatrix}$$

   (a) $x = 1, y = 1, z = 3$
   (b) $x = 0, y = 2, z = 0$
   (c) $x = 1, y = 2, z = 2$
   (d) There are infinitely many solutions
   (e) There is no solution
   (f) None of the Above

12. The value of the 1998 Ford Torus has depended linearly on the year since 2010, when it was valued at \$5000. If the car was valued at \$3500 in 2014, how much was the care worth in 2016?

   (a) \$2000
   (b) \$2250
   (c) \$2500
   (d) \$2750
   (e) \$3000
   (f) None of the Above

13. Solve the following system of equations:

$$\begin{array}{rcrcrl} x & + & y & + & z & = 4 \\ 2x & - & y & - & 2z & = -5 \\ x & + & y & & & = 0 \end{array}$$

(a) $x = 1, y = 1, z = 2$
(b) $x = 1, y = -1, z = 4$
(c) $x = 2, y = -2, z = 4$
(d) The system has infinitely many solutions.
(e) The system has no solution.
(f) None of the Above

14. Row reduce the following matrix to the correct reduced form:

$$\left(\begin{array}{ccc|c} 1 & 2 & 1 & 1 \\ 1 & 2 & 3 & 7 \\ 2 & 6 & 2 & 0 \end{array}\right)$$

(a) $\left(\begin{array}{ccc|c} 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 2 \\ 0 & 0 & 0 & 0 \end{array}\right)$
(b) $\left(\begin{array}{ccc|c} 1 & 0 & 1 & 3 \\ 0 & 1 & 0 & -1 \\ 0 & 0 & 0 & 0 \end{array}\right)$
(c) $\left(\begin{array}{ccc|c} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 3 \\ 0 & 1 & 0 & -1 \end{array}\right)$
(d) $\left(\begin{array}{ccc|c} 1 & 1 & 0 & -2 \\ 0 & 0 & 1 & 3 \\ 0 & 0 & 0 & 0 \end{array}\right)$
(e) $\left(\begin{array}{ccc|c} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & -1 \\ 0 & 0 & 1 & 3 \end{array}\right)$
(f) None of the Above

15. What line is parallel to the line

$$3x + 4y = 12$$

and contains the point $(7, 3)$?

(a) $3x + 4y = 3$
(b) $3x + 4y = 7$
(c) $3x + 4y = 12$
(d) $3x + 4y = 33$
(e) $3x + 4y = 45$
(f) None of the Above

16. Find the entry of the second row and fourth column of the following matrix product:

$$\begin{pmatrix} 10 & 0 & 1 \\ 2 & -2 & 3 \\ 4 & -7 & 13 \end{pmatrix} \begin{pmatrix} -1 & 1 & 2 & 4 \\ 1 & -2 & 4 & -8 \\ \frac{1}{3} & \frac{1}{9} & -\frac{1}{9} & -\frac{1}{3} \end{pmatrix}$$

(a) -7
(b) -3
(c) $10\frac{1}{9}$
(d) 23
(e) $39\frac{2}{3}$
(f) None of the Above

17. A village produces hemp rope and fish. The fishers of the village consume on average 1 foot of rope for every 100 fish they catch, and eat 2 fish in the process. The ropemakers eat on average 1 fish for every 10 feet of rope they make. Which of the matrices below could reasonably be a technology matrix modeling the local economy? (the units used are 10 feet of rope and 100 fish)

(a) $A = \begin{pmatrix} 0 & .1 \\ .01 & .02 \end{pmatrix}$

(b) $A = \begin{pmatrix} 0 & .01 \\ .1 & .02 \end{pmatrix}$

(c) $A = \begin{pmatrix} 1 & -.1 \\ -.01 & .98 \end{pmatrix}$

(d) $A = \begin{pmatrix} 1 & -.01 \\ -.1 & .98 \end{pmatrix}$

(e) $A = \frac{1}{.979} \begin{pmatrix} .98 & .1 \\ .01 & 1 \end{pmatrix}$

(f) None of the Above

18. The 1990 Dodge Ram cost \$16,000 when it was first released, and depreciated in value linearly. The 1990 Ram cost \$11,000 in 1995. The 1990 Chevy Malibu initially cost twice as much as the Ram, but depreciated in value three times as quickly. In what year did the vehicles have the same value?

(a) 1990
(b) 1995
(c) 1998
(d) 2001
(e) 2005
(f) None of the Above

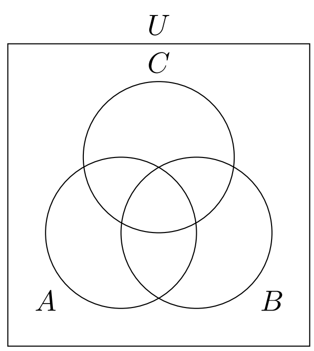
D116 Quizzes

These quizzes were turned in at the beginning of class, after which I showed students how to work through the problems using a projector. Each quiz had three questions ordered by increasing difficulty, covering content from the previous lecture, with the intent that almost every student would be able to complete the first two problems accurately and quickly, and that the last problem would be more challenging.

Quiz. Section 1.3
Problem 1. If $A = \{1, 2, 3, 4, 5\}$ and $B = \{2, 4, 6, 8, 10\}$ then what are $n(A), n(B), n(A \cap B)$, and $n(A \cup B)$?

Problem 2. In a universal set U containing the sets A and B, suppose $n(U) = 100, n(A \cap B) = 30, n(A \cap B') = 30$, and $n(B') = 50$. What is $n(A \cup B)$?

Problem 3. Let U be a universe set containing the sets A, B, C. Let $n(A \cap B \cap C) = 0, n(A \cap B) = 5, n(A \cap C) = 5, n(B \cap C) = 6, n(A) = 12, n(C) = 13, n(B) = 14$. What is $n(A \cup B \cup C)$?



Quiz. Section 3.1
Problem 1. The forecast predicts a 40 % chance of rain. What is the probability it does not rain? Give your answer as a percent.

Problem 2. On a particular exam, $\frac{1}{3}$ of students failed and $\frac{1}{10}$ of students received an A. What is the probability that a randomly selected student passed the test, but did not receive an A?

Problem 3. The forecast predicts rain with probability .6, high wind with probability .7. More specifically, there is a .5 chance that there will be both rain and high wind. What is the probability that it will just be rainy, or just windy, but not both rainy and windy.

My intent at the time was that the challenging problem would motivate students to keep up with the coursework, and would also provide them with more meaningful feedback than the easier problems. However, if I found myself using quizzes to motivate attendance now, I would make the quizzes open note and structure them as review of the previous topic, or preparation for an upcoming topic. For example:

Quiz. Section 1.3 (Revised)
Recall that $n(S)$ denotes the number of elements in S, that $A \cap B$ is the set of all elements which are in both A and B, and $A \cup B$ is the set of all elements which are in either A or B or both.

Problem 1. If $A = \{1, 2, 3, 4, 5\}$ and $B = \{2, 4, 6, 8, 10\}$ then what are $n(A), n(B), n(A \cap B)$, and $n(A \cup B)$?

Problem 2. In a universal set U containing the sets A and B, suppose $n(U) = 100$, $n(A \cap B) = 30$, $n(A \cap B') = 20$, and $n(B') = 60$. Draw a Venn diagram for the sets A and B in U, and place the numbers 30 and 20 in the appropriate places in the diagram.

Problem 3. Copy your Venn diagram from problem 2, and fill in the rest of the diagram.

Quiz. Section 3.1 (Revised)
Recall that the probabilities of all disjoint outcomes in a scenario should add up to 1, or 100%.

