PROJECT DESCRIPTIONS — MATHCAMP 2024

Like classes, projects are assigned a chili level, which is intended to summarize their overall difficulty. Projects are also evaluated on a different scale, represented by 📅's, which summarizes the amount of time, commitment, and independence you will need to complete the project. Read the project description for more details of what is required. Here are what the symbols mean:

📅: Approximately 0.5–1 hours per week: about 30 minutes of work, 1 or 2 days per week.
📅📅: About 1.5–2.5 hours per week.
📅📅📅: About 3–4 hours per week. Requires you to have a certain amount of independent drive.
📅📅📅📅: 5–10 hours per week: 60 to 90 minutes of work per day, or more, four or five days per week. Requires you to have a lot of commitment and independence.

Contents

Ask any teaching staff's projects

Teach a class. (Ask any teaching staff)

Do all of the wonderful classes you've been taking at Mathcamp make you want to try teaching one of your own? Well, you can! If you sign up to do a teaching project, you'll work with a member of the teaching staff to put together a one-day class. This could be any of us, so ask around! Even if one of us isn't the best choice, we can probably tell you who is.

Structure and commitment: Meet periodically with whoever is overseeing your teaching project to talk about how to structure the class and give practice talks. This will be a lot of work, probably more than you think! Expect to have lots of meetings over the course of camp and practice your class multiple times.

Final product: At the end of camp, you can teach your class in the evening, as a Week 5 class, or in another format. Note though, that getting a slot in the Week 5 schedule is not guaranteed — you will be offered that option only if the staff decides you are ready for it.

Prerequisites: Enthusiasm and a willingness to work hard on presenting your ideas well.

Arya's projects

Fun with isoperimetric inequalities. 🌶️🌶️🌶️ → 🌶️🌶️🌶️🌶️ 📅📅📅 → 📅📅📅📅 (Arya)

The isoperimetric inequality states that among the collection of all n-gons with a fixed area, the n-gon with the least perimeter is the regular n-gon. This result is true in Euclidean, spherical and hyperbolic geometry.

What if you generalise to multiple connected components? That is, suppose you are allowed to divide your area into finitely many disconnected n-gons, and define the perimeter of this configuration as the sum of the perimeters of the n-gons, then among all such configurations, would the configuration with a single regular n-gon still have the smallest perimeter? Turns out, this is true in Euclidean and spherical geometry, but not so in hyperbolic geometry.

The goal of this class is to understand computations in Euclidean, spherical and hyperbolic geometry, using trigonometry in each of these settings, and understand these results. If time/interest permits, we can study some related open questions.

Structure and commitment: Weekly meetings.

Final product: Presentation.

Prerequisites: Some familiarity with spherical and hyperbolic geometry.

How to handle Hanabi. 🌶️ 📅📅 (Arya & Della)

Hanabi (Japanese for fireworks) is a very fun game (with a few copies available in the Games Lounge). In this project, we shall study the game theory for Hanabi — do we usually have winning strategies? What is the probability that completing all the fireworks is impossible? What if we have n colours instead of 5? And so on. If there is interest, we would also like to code a Hanabi bot in Python.

Structure and commitment: Meeting once a week to discuss progress, with campers thinking about the problems themselves outside of the meeting times.

Final product: Depends on the campers — either a poster presentation or a Python code.

Prerequisites: Know / willing to learn the game Hanabi.

Athina's projects

Classical cryptanalysis. 🌶️🌶️🌶️ 📅📅 → 📅📅📅📅 (Athina & Ben)

In 2015, a paper by Alan Turing (1912–1954) appeared on the arXiv, an online repository of math papers.[1]

The paper discusses how to use probability to attack the Vigenère cipher, a commonly-used encryption method that is broadly similar to the Enigma cipher.[2] In this project, we'll try to implement Turing's methods to break this cipher, and possibly other ciphers, either by computer or by hand.

[1] Due to more of his notes becoming available, not necromancy. In case you were concerned.

[2] The Vigenère cipher is way simpler, though

Structure and commitment: Meeting at least weekly, a total of few hours of work a week, either reading or implementing algorithms. Expected to build experience with probability and cryptanalysis.

Final product: Perhaps a presentation at the project faire, breaking Vigenere ciphers for fun?

Prerequisites: None; probability not required ahead of time. If you want to do this on the computer, prior experience coding would be useful.

Make a Mathematical Tarot Deck. (Athina)

This project merges art, mathematics, and mysticism! Our meetings will mostly revolve around the conceptual development of our deck. We will first learn some of the basics of tarot and then try to determine how mathematical concepts will translate into tarot symbolism. For example, we could replace the four traditional suits with different branches of math, have each court card represent a famous mathematician, and assign significant mathematical concepts or theorems to the Major Arcana cards. . . or we could do something totally different! When we feel like we have a plan, we will execute it and maybe even read (mathematical) fortunes at the Project fair at the end of camp!

Structure and commitment: We'll meet once or twice a week to plan and talk about our progress, but I expect most of the artistic part of the project to happen through your own independent effort between meetings.

Final product: Anywhere between a few cards to a full deck of 78 cards, depending on number of campers and level of commitment.

Prerequisites: None!

Ben's projects

Classical cryptanalysis. (Athina & Ben)

See Athina's projects.

Fractal art. (Ben)

"Fractal" is generally used to mean either one of the famous "fractal shapes" (like the Mandelbrot set) or a self-similar object of any kind. Visually, fractals are often quite beautiful, so why not make some? My own art is usually embroidery, so that's the project I'm most comfortable advising, but I'm happy to talk through some common fractals and fractal constructions for anyone who's interested!

On a side note, if anyone is so inclined, for a few years I've wondered what might be meant by "fractal poetry," so if anyone has an idea there. . .

Structure and commitment: Campers would work on some creative project, possibly involving poetry or embroidery, and also possibly involving fractals

Final product: Ideally some form of art (either poetic or visual)

Prerequisites: None.

Chloe's projects

A friendly introduction to number theory: further reading. (Chloe)

The Intro to number theory class not enough number theory for you?? Do some more with a reading project in 'A Friendly Introduction to Number Theory' by Joseph Silverman.

This is a very readable book with some great problems to think about. I would also be open to reading sections from 'A Classical Introduction to Modern Number Theory' by Ireland and Rosen, which is a slightly denser book.

Structure and commitment: 1 meeting per week to discuss readings and problems.

Final product: None expected.

Prerequisites: None required, some introductory number theory recommended

Lean on me (teaching math to computers). 🌶 → 🌶🌶🌶 📅📅 (Krishan & Chloe (the real KC))

Have you ever thought writing proofs was too hard? Great news! It can get harder, you could try to convince a computer that your proof is correct. Believe it or not this is actually pretty fun.

Almost all math is done on a pen and paper, and everyone just hopes that the proofs work. We don't know how math will work in the future, but some people think it'll involve a lot of Lean. Lean is a programming language that you can use to explain your proof to a computer. That way the computer can check your logic, and maybe even fill in a missing a missing step!

There are different ways that you can engage with this project. On one end, you could play through the Natural Numbers Game: a guided tutorial to lean complete with boss battles. And on the end, you could try to write your favorite proof in Lean, and maybe even try to add something new to the Lean library!

Structure and commitment: 1 meeting per week during TAU, with self paced individual work

Final product: None expected, possibly formalizing a proof

Prerequisites: Some familiarity with programming or familiarity with proof writing

Della's projects

How to handle Hanabi. 🌶 📅📅 (Arya & Della)

See Arya's projects.

Read *Mathematics Made Difficult*. 🌶🌶🌶 📅📅 → 📅📅📅 (Della)

This project is for campers who think basic math, like arithmetic on natural numbers, is too easy. *Mathematics Made Difficult* presents that and other topics to readers who don't believe in numbers but are comfortable thinking abstractly, with a lot of humor.