Problem 1. Identify which of the following situations is impossible, and explain why.

- The forecast predicts a 40% chance it will rain, and a 60% it will not rain.
- In one math class, the probability of a student receiving an A is .2, the probability of receiving a B is .3, the probability of receiving a C is .4, the probability of receiving a D is .1, and the probability of receiving an F is .2.

Problem 2. On a particular exam, $\frac{1}{3}$ of students failed and $\frac{1}{10}$ of students received an A. What is the probability that a randomly selected student passed the test, but did not receive an A?

Problem 3. The forecast predicts rain with probability .6, high wind with probability .7. More specifically, there is a .5 chance that there will be both rain and high wind. What is the probability that it will be just rainy, or just windy, but not both rainy and windy?

hint: Draw a Venn diagram, and label each region in the diagram with a probability. All four probabilities should add up to 1.

M106 Scheduling Guide

The following four pages contain a sample of a guide I created for instructors of M106. This document was meant to help concurrent instructors teach uniformly, a matter discussed further in section 5.1.1.

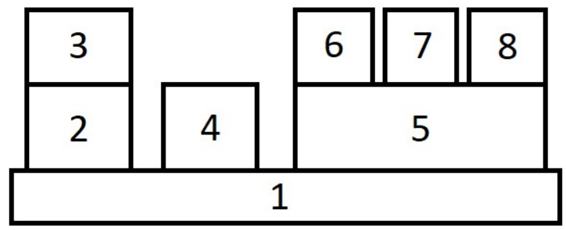
Coordinating the Graph Theory module

The notes have these sections:

1. Graphs and Digraphs
    a. Graphs, vertices, edges, degree
    b. Weighted graphs
    c. Directed graphs
2. Euler Circuits
    a. Walks
    b. Cycles
    c. The Konigsberg Bridge Puzzle
    d. Eulerian Circuits and Paths
3. Eulerian Graphs and Eulerization
    a. Eulerian Graphs
    b. Connectedness
    c. Eulerization by duplicating edges
    d. Eulerization by removing edges
4. Graph Drawings and Isomorphisms
    a. Graphs vs. Graph Drawings
    b. Isomorphic Graphs
    c. Planarity
5. Special Types of Graphs
    a. Complete Graphs
    b. Cycle Graphs
    c. Subgraphs
    d. Trees
    e. Bipartite Graphs
6. Hamiltonian Circuits
    a. Hamiltonian Circuits
    b. Graphs without H. Circuits
    c. Traveling Salesman Problem
    d. Nearest Neighbor Algorithm
    e. Sorted Edges Algorithm
7. Spanning Trees
    a. Trees
    b. Spanning Trees
    c. Minimum spanning trees
    d. Kruskal's Algorithm
8. The Chromatic Number
    a. Proper Coloring
    b. N-colorable
    c. Chromatic Number
    d. Clique and Clique Number
    e. Greedy Coloring
    f. Scheduling Problems

Each of these sections are intended to be accessible to students. They each have an associated homework assignment consisting primarily of routine problems. Each section in the notes also ends in some exercises, most of which are more thought provoking than the standard assignments – documents exist to turn some of these problems into longer in-class exercises. The red sections are what you are expected to cover in a typical course. The information in the other sections would typically filter into your course *anyway*, so you can either treat them as independent topics (as they are written in the notes), or just cover those ideas as they become relevant.

The dependency of the sections is approximately:



In addition to the lecture notes, the following resources are available to you:

- An assignment for each section
- Additional assignments for certain sections
- Two exam practice assignments
- An exam problem bank
- Old exams

A specific account of what documents exist is given on the next page.

However you decide to organize your course, consistency is important. You and the other instructors should agree on exactly which topics to include on the exam, before you start teaching the section. One good way to do this would be to draft the exam before this section starts. Or, you might agree on a set of assignments to assign and build the exam around.

Available Documents

You have access to a number of assignments and other resources, although you need not use all of them. You should probably assign the worksheets which are marked in red, as well as an additional couple of worksheets, and an exam practice problem set. For most of these documents, both the .pdf and .tex are available.

Notes

main.pdf	These are the graph theory notes for the course
Konigsberg2.png, NewEngland.png	These are used in the notes

Assignments

1. Graphs and Digraphs.pdf	Section 1 worksheet
2. Euler Circuits.pdf	Section 2 worksheet
2. Euler Circuits – Konigsberg.pdf	Section 2 additional worksheet
3. Euler Graphs and Eulerization.pdf	Section 3 worksheet
4. Graph Drawings and Isomorphisms.pdf	Section 4 worksheet
5. Special Types of Graphs.pdf	Section 5 worksheet
6. Hamiltonian Circuits.pdf	Section 6 worksheet
7. Spanning Trees.pdf	Section 7 worksheet
8. Graph Coloring.pdf	Section 8 worksheet
8. Graph Coloring – Scheduling Problems.pdf	Section 8 additional worksheet

Exam Resources

Exam Prep.pdf	A set of practice questions for the exam
Exam Practice Questions.pdf	Additional practice questions
Exam Sample Questions.pdf	A problem bank of exam questions: you are encouraged to write your exam using these.

Old Exams

Graph Exam Dec 2017 Condon.pdf	Old graph theory exam
Graph Exam Dec 2017 Hussung.pdf	Old graph theory exam

Meta

Instructor Readme.pdf	.docx file also available
Graph Theory Section Dependence.png	

All pdfs except for the old exams come with .tex files.

The following gives a sample schedule for during the semester (50 minute lectures):

Day	Sections	Learning Objectives	Assignments
1	Graphs and Digraphs	Vocab: graph, vertex, edge, digraph, degree Use graphs to represent real world situations	Section 1 Worksheet
2	Konigsberg	Vocab: walk, circuit Discover a characterization of Eulerian graphs	Konigsberg Worksheet
3	Eulerian Graphs	Vocab: Eulerian, connected, component Identify which graphs have Eulerian Circuits or Paths	Section 2 Worksheet
4	Eulerization	Vocab: Eulerization Eulerize graphs by duplicating edges	
5	Eulerization	Eulerize graphs by removing edges Identify methods of Eulerization appropriate to a particular problem	Section 3 Worksheet
6	Graph Drawings	Vocab: drawing, equal, isomorphism, planar Distinguish between graphs and drawings Identify isomorphic graphs Be able to redraw graphs differently	Section 4 Worksheet
7	Special Graphs	Vocab: tree, leaf, cycle, complete graph, bipartite, subgraph Identify certain special graphs and some of their properties	Section 5 Worksheet
8	Hamiltonian Circuits	Vocab: Hamiltonian Circuit, cut vertex, the Traveling Salesman Problem, algorithm, greedy Identify when a graph clearly has no Hamiltonian Circuit Apply the Nearest Neighbor Algorithm	
9	Hamiltonian Circuits	Apply the Sorted Edges Algorithm Identify the failings of the NN Algorithm and SE Algorithm	Section 6 Worksheet
10	Spanning Trees	Vocab: Spanning tree, minimum spanning tree Know when to use a minimum spanning tree Apply Kruskal's Algorithm	Section 7 Worksheet
11	Graph Coloring	Vocab: proper coloring, chromatic number, clique, clique number Identify a clique on a graph Find the chromatic number of a graph Apply the greedy coloring algorithm	Section 8 Worksheet
12	Scheduling Problems	Practice coloring and solve scheduling problems	Scheduling Problems Worksheet
13	Review		
14	Review		
15	Exam		

The following gives a sample schedule for during the summer (120 minute lectures):

Day	Sections	Learning Objectives	Assignments
1	Graphs and Digraphs Konigsberg	See above	Section 1 worksheet Konigsberg Worksheet
2	Euler Circuits Eulerization		Section 2 Worksheet
3	Eulerization		Section 3 Worksheet
4	Graph Drawings Special Graphs		Section 4 Worksheet Section 5 Worksheet
5	Hamiltonian Circuits		Section 6 Worksheet
6	Spanning Trees		Section 7 Worksheet
7	Graph Coloring and Scheduling Problems		Section 8 Worksheet Scheduling Problems Worksheet
8	Review		
9	Review and Exam		Exam

M106 Sample Notes

The following six pages contain notes I wrote for the graph theory unit of *M106 The Mathematics of Decision and Beauty.* These are from the instructor edition, which differs from the student edition by the inclusion of comments in the margins.