Structure and commitment: We'll meet as often as you want, and at least each time you finish a chapter, to talk about the mathematical content. The explanations in the book can be quite terse, so I'm happy to go through it with you more slowly. It's fairly short but dense, and you likely won't read the whole book during camp.

Final product: A deeper, or at least different, understanding of "simple" math.

Prerequisites: None.

Write logic puzzles. 🌶 📅 → 📅📅📅 (Della)

Have you always wanted to write your own sudoku? Did you take a week 1 class on logic puzzles that left you hungry for more? Do you want to make something to entertain, frustrate, or impress your friends?

I will show you some tools, give you general advice, and testsolve your puzzles. You can do this project without taking my puzzles class.

Structure and commitment: Once I show you the ropes, we'll meet whenever you are looking for additional guidance or have a puzzle you want to show me.

Final product: Puzzles! As many as you put in the time to make.

Prerequisites: None.

Elizabeth's projects

Make Compliant Solid Parts. (Elizabeth)

If you read the blurb for my EEEE (Eigenvalues and Eigenvectors through the Eyes of an Engineer) class, you know that I enjoy thinking about solid mechanics. Solid mechanics is a field where we study how things bend and deform and ultimately break under the loads applied to them. I think there are some physical tools we can make to help ourselves understand solid mechanics better, since some of the ways objects deform aren't obvious until you actually see them happen. We will investigate what kinds of materials are best, then build some fun squishy models!

Structure and commitment: Meeting 1–2 times a week to discuss and then build these physical objects. Independence level flexible, no independent work necessary.

Final product: Some physical models to help explain solid mechanics concepts that people can pick up and play with!

Prerequisites: This project will be better if you take my class, but it's not a strict requirement. Expect to put more time in to understand the background if you don't take EEEE.

Make a Gingerbread Calculator. (Elizabeth)

In 1642, Blaise Pascal developed a calculating machine, inspired by his father's tedious calculations in his job as a tax collector. Only a few of these were ever made, but some of them survived to this day, and we know how they worked as a result. Previously, someone named David S. Touretzky figured out how to laser cut one and made it open source. However, laser cutting is ~~lame~~ very cool, but I don't have a laser cutter, and cookies are delicious—so let's explore how this calculator worked, and then figure out how to build our own edible version!

Structure and commitment: Meeting about twice a week, some time outside of TAU to dedicate to baking, collaborative work expected.

Final product: A gingerbread Pascaline calculator! Or at least our best attempt at one.

Prerequisites: None.

Eric's projects

Learn change ringing. (Eric & Tim!)

Change ringing is the musical tradition of performing symmetric groups on bells. You might have seen Eric and Tim! running events about it or heard about it in Eric's week 1 group theory class. This project is your chance to learn it for yourself! It is a wonderful combination of music, mathematics, concentration, and meditation. We'll teach you some basic ringing patterns and how to perform them in practice. Optionally, we can talk about the mathematics behind the patterns we choose to ring.

Structure and commitment: Attend practices several times a week. This project requires a regular commitment to practicing, but is not spicy otherwise. We'll be practicing ringing using a set of handbells.

Final product: Possibilities include a poster at the project fair, a performance at the talent show.

Prerequisites: None!

Glenn's projects

How does AlphaGeometry work? 🌶️🌶️🌶️ 📅📅📅→📅📅📅📅 (Glenn)

Earlier this year, Google DeepMind released AlphaGeometry, a computer program that can solve IMO geometry problems somewhere between the level of a silver and gold medalist. Unfortunately, the paper they wrote, while actually fairly easy to read, is quite short on mathematical details. But luckily, their code is all open-source, so it may be possible to reverse engineer the math. The purpose of this project is to read the AlphaGeometry paper and pore over its code to really understand how it works, and maybe even uncover some of its limitations that Google was shy about.

Structure and commitment: Expect to spend at least 2–4 hours per week reading the paper, reading the code, testing parts of the code, and scribbling some math to guess how it works. Meetings with me are flexible — let's plan for at least a 30 minute meeting per week to check in, but if discover something you're excited to share or find yourself stuck, let me know anytime!