With the benefits of having taught the course with these materials, and having seen alterations made by later instructors, I have the following reflections:

- I stand by my choice to give informal definitions rather than set-theoretic ones, something that some later instructors changed.
- Problem 2 is very important because it catches a common mistake that students make - thinking that the crossing of edges in the middle of the graph constitutes a vertex.
- Problems 3-5 are both conceptually challenging and technically challenging[1] for many students. I would only give these problems as classwork, not homework, and the instructor edition could benefit from a note to this effect. The problem would likely be improved if one of the people was removed.
- Problem 7 requires some tricky arithmetic. While one might feel college students should have no trouble with arithmetic, arithmetic isn't the point of this class, and the instruction of *graph theory* would benefit from a different presentation of this problem.
- Another instructor combined problem 8 with the ideas from problems 3-5, which I think was excellent, though again the number of vertices involved should probably be kept to at most six.
- Problem 9 could benefit from a less intimidating presentation, or a discussion of graphs and digraphs and which makes more sense here.

[1] Counting the edges of K_6 is harder than you might expect.

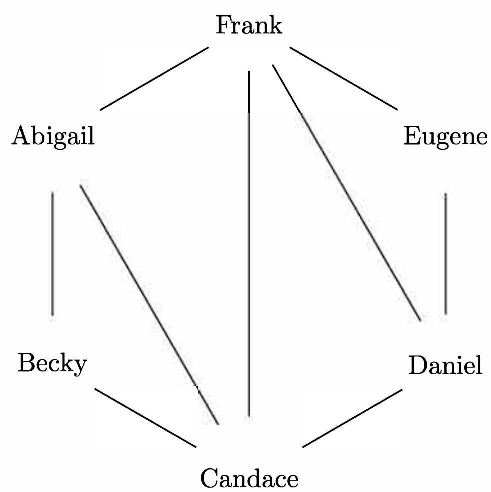
Graph Theory

4.1 Graphs and Digraphs

Graph theory is the study of networks.

This section uses a lot of color coding. You may want to ask your students if any of them have issues distinguishing between colors: you can easily change the color coding in the preamble to the .tex file for these notes, and give them a personalized copy.

Definition. *A **graph** is a collection of objects and relationships between pairs of those objects. We call the objects **vertices** (plural of **vertex**) and we call the relationships **edges**.*



In the last decade or so, online social networks have become very important, and these can be studied as graphs. For example, imagine Abigail, Becky, Candace, Daniel, Eugene, and Frank are all students at the same school - probably some of them are Facebook friends, and some are not. We can represent this information using a graph.

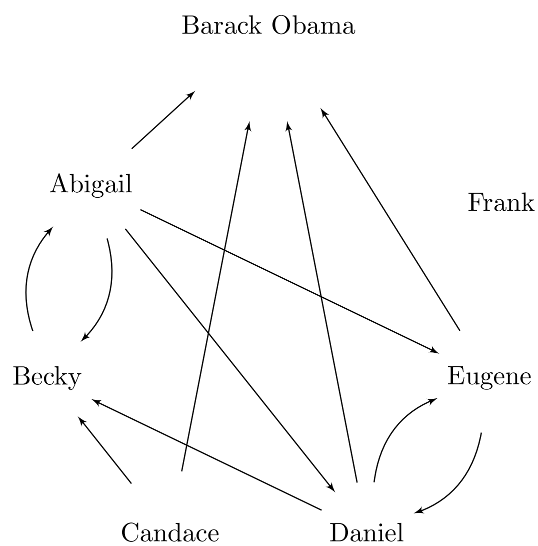
I suspect "Facebook friends" is rapidly becoming an archaic reference. Maybe use a different example in order to seem cool to the young people.

The vertices on this graph are the students. The edges are the lines between them, which represent that two students are Facebook friends. Abigail is Facebook friends with Becky, Candace, and Frank because there are edges between her vertex and their vertices. Abigail is not Facebook friends with Eugene or Daniel because there is no edge between her vertex and theirs.

Comprehension Check. *Who among the six students are Facebook friends with Becky? How many of the students are Facebook friends with Frank?*

Becky's friends are Candace and Abigail. Frank has four friends among the group.

Facebook friendship is a mutual or symmetric relationship - if Abigail is friends with Becky, then Becky must also be friends with Abigail. Not all relationships are symmetric, and we sometimes represent such relationships on graphs with the use of arrows. Keeping with the theme of social networks, Twitter users can choose to follow another user's messages. This is not a symmetric relationship - just because Daniel reads Barack Obama's tweets, does not mean Barack Obama returns the favor. Typically, high profile figures are followed by many people, but do not follow many people. We can use a graph with arrows to represent this type of relationship.



In this graph, the person at the tail of an arrow is a Twitter follower of the person at the head of the arrow. Candace has no followers. Barack Obama does not follow anyone. Some pairs of people (such as Abigail and Becky) do have a symmetric relationship - we choose to represent that with a pair of arrows, but there are other ways you could represent that symmetry. The drawing above is a typical representation of a directed graph or digraph.

Definition. *A* ***digraph*** *is a collection of* ***vertices*** *and* ***directed edges****, where a directed edge represents a one-way relationship between two vertices.*

Comprehension Check. *Which person in the digraph has the most followers? Who follows the most people? Which person appears not to know how to use Twitter? Which pair of people (besides Abigail and Becky) have a symmetric relationship?*

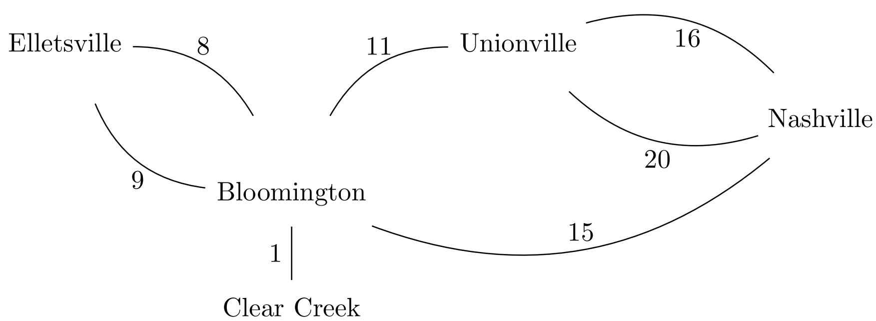
Barack Obama has the most followers. Abigail follows the most people.
Frank is bad at Twitter. Daniel and Eugene have a mutual relationship.

Another aspect of a network we might want to represent is the magnitude of a relationship.

Definition. *When we wish to associate a number with each edge on a graph, we call that number the* ***weight*** *of that edge. We call each edge with a number a* ***weighted edge****, and we call a graph with weighted edges a* ***weighted graph****.*

A very typical use of weighted graphs is to represent connections and distances between places. For example, the following graph depicts a group of towns in Indiana, and the distances between them by road.

The number we associate with each edge often indicates the *significance* of that edge. Usually a big number means more significance, but it may be worth pointing out that here a larger number signifies a weaker relationship between the vertices.



According to this graph, the distance from Bloomington to Unionville is 11 miles. We do not typically write units on our graph because it clutters the diagram, but it is important to understand what the units are in context. There is no direct path from Unionville to Clear Creek, but the distance between those two cities is 12 miles via Bloomington.

Comprehension Check. *What is the shortest route from Nashville to Elletsville?*

The shortest route is 15 miles to Bloomington and then 8 miles to Elletsville for a total of 23 miles.

Observe that on this graph, there are multiple edges between some pairs of vertices.

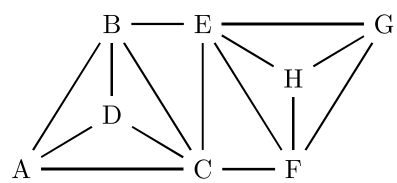
Definition. *We call a graph with multiple edges between some vertices a* ***multigraph****. Usually in this class we will consider multigraphs to be a special type of graph. In some texts, they are considered a similar but distinct object from graphs.*

Depending on a person's interests in the graph, they might choose to represent it with no duplicated edges. For example, a person who wanted to tour all five of these towns would always take the fastest route, and could safely ignore the redundant roads. They might redraw this graph without certain edges. On the other hand, a person who was interested in the roads themselves (perhaps a snow plow owner) would want to use the entire multigraph.

Exercises

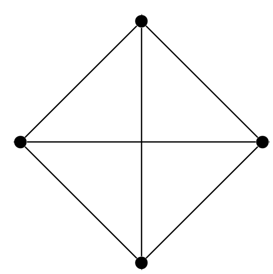
The **degree** of a vertex is the number of edges connected to that vertex.

1. Answer the following questions about this graph:



   (a) How many vertices does this graph have?
   (b) How many edges does this graph have?
   (c) What is the degree of vertex A?
   (d) What is the highest degree of any vertex on the graph?

2. Answer the following questions about this graph:



   (a) How many vertices does this graph have?
   (b) How many edges does this graph have?
   (c) What is the highest degree of any vertex on the graph?

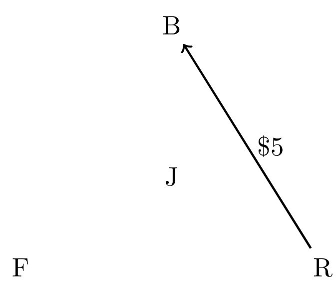
3. Alfred, Annie, Alex, Bob, Brittany, and Berthe are all attending a party. Each of the people whose names start with A already know each other, but know none of the people whose names start with B. The people with names that start with B all know each other already. Draw a graph representing each person as a vertex, and use edges to indicate that two people know each other. How many edges are there?

4. Using the same scenario as in the previous problem, draw a graph where edges represent that two people do not know each other. How many edges are there?

5. On a graph with 6 vertices, where there is an edge between every two vertices, how many edges are there? How does this relate to the previous two questions?

6. Freddie, Brian, Roger, and John all play in a band together. John also plays in a band with Jimmie and Robert. In fact, John plays in another band with Paul, George, and Ringo. Draw a graph in which each of these people is a vertex, and draw an edge between each pair of people who are in a band together.

7. Freddie, Brian, Roger, and John all go out for a night on the town: they agree that the following day, they will pay each other back for the costs of the evening. Freddie drives, and spends $12 on gas. Brian pays $60 for the group's dinner. Roger buys movie tickets, spending $40. Use a *directed, weighted* graph to represent how much money each friend owes to each other. The first edge is already drawn: the weight is the amount that Roger owes Brian, minus the amount that Brian owes Roger.



8. Draw a graph where each vertex represents a state in New England, and edges represent that two states share a border. You may find it is helpful to draw your graph on top of this map of New England.

9. Lazyname Airlines offers daily flights between 6 major cities: New York City, Indianapolis, Atlanta, Reykjavik, Paris, and London. The table of available flights is given here.

Flight	**Departs**	**Arrives**	Cost
103	Indianapolis	Atlanta	$ 200
102	Indianapolis	New York	$ 400
201	New York City	Indianapolis	$ 400
203	New York City	Atlanta	$ 200
204	New York City	London	$ 800
301	Atlanta	Indianapolis	$ 200
302	Atlanta	New York	$ 200
304	Atlanta	London	$ 900
306	Atlanta	Reykjovik	$ 800
402	London	New York	$ 800
403	London	Atlanta	$ 900
405	London	Paris	$ 100
406	London	Reykjovik	$ 400
504	Paris	London	$ 100
506	Paris	Reykjovik	$ 600
603	Reykjovik	Atlanta	$ 800
604	Reykjovik	London	$ 400
605	Reykjovik	Paris	$ 600

Use a weighted graph to represent the cities Lazyname flies to, which flights are available, and how much each flight costs.

10. Every year Lazyname Airlines shuts down most of their flights for a week in celebration of President's Day, leaving only the following schedule.

Flight	**Departs**	**Arrives**	Cost
103	Indianapolis	Atlanta	$ 200
201	New York City	Indianapolis	$ 400
204	New York City	London	$ 800
302	Atlanta	New York	$ 200
406	London	Reykjovik	$ 400
504	Paris	London	$ 100
603	Reykjovik	Atlanta	$ 800
605	Reykjovik	Paris	$ 600

Draw a weighted digraph to represent the flights that are available. Is it possible to travel from any city to any other city using just these flights?

M106 Voting Theory Assignment with Student Work

The following question from my *Voting Theory* course notes is the basis for a group activity, which I discuss briefly in my Teaching Statement.

11 Design a voting system which you feel fairly and accurately reflects the wishes of an electorate. You should be able to answer the following questions about your voting system, and they might give you some ideas about approaching this exercise:

(a) What information does each voter put on their allot?

(b) Are all voters equal? If not, how does the role of different voters vary?

(c) Are all candidates equal? If not, how does the role of different candidates vary?

(d) Is your system deterministic?

(e) Is your system a Condorcet method?

(f) Is your system similar to any of the systems discussed so far in class? If so, how have you improved it?

Write down the rules of your system clearly and precisely, and answer the above questions about it.

Over the years I have used this activity with different prompting questions, so there is some variation in the solutions that I have documented on the following pages. I typically tell students they will be graded on their ability to describe the rules of their voting system unambiguously; I make this is an exercise about communication as much as about voting systems.

I give students whose descriptions are ambiguous feedback and the opportunity to resubmit. Usually these students resubmit the assignment individually, for logistical reasons. Also for logistical reasons, it was easier for me to get permission from those individual students than from groups for me to share their work, so the work that follows represents students' second attempt to describe their voting system.

I follow up on this activity later in the unit, by asking students to determine which fairness principles apply to their voting system. I have sometimes also discussed with students how strategic voting might be used in their voting system.

The voter profile would be evaluated by comparison between each 2 candidates, and the winner would be determined by the candidate with the greatest winning margin.

30	4	3	27	27	5
A	A	B	B	C	C
B	C	A	C	A	B
C	B	C	A	B	A

We would evaluate the candidates by comparing A+B, A+C, etc. individually.

61 voters support A over B; 35 support B over A.
Margin of A > B = 26
(etc.)
This process would be repeated comparing all pairs of candidates (x, y).

greenroom

11. 10 points to distribute (per voter)
(3 candidates) - or any number less than 10 candidates
Ballot

Candidate	X -	9	5	0
	y -	1	3	10
	z -	0	2	0

each voter can give ~~the~~ each candidate their chosen number, giving them more power to give weight to each candidate vote than for instance, the Borda count, where the order decides the weight definitively. All voters and candidates are equal and the result is most likely definitive.