Final product: A written description of how AlphaGeometry works that is more detailed than the original paper.

Prerequisites: Python programming experience, basic linear algebra (systems of equations as matrices). Solving IMO geometry questions not required.

Let's make a game! 🌶️🌶️ 📅📅📅→📅📅📅📅 (Glenn)

Video games are really cool. Let's make one!

Note: A game is a big project. There's not only game design, but math, programming, art, and sound effects/music. You don't need to be familiar with all (or any!) of these to get started, but I have two guidelines to help you finish in time:

(1) No 3D.
(2) No online play.

Structure and commitment: In the first meeting, we'll play a bunch of games and analyze what makes them fun! We'll also make teams. (I'll recommend 2–3 people per team.)

After that, I'll be around to help you get started, brainstorm, plan, resolve technical issues, etc. but you'll mostly be working on your own time. Expect to spend at least 3-4 hours/week working with your team, I'll meet with each team for 30 minutes every week to check in. (Definitely also ask me questions outside the meeting!)

Final product: A short video game that can be enjoyed in 5 minutes or less.

Prerequisites: +1 chili if this is your first time programming.

Kailee's projects

Paper 101. 🌶️🌶️ 📅📅 (Kailee)

Have you ever wanted to read a math paper and actually understand it? Let's read and work through a short paper together, and hopefully you can feel more confident approaching reading papers after this project! What is the paper, you might ask? We'll look at Hao Huang's proof of the sensitivity conjecture. Boolean hypercube graphs, linear algebra (eigenvalues and interlacing), and more, oh my!

Structure and commitment: Meet once or twice a week during TAU to discuss, and spend about 1–2 hours between meetings reading/understanding.

Final product: Confidence to read more math papers! Presentation in project fair if you want.

Prerequisites: Linear algebra (specifically eigenvalues and eigenvectors).

Probabilistic Methods 2.0. (Kailee)

Did you take Probabilistic Methods in Week 1? If you want continue what we learned in Week 1, this is the reading project for you! Exact topics can be flexible based off what you find exciting!

Structure and commitment: Meet once or twice a week during TAU to discuss concepts and problems, and spend about 2 hours outside meetings working on problems.

Final product: Presentation in project fair if you want.

Prerequisites: Take Probabilistic Methods in Week 1, or be very comfortable with basic probability and talk to Kailee first.

Zinefluencing. (Kailee & Narmada)

Have you ever wanted to make a zine? Math doesn't have to be all chalkboards and LaTeX. It can also be drawing and painting! Zine making is like IRL TikTok!

Structure and commitment: Meet once or twice a week to work on our zines. You're encouraged to think about what kind of math you'd be excited to turn into a zine between meetings.

Final product: A zine!

Prerequisites: Be at Mathcamp

Kevin's projects

Algebraic number theory. (Kevin)

Algebraic number theory studies the integers, rational numbers, and their "extensions" using tools from abstract algebra. This will be a reading project covering the basics of the subject. One important question we'll try to understand is how prime factorization generalizes to settings other than the integers. For example, in $\mathbb{Z}[\sqrt{-5}]$, we have two factorizations $6 = 2 \cdot 3 = (1+\sqrt{-5})(1-\sqrt{-5})$, which seems incompatible with unique prime factorization. We'll see how this question is resolved using tools from ring theory. If time permits, we'll study further topics (e.g. finiteness of the class group).

Structure and commitment: Two meetings per week at TAU. Campers are expected to complete readings on their own.

Final product: A poster board and/or writeup summarizing what you've learned.

Prerequisites: Ring theory (rings, ideals) is required. Field theory and group theory are helpful but not required.