Voting Homework 4 (Voting System Design)

Rules:

11. a. Each voter casts their ballot in a social ordering.
    ex. A>B>C?
b. All voters are equal, but their lowest ranked social ordering holds no weight.
c. All candidates are equal.
d. not deterministic
e. not condorcet
f. this system is very similar to the Borda Count and runoff systems

Steps: 1. allocate points for each candidate using the Borda Count.
2. have a runoff between the candidates with the two highest point values.

Ex:

	5	1	3	5	5	1
2	A	A	B	B	C	C
1	B	C	A	C	A	B
0	C	B	C	A	B	A

→ A: 20, B: 22, C: 18 → runoff - A: 11, B: 9

↓

A wins

#11

New voting system:

Plurality with a second and third place Borta count. Once the winner is chosen with plurality, they are taken out and a Borta count is done with second, third, fourth, ect candidates. This shows if the original plurality was correct or not.

example:

	10	10	9	6	4	15
2	~~A~~	~~A~~	B	B	C	C
1	B	C	~~A~~	C	~~A~~	B
0	C	B	C	~~A~~	B	~~A~~

A: 20
B: 15
C: 19

with plurality, A wins, then B and C go head to head in a Borta count and in this count A or the winner is not counted.

B: 30 + 25 = 55 votes
C: 38 + 16 = 54 votes

From this, we see that with plurality the result was A > C > B, but then when a Borta count is done between 2nd and 3rd place, the results will not always be the same, now in the borta count, B > C.

M106 Sample Exam

This test was given over the 2019 summer semester during the graph theory unit. In reflection:

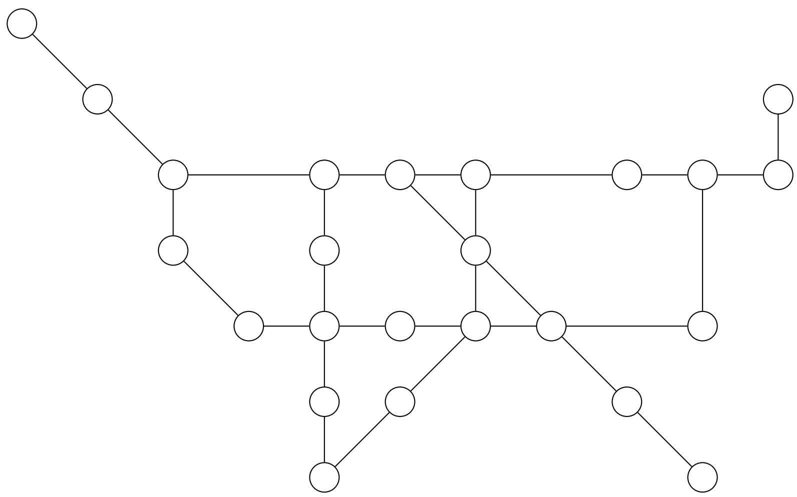
- Problem 1(a) is harder than I anticipated when I wrote the test; most students were able to produce an intelligent answer using sensible methods, but few found the optimal answer. The other instructor and I agreed on a generous grading scheme for this problem that reflected this, so that students who had used the methods taught in the class still earned nearly full credit. But I would not intentionally use a problem this technically difficult in the future.

- Problem 4 is technically easy (it involves a graph with 6 vertices and 8 edges) but conceptually a little challenging, and goes slightly beyond typical scheduling problems. In spite of not having been shown a problem exactly like this in the course, most students solved this problem correctly. I prefer problems of this kind, where students see something new on fair terms, to those like problem 1, where the challenge is mostly technical.

Name:

Read each question carefully. You should show all of your work in order to receive full credit on this exam. Believe in yourself, as I believe in you.

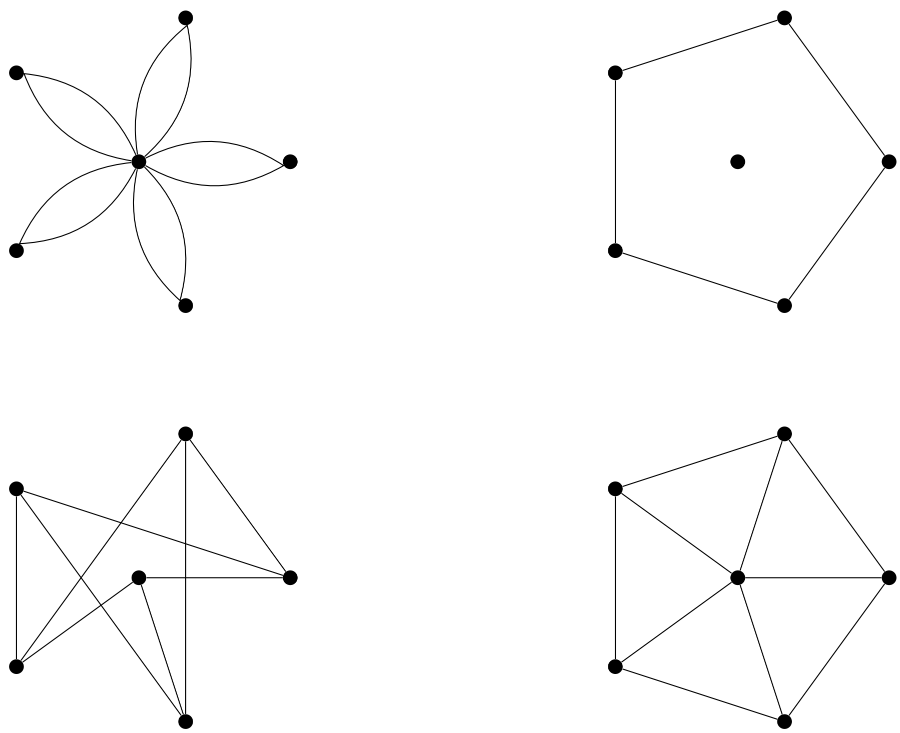
1. The graph below represents a railray map - each oval is a station, and each section of rail between stations is one mile.



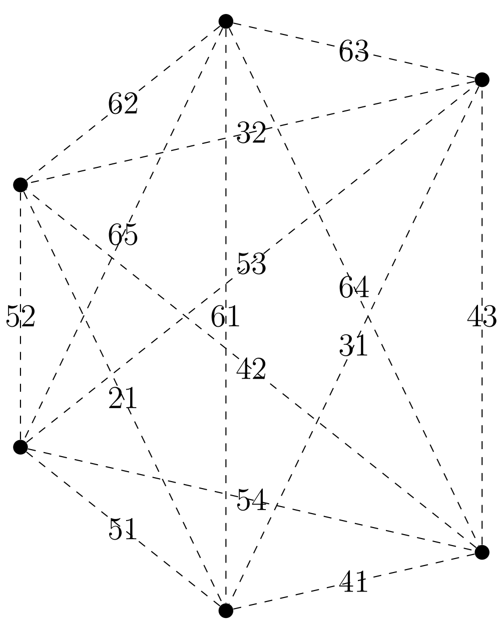
   (a) Mr. Miyazaki wishes to sightsee from the railway, and he doesn't want his trip to become repetitious. What is the longest route he can take without repeating any section of railway, if he doesn't mind revisiting some stations?

   (b) Dr. Goldman also wishes to sightsee, but she doesn't want to miss any part of the railway. She also wants to end her trip at the same station she starts at. What is the shortest route she can take to accomplish this?

2. Determine which of the graphs below have Hamiltonian circuits, and which do not. If a graph does not have a Hamiltonian circuit, you should explain why.



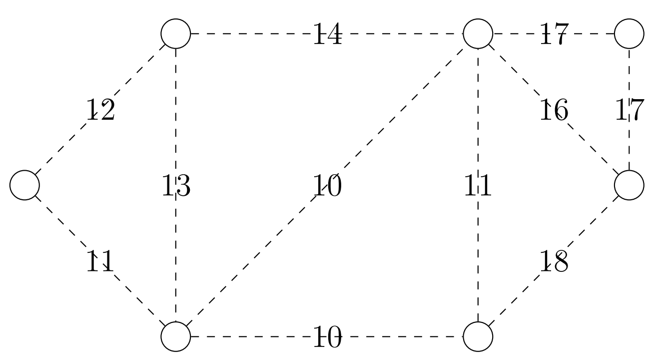
3. Use the sorted edges algorithm to find a Hamiltonian circuit on the graph below.



4. Amos, Ben, Cindy, Delmar, Escobar, and Francis are going rafting in three rafts, with two people in each raft. Amos and Ben are both too heavy to go in the same raft, whereas Escobar, Delmar, and Francis are all too light to be paired up. Cindy and Ben are both adventurous and plan to hit the most dangerous parts of the river; neither of them can share a raft with Amos or Delmar, who are both skittish. Cindy is allergic to Escobar's cat, which travels with him *everywhere*.

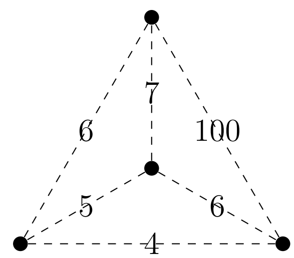
   Sketch a graph of the conflicts prohibiting these people from rafting together, find a coloring of that graph, and deduce how the rafters should be paired up.

5. The nodes in the graph below represent military bases that need to be connected into a communications network. The weighted edges of the graph represent the cost of establishing a connection (in thounds of dollars) between two bases. What is the minimum cost to build a <u>connected</u> network that includes every base?



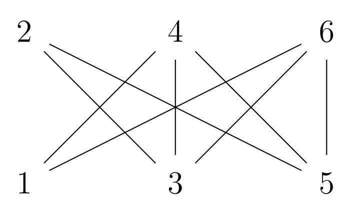
In each of the following problems, you are asked to apply an algorithm from the class. You will also be asked whether the algorithm gives an optimal solution to the problem and, if not, to produce a better solution.

6. (a) Use the Nearest Neighbor algorithm (starting from the middle vertex) to find a cheap Hamiltonian circuit on this graph, and say the cost of that circuit.



(b) Was this the cheapest possible Hamiltonian circuit? If not, say the cost of the cheapest Hamiltonian circuit.

7. (a) Use the greedy coloring algorithm to color this graph.



(b) Is this a minimal coloring? If not, what is the chromatic number of this graph?

Voting Theory Syllabus

The following ten pages contain the syllabus for a voting theory course which was approved to run at IU in the Spring semester of 2022. I have approval to continue editing some parts of the syllabus, and I plan to update it to better reflect my plan for the course. Some changes I have made to my plan for the course, which I have not yet updated on the syllabus, include:

- Small changes to the course outline,
- A diversification of the types of assignments, for example:
  - activities that exist primarily to be experienced (such as discussions and roleplay) now have written reflection assignments associated with them,
  - some creative activities now have a peer-review component,
  - I hope to do an activity, open to people from outside of the class, where students have a chance to educate others about some voting methods.

The Mathematics of Voting – CLLC-L 230, Spring 2022

Instructor: Daniel Condon, dmcondon@iu.edu

Office Hours: Collins Coffeehouse, Time TBD

Abstract: You and your fellow students play the role of a democratic activists in a fictional democracy. You will use what you learn in the class to report on political developments in the region and lobby for or against changes to the rules of the democracy. You will also act as voters and will learn how political strategists can manipulate the rules of democracy to their advantage.

This is a course in the procedural, rather than social, aspects of elections. We will study the mathematics of such procedures as first-past-the-post voting, ranked-choice voting, approval voting, districting, and district apportionment, to see how the specific rules of a democracy impact different notions of 'fairness.' These and other examples will help us to see how rigid notions of fairness may contradict each other or be undermined.

The course is driven by activities and discussions, though these will focus on ideas introduced by lecture.

Topics in the Course: This course is about the mathematics of certain procedural aspects of democracy, including voting, districting, and district apportionment, with respect to notions of fairness.

For example, we will explore first-past-the-post, ranked choice voting, approval voting, single-transferable vote, as well as less common election procedures. We will explore what these procedures are good at, what they are bad at, and how they may be susceptible to manipulation by political strategists.

We will study different notions of fairness for elections, for example:

- voters should be treated equally,
- candidates should be treated equally,
- getting more votes should benefit a candidate,
- it should be in a voter's best interest to vote for their favorite candidate.

We will see how these ideas (and others) are mutually contradictory, susceptible to manipulation, or simply impossible to attain in a mathematical sense.

We will also study district apportionment: if some political seats are to be split amongst given districts based on their population, how do you do this fairly? We will explore several methods, and again will see that different notions of fairness are mutually contradictory.

We will also study districting, through the lens of gerrymandering. We will seek to determine rules for districting that make gerrymandering difficult. We will also explore different methods of quantifying success in this endeavor.

The last few weeks of the semester will be spent on student driven projects. During this time, there will be some lectures on voting theory in the context of the United States Electoral College, machine learning, and honeybee democracy.

Weekly Outline of Topics

Date	Topics
Week 1	Syllabus, Introduction to Social Choice, Establish Project Groups
Week 2	Plurality Voting, Ranked Choice Voting, Duverger's Law, the Spoiler Effect
Week 3	Coombs's Method, Condorcet Criteria
Week 4	Fairness Criteria and Possibility Theorems
Week 5	The Borda Count, Approval Voting, Systems with Points
Week 6	Agenda Voting, Referendums, and Bracket Manipulation
Week 7	Single Transferrable Vote, Proportional Representation List Systems
Week 8	Methods of District Apportionment
Week 9	Fairness Criteria for District Apportionment
Week 10	Fair Districting
Week 11	Gerrymandering
Week 12	Review + Exam
Week 13	The Electoral College, Designing an Election System Project
Week 14	Honeybee Elections, Election Reform Project
Week 15	Ensemble Machine Learning, Prepare Project Presentation
Week 16	Project Presentations

A complete outline of planned topics and activities by week follows at the end of this syllabus.

Learning Outcomes: By the end of this course, students will:

- Apply common democratic procedures to determine election winners and apportion voting districts according to those procedures.
- Apply strategic voting methods to affect elections in their favor.
- Analyze notions of fairness and understand their relationships with each other and strategic voting methods.
- Evaluate common democratic procedures in terms of fairness criteria.
- Evaluate common arguments in the discourse on election reform.
- Create new democratic procedures and evaluate the ways in which they are fair/unfair, and how they may be susceptible to strategic manipulation.
- Communicate unambiguously about the rules of elections and fairness criteria.

Readings and Resources: the main text for this course will be *A Mathematical Look at Politics* by Robinson, Ullman, and it is recommended students obtain a copy of this text.

The course will also use material from

- *Chaotic Elections, a Mathematician Looks at Voting* by Donald G Saari
- *Social Choice Theory and Research* by Paul E. Johnson
- *Electoral Systems: A Comparative Introduction*, by David Farrell
- *Honeybee Democracy* by Thomas Seeley
- *Votes from Seats* by Matthew Shugart, Rein Taagepera

Lecture notes will be provided for material not found in the main text.