Mathematical literature: Oulipo. → (Kevin)

Founded in 1960 in France, Oulipo is a collective of writers and mathematicians who create experimental literature using constrained writing techniques. This could mean a novel without the letter "e," a collection of 99 retellings of the same story in 99 different styles, or a story told entirely in the

2nd person. In this project, we'll be reading and discussing some Oulipan literature. Some books I had in mind were

- *Invisible Cities*: A magical realist travelogue structured in a really cool way and written beautifully. This is one of my absolute favorites!
- *Life: A User's Manual*: This (big) book contains a bunch of interweaving stories about the inhabitants of a single Parisian apartment block. The 99 chapter story proceeds along an (incomplete) knight's tour of the apartment block, which is structured like a grid with 10 stories and 10 rooms per floor.

I'm open to other suggestions too!

Structure and commitment: We'll meet twice per week at TAU. Campers will spend time reading on their own.

Final product: A creative project like a poem, short story, or poster inspired by the readings.

Prerequisites: None.

Plank while reciting digits of π. 🌶 📅→📅📅 (Kevin)

I've always wanted to learn more digits of π, but I've always been too lazy. Now I've found some additional motivation: planking!

If you're a fan of other irrational numbers like e or $\log 2$, that's cool too!

Structure and commitment: Meet a couple times a week to practice.

Final product: Know more digits of π and/or get better at planking.

Prerequisites: A love of planking.

Point-set topology. 🌶🌶 📅📅📅 (Kevin)

This project will be an introduction to topology, the study of properties of spaces preserved by continuous deformation. We'll learn about basic notions of point-set topology like open and closed sets, continuity, and compactness, with a goal being the proof of Tychonoff's theorem. If there's enough time, we can also do some algebraic topology (fundamental group stuff).

Structure and commitment: Two meetings per week at TAU. Campers will do readings on their own.

Final product: Poster board and/or writeup explaining what you learned.

Prerequisites: Some analysis or prior exposure to metric spaces would be good, but there are no required prereqs.

The circle method. 🌶🌶🌶🌶 📅📅📅 (Kevin)

This is a continuation of my class on the circle method and Waring's problem. In that class, we learned about how the circle method could be used to count solutions to $x_1^3 + ... + x_n^3 = N$. This project would be a reading project covering applications of the circle method to counting solutions of more general equations. For instance, what if the polynomial on the left had higher degree, what if it had cross terms like $x_1^2 x_2$, and what if we were trying to count solutions where $x_1, \ldots, x_n, N$ are polynomials instead of integers?

Structure and commitment: I'd expect to meet twice a week at TAU. Campers are expected to read parts of textbooks on their own.

Final product: A poster board summarizing math the students learned

Prerequisites: My Week 1 class on the circle method

Krishan's projects

Lean on me (teaching math to computers). (Krishan & Chloe (the real KC))

See Chloe's projects.

Reading course in model theory. (Krishan)

Campers will read from a model theory textbook and we will meet weekly as a group to discuss the reading and work on exercises. The exact topic will depend on the interests of the campers involved — some potential topics include proving the compactness theorem, proving the Lowenheim-Skolem theorem or a high level overview of Morley's categoricity theorem.

Structure and commitment: Weekly meetings with the exception that campers will spend a few hours reading and thinking about material outside of the meetings.

Final product: Nothing required, but campers could prepare a poster to present at the end of camp.

Prerequisites: Some familiarity with either groups or rings.

Laithy's projects

Differential Geometry of Surfaces. (Laithy)

In this project, we will develop a calculus-based geometric theory of 2-dimensional surfaces in $\mathbb{R}^3$. Some examples of surfaces are the sphere S^2, the torus $\mathbb{T}^2$, the Möbius strip, the cylinder, etc. We will begin by giving a mathematically precise definition of what surfaces are. Then we will study the intrinsic and extrinsic geometric properties of surfaces. The intrinsic properties are the ones that only depend on the surface and not on the space they live in, while extrinsic properties are the ones that depend on how the surface lives and bends in $\mathbb{R}^3$. We will then define the Gauss curvature and discuss the intuition behind it.

Campers can then choose which topics to explore further. Some topics we can explore include: the classification of compact surfaces, the Gauss-Bonnet theorem and its applications, the rigidity of the sphere, the fundamental theorem of space curves, and finding all geodesics in known surfaces.