Weekly Class Structure

Students will form groups of 4-6 with whom they will complete most assignments throughout the class. The first half of each week will be spent on introducing a topic: typically this will involve some lecture, some discussion, and a worksheet to complete.

The second half of each week will be spent on an assignment motivated by real world examples but framed as part of a single ongoing activity. Students play the role of political activists in an evolving democracy. They must use what they have learned to lobby for and against changes to the rules of the democracy, and report on developments that may make their political system less fair. They will also act as voters on some issues, and evaluate how political strategists may use the rules of the democracy to their advantage.

Grading Scheme

60% of your grade comes from **classwork**. Each day of classwork is weighted equally. Math problems will be graded for accuracy and you are expected to show your work. Non-math problems (usually asking you to comment on a democratic procedure) will include very specific prompts, and your grade will reflect whether you addressed those prompts and (if applicable) whether your response was precise and mathematically accurate. Classwork will generally be due at the end of class.

10% of your grade comes from the **exam**, which will be graded for accuracy.

10% of your grade comes from each of two **projects** at the end of the course. In the last week, your group may give a presentation on one of those projects to earn some extra points on that project.

10% of your grade comes from **attendance**. You must attend 70% of classes to pass the class. If you attend 90% of classes or more, you will receive full credit on your attendance grade. If you attend between 70% and 90% of classes, your grade will be interpolated linearly (for example, attending 80% of classes will earn you a 50% attendance grade). If you miss many classes due to extreme circumstances, the attendance policy may be altered to your benefit at the instructor's discretion.

Dropped Assignments: 10% of classwork grades will be dropped, and this amount may be increased.

Technology Policy: You are welcome to use your laptops to take notes and participate in the class. Students using laptops for activities unrelated to the class will be asked not to use them in the future.

Academic integrity: As a student at IU, you are expected to adhere to the standards and policies detailed in the Code of Student Rights, Responsibilities, and Conduct. When you submit an assignment with your name on it, you are signifying that the work contained therein is yours, unless otherwise cited or referenced. Any ideas or materials taken from another source for either written or oral use must be fully acknowledged. All suspected violations of the Code will be reported to the Dean of Students and handled according to University policies. If you are unsure about the expectations for completing an assignment or taking an exam, be sure to seek clarification beforehand. The following is the IU policy on plagiarism, which can be found here: http://www.indiana.edu/~istd/definition.html

3. Plagiarism: Plagiarism is defined as presenting someone else's work, including the work of other students, as one's own. Any ideas or materials taken from another source for either written or oral use must be fully acknowledged, unless the information is common knowledge. What is considered "common knowledge" may differ from course to course.
a. A student must not adopt or reproduce ideas, opinions, theories, formulas, graphics, or pictures of another person without acknowledgment.
b. A student must give credit to the originality of others and acknowledge an indebtedness whenever:
1. Directly quoting another person's actual words, whether oral or written;
2. Using another person's ideas, opinions, or theories;
3. Paraphrasing the words, ideas, opinions, or theories of others, whether oral or written;
4. Borrowing facts, statistics, or illustrative material; or
5. Offering materials assembled or collected by others in the form of projects or collections without acknowledgment.

Disability services: Every attempt will be made to accommodate qualified students with disabilities (e.g. mental health, learning, chronic health, physical, hearing, vision, neurological, etc.). You must have established your eligibility for support services through the appropriate once that services students with disabilities. Note that services are confidential, may take time to put into place and are not retroactive; captions and alternate media for print materials may take three or more weeks to get produced. Please contact Disability Services for Students at

http://disabilityservices.indiana.edu

or 812-855-7578 as soon as possible if accommodations are needed. The office is located on the third floor, west tower, of the Wells Library, Room W302. Walk-ins are welcome 8AM to 5PM, Monday through Friday. You can also locate a variety of campus resources for students and visitors that need assistance at:

http://www.iu.edu/~ada/index.shtml.

CAPS: IU offers Counseling and Psychological Services to students. The services are confidential, and your first appointment is free.

https://healthcenter.indiana.edu/counseling/

Bias reporting: Every member of our classroom has a right to participate in the course without being subject to harassment or discrimination based on age, color, religion, disability (physical or mental), race, ethnicity, national origin, sex, gender, gender identity, sexual orientation, marital status, or veteran status. To learn more, or to report an incident of bias, use the link below:

https://studentaffairs.indiana.edu/student-support/get-help/report-bias-incident/index.html

Religious observances: Students with conflicts between course requirements (e.g. exams) and religious observances must contact their instructors during the first week of the term and follow the procedures outlined by campus policy, available at:

http://enrollmentbulletin.indiana.edu/pages/relo.php

Sexual misconduct: As your instructors, one of our responsibilities is to help create a safe learning environment on our campus. Title IX and our own Sexual Misconduct policy prohibit sexual misconduct. If you have experienced sexual misconduct, or know someone who has, the University can help. If you are seeking help and would like to speak to someone confidentially, support resources for individuals who have experienced sexual assault are available 24 hours a day. Call (812) 855-8900. More information about available resources can be found here:

http://stopsexualviolence.iu.edu/help/index.html.

It is also important that you know that federal regulations and University policy require us to promptly convey any information about potential sexual misconduct known to us to our campus' Deputy Title IX Coordinator or IU's Title IX Coordinator. In that event, they will work with a small number of others on campus to ensure that appropriate measures are taken and resources are made available to the student who may have been harmed. Protecting a student's privacy is of utmost concern, and all involved will only share information with those that need to know to ensure the University can respond and assist. To learn more, we encourage you to visit

http://stopsexualviolence.iu.edu.

Week 1

We will go over the syllabus and learn about social choice, the broader mathematical field around voting theory. Students will be introduced to the theme of the activities of the course and will create fair procedures for organizing project groups and making decisions as a class, and then those procedures will be used to organize project groups and vote on some toy issues.

The theme of the activities of the course is that the students are democratic advocates in an evolving democracy. Students act as voters, political strategists, and reporters.

Lecture: We will introduce the field of social choice and give some examples of social choice problems, including marriage matching, medical school residency matching, high school assignments in Amsterdam, IMDB ratings, Netflix ratings, and university rankings. We will discuss: What is democracy? What are its features and guiding principles?

Assignment: How should students be matched into groups? How should the class vote on issues? We will create two voting methods, one of which uses project groups as voting blocs, and another where each member of the class votes as an individual. These procedures should be scalable to large systems with lots of people, so they should involve surveying individuals and a predetermined procedure for aggregating individual preferences.

We will employ the chosen mechanisms to form groups of 4-6 students. Students will work within these groups for the rest of the semester on most assignments, and the projects at the end of the semester.

We will then use the voting methods to determine some aesthetic attributes of the democracy: state flag, state bird, etc. We will then discuss whether these methods worked as intended, and how one might vote strategically using them.

Week 2

We will start to use the vocabulary of voting theory and will discuss plurality voting, ranked choice voting, Duverger's law, and the spoiler effect. We will also discuss the voting strategies of compromise and pushover voting.

Lecture: How does plurality (first-past-the-post) work? Define the terms social choice function, voting method, anonymity, monarchy, dictatorship, neutrality, monotonicity, decisive, nearly decisive, preference order, electorate. Discuss the parity method, and the Hare method (ranked choice voting). Discuss compromise voting and how it leads to the spoiler effect and Duverger's Law. Discuss pushover voting.

Assignment: Students will evaluate the winners of a sequence of elections under plurality, with the condition that parties that consistently underperform eventually drop out of future elections. We will demonstrate Duverger's Law with the students as voters.

Assignment: Students will act as political strategists in a simulated election held according to the Hare method. We will critically investigate the common claim that ranked-choice-voting incentivizes a many-party system, and will demonstrate a surprising attribute of the Hare method.

A Mathematical Look at Politics pg 5-30, 32-34

Course notes on Duverger's Law and pushover voting will be provided.

Week 3

This week we use Condorcet's criteria as a means to introduce the idea of fairness criteria, and we see some new voting methods.

Lecture: We will learn about Coombs's method before switching gears. We will discuss the Condorcet Criteria as well as Condorcet's Paradox. We will discuss Condorcet methods, including Agenda methods, Copeland's method, Dodgeson's Method, and Baldwin's Method. Define the terms Condorcet criteria, fairness criteria. We will discuss burying, a voting strategy effective for Condorcet methods. We discuss: What are some hard (mathematically expressible) and soft fairness criteria?

Assignment: Demonstrate that every voting method discussed so far violates a natural fairness criterion, by giving examples of explicit voter profiles.

Assignment: Act as political strategists to undermine various elections by burying.

A Mathematical Look at Politics pg 34-46, 52.

Course notes on Dodgeson's Method, Baldwin's Method, and Burying will be provided.

Week 4

We will continue our investigation of fairness criteria, and discuss Arrow's Theorem.

Lecture: Recall our fairness criteria discussed so far and introduce some new ones. Define unanimity criterion, majority criterion, neutral, Pareto criterion, anti-Condorcet criterion, independence criterion. Discuss May's Theorem and Arrow's Theorem and their implications.

Assignment: Write logical arguments regarding the relationships between certain criteria.

Assignment: Explore which voting methods satisfy which criteria. Explore the relationship between voting strategies (compromise, burying, and pushover) and certain fairness criteria.

A Mathematical Look at Politics pg 46-83.

Week 5

We discuss voting methods that award candidates points.

Lecture: Discuss the Borda Count, Black's Method, Positional Methods, Approval Voting, Cumulative voting. Discuss the strategy of bullet voting, and the Gibbard-Satterthwaite Theorem.

Assignment: Act as political strategists trying to manipulate upcoming film awards.

Assignment: Based on what we have seen so far, determine a good voting method for a national presidential election.

A Mathematical Look at Politics pg 31-32, 37, 71-72, 93-108.

Week 6

We return to Agenda Voting and discuss political referendums and bracket manipulation.

Lecture: We discuss how elections structured as a series of choices between two options can enable majoritarian affirmation of hugely unpopular alternatives. We discuss the chaos theorems and how to construct such brackets.

Assignment: We investigate a political issue represented on two axes and show that, through a carefully structured series of referendums, voters can be coerced into affirming almost any position.

Course notes will be provided, based loosely on Chaotic Elections, a Mathematician Looks at Voting *by Donald G Saari, and* Social Choice Theory and Research *by Paul E. Johnson.*

Week 7

We discuss voting methods with multiple winners, and especially their advantages over single-winner methods for parliamentary elections. We introduce the ideas of bloc voting and districting.

Lecture: We discuss Single Transferrable Vote as an analogue to Hare's Method, and Proportional Representation List Systems. We discuss how these multi-winner methods allow for systems with many political parties and introduce the notion of wasted votes. We discuss the statistical models of Dr. Rein Taggepera which suggest that in such systems the number of major parties depends more on population size and quantifiable social factors than the specific rules of the methods. We discuss the Hare and Droop quotas for Single Transferrable Vote.

Assignment: Determine the winners of election profiles using Single Transferrable Vote and a Proportional Representation List method based on plurality, using different quota methods. Calculate the numbers of wasted votes under these methods and compare to analogous elections with single winners.

Assignment: Based on what we have seen so far, determine a good voting system for a national parliamentary election.

Course notes will be provided, based loosely on the contents of Electoral Systems: A Comparative Introduction*, by David Farrell, and* Votes by Seats*, by Matthew Shugaart and Rein Taagepera.*

Week 8

We introduce the problem of district apportionment and discuss several methods of apportionment.

Lecture: Introduce the notion of district apportionment in the context of apportionment of Congressional Seats in the United States, and thus electoral college votes. Compare this issue to the question of quotas for Single Transferrable Vote. We discuss Hamilton's Method, and Jefferson's Method, and note the paradoxes that arise from these (Alabama Paradox, Population Paradox, New State Paradox, Quota Violation).

Assignment: Use both Hamilton's Method and Jefferson's method to apportion districts. Propose some fairness criteria for districting.

Assignment: Invent a district apportionment procedure.

A Mathematical Look at Politics pg 145-166

Week 9

We discuss fairness criteria for district apportionment and impossibility theorems.

Lecture: We review the fairness criteria proposed during the previous week's assignment and define fairness criteria for district apportionment. I then add to this list the normal notions of house monotonicity, population monotonicity, relative population monotonicity, neutral, proportional, and quota rule, if these are not already included. Then we prove Balinski and Young's theorem that no neutral apportionment can satisfy the quota rule and population monotonicity.

Assignment: Determine whether each apportionment method discussed in class or invented by students satisfies each of the fairness criteria from the preceding discussion.

A Mathematical Look at Politics pg 167-183

Week 10

We look at Hill's and Webster's methods of apportionment. We then begin to look at methods of drawing districts.

Lecture: We look at Hill's and Webster's methods of apportionment; these are the current system of apportionment in the United States, and a leading contender for a new apportionment method. We then look at methods for fairly drawing districts once seats have been apportioned. We will try out the shortest split-line method and see examples of other geometric methods.

Assignment: Apply the splitline method to properly district various sample maps. Then, try to appropriately district various maps of real municipal governments according to their own rules: these do not generally prescribe a methodology, but rather establish requirements for the districts.

A Mathematical Look at Politics pg 167-183

Course notes will be provided regarding districting methods.

Week 11

We discuss gerrymandering and tests to measure it.

Lecture: We loosely define gerrymandering and discuss its history in the United States, and its current legal status. We discuss tests for gerrymandering: district-to-convex-polygon ratio; the Polsby-Popper Test; the Efficiency Gap. We discuss the discourse around these tests (in political and mathematical circles) and how they may be applied to create districting procedures.

Assignment: Sketch "round" voting districts on a sample map. On the same map, find the districting with the lowest efficiency gap which you can. On the same map, find the districting with the highest efficiency gap which you can.

Course notes will be provided regarding gerrymandering tests.

Week 12

This week we review everything we have learned, and we have a math test. The test is graded for accuracy, but students will be able to turn in a corrected test the following week to earn back up to half the points they lost.

Week 13

I will give a brief lecture on the Electoral College. Students will have the rest of the time this week to create a project where they draft a national election system from the top down. This system must address districting rules, apportionment, method for parliamentary elections, and method for presidential elections. Students must present the rules of their system unambiguously, and explain the decisions they made in order to maximize fairness.

Week 14
I will give a brief lecture on Honeybee Elections. Students will have the rest of the time this week to work on a project where they research the literature of a major election reform group and evaluate their arguments mathematically. Suggestions for groups to study will be given along with specific prompts. Students may propose another group to evaluate if they wish, subject to the instructor's approval: the purpose of the project is to evaluate the group's argument mathematically, and many election reformers care about issues that are not easy to evaluate in this way.

Week 15
I will give a brief lecture on Ensemble Machine Learning. Students will have the rest of the time this week to polish one of the previous two projects, and prepare a presentation on that project. In so doing they may improve their original grade on that project.

Week 16
Students will give presentations on their projects.