Structure and commitment: We should meet for 15–30 mins during TAU, 2–3 times a week,

Final product: A poster board summarizing what has been learned.

Prerequisites: Single variable calculus and linear algebra (basis, linear independence, inner products). Previous exposure to multivariable calculus is recommended.

Quantum Mechanics. (Laithy)

This is a reading project on Quantum mechanics, a fundamental theory in physics that describes nature at the smallest scales. Topics include wave-particle duality, quantum superposition, quantum entanglement, the uncertainty principle and scattering theory. If you have prior knowledge of Quantum, we can quickly delve into more advanced topics of your choice.

Structure and commitment: We will meet 2–4 times a week during TAU to discuss your progress.

Final product: A poster board summarizing what you have learned.

Prerequisites: A foundation in physics is recommended but not required.

The many representations of e. 🌶🌶 📅📅 (Laithy)

In this project, you will investigate the many ways to represent e as an infinite sum, a continued fraction, an infinite product, a limit of a sequence, as a recursive function, etc. In fact, you might find yourself coming up with a new one that is not known!

Hardy and Littlewood, in 1914, proved that the fractional part of x^n, denoted by $\{x^n\}$, is equidistributed on the interval $[0, 1)$ for almost every $x > 1$. You will use the many representations of e to investigate whether or not that holds for $x = e$.

Structure and commitment: We will meet 2–4 times a week during TAU to discuss any progress.

Final product: A proof on whether or not $\{e^n\}$ is equidistributed on the interval $[0, 1)$.

Prerequisites: Convergence of sequences.

Misha's projects

Become a Mathematicatician. 🌶🌶🌶 📅📅 (Misha)

A short outline of this project:

(1) Think of a problem;
(2) Solve it with Mathematica;
(3) Present your solution with Mathematica.

Do you need a problem? I can come up with some! You could figure out which 7 letters for the NY Times Spelling Bee let you spell the most pangrams, or explore how famous fractals change if you vary the construction slightly, or teach a computer to beat you at $4 \times 4 \times 4$ tic-tac-toe, for example.

I will also teach you how to use Mathematica to do steps 2 and 3.

Structure and commitment: How long this project takes depends on the problem you decide to solve and on your programming experience, but 1-2 meetings a week in the computer lab seems reasonable.

Final product: Some kind of presentation (interactive, or a printout) made in Mathematica.

Prerequisites: A computer to use Mathematica on. (The computer lab in Thompson should have some good-enough alternatives.)

Expert Chickenology, or the Continued Adventures of Shercluck Holmes and Doctor Wattles. 🌶 → 🌶🌶 📅📅📅 (Misha)

In "Advanced Chickenology", we learned about tournaments in graph theory via logic puzzles. In this project, it's your turn to write logic puzzles of your own!

Feel free to continue one of our stories about chickens, or write your own flavor text. You could write more puzzles about directed graphs or pick your own area of math (I was inspired by Raymond Smullyan, who wrote a book of these puzzles about lambda calculus).

The goal is just to think up ways to frame a mathematical topic as a sequence of logic puzzles, and then present them in the way that seems most appealing to you.

Structure and commitment: I don't think there's much need from frequent meetings with me, but you'll have to do a lot of creative work yourself, and come up with your own ideas. This will be easier in a group—among other things, you can testsolve each other's problems.

Final product: A collection of logic puzzles!

Prerequisites: None, but if you didn't take Advanced Chickenology, you might want to look at the Slack channel to see what the big idea is.

Smallerworld a.k.a. Do-mini-on a.k.a. 0.1-Night Werewolf a.k.a. Bugcloset a.k.a. Setters of CaTiny. 🌶🌶 📅📅→📅📅📅 (Misha)

You may have heard of the Japanese game *gomoku*, in which two players compete to form 5-piece lines on a 19×19 board. But have you heard of "tic-tac-toe", a mini variant of gomoku that you can play on a 3×3 grid?

This project is coming up with mini variants of card and board games you enjoy playing. You will formulate rules for and playtest several mini games. If you choose to present at project fair in week 5, you can show off your successes! (It is expected that not every mini variant you come up with will be fun—if an idea isn't working out, move on.)

Structure and commitment: Weekly meetings in the evening in the games lounge; at least 1-2 times a week with me—more if you want—and probably more meetings with your group. (I don't think this project works well as an individual.)

Final product: A small game that is fun to play.

Prerequisites: You must enjoy playing many different games.

Narmada's projects

Zinefluencing. 🌶 📅 (Kailee & Narmada)

See Kailee's projects.

Rina's projects

Mathcamp Analytics. 🌶→🌶🌶🌶 📅→📅📅📅 (Rina)

Do campers have different sign in patterns? Do algebraists get less workshifts than geometers? Is it even possible to split campers into categories based on their mathematical interests? Let's find out! Using several Mathcamp-related datasets, we will come up with a research question and answer it with quantitative analysis. There's lots of flexibility: we could focus on descriptive analytics and create diagrams that are easy to understand, use statistics to look for dependencies between factors, or even try out simple machine learning models.

Structure and commitment: I suggest to have 1–2 meetings per week to discuss findings and brainstorm next steps + some time for analysis on your own. You can choose the level of my involvement in your project based on how much help you need with ideas and implementations. You can also team up with other campers!

Final product: A set of infographics, a presentation, or an interactive dashboard, answering your research question and showing interesting findings.

Prerequisites: Ideally, some knowledge of Python. But we can also try to do everything in spreadsheets!

Tim!'s projects

Learn change ringing. 🌶🌶 📅📅📅 (Eric & Tim!)

See Eric's projects.

Mathematical engineering with Arduino and Raspberry Pi. 🌶🌶→🌶🌶🌶🌶 📅📅📅→📅📅📅📅 (Tim!)

An Arduino board is an inexpensive microcontroller designed for makers and artists. It's really good at **interacting with the real world**. It can take inputs—like light sensors, temperature sensors, joysticks, ultrasonic distance sensors, capacitive touch sensors—and turn them into outputs, like controlling a motor, making a sound, or lighting up 900 individually addressable LEDs arranged in a ball that will put the Sphere in Las Vegas to shame. It's designed for people who are not programmers (though if you have programming experience, that further expands what you can do with it), so this project has **no programming experience required**. A Raspberry Pi is a small, relatively inexpensive computer that run linux and allows you to realize even more complex ideas.

The goal of this project is to bring a mathematical concept (or non-mathematical, if you prefer) into the real world—make a game where you can move the pieces, a sculpture you can interact with, etc. You do *not* need to have a specific idea in mind to join this project: you will follow a **three-step engineering design process** to generate your final project plan.

For inspiration, here are a few of my ideas (and partial ideas). You are welcome to choose one of the ideas, but you will also get to go through the engineering design process to generate your own.

- **Guess-my-object with a lie.** This is a human-vs-computer game. There are sixteen objects, and the human player secretly chooses one of them. The game goes through seven rounds; in each round, the computer lights up some of the objects, and the player indicates whether their object is lit up by touching a capacitive touch sensor hidden in the board. The player is allowed to lie in one of the rounds (or always tell the truth if they prefer), but the computer is able to figure out the lie and identify the object.
- **Visualizing groups of symmetries.** There is a board on which you a polygon made of some solid material. The polygon has magnets embedded in it, and the board has magnet sensors in it that can detect the position of the polygon. When the user rotates or flips the polygon, that transformation is an element of a dihedral group, and that element can be written out on a two-line LCD display. This could also be done with a 3D polyhedron instead of a polygon. It can be turned into a game in various ways—for instance, the computer could display a group element or a product of group elements, and the user would try to perform that operation on the polygon.
- **Snake on a hyperbolic plane.** Make a hyperbolic plane (or another favorite space) and put lights on it. Then play the classic video game snake on it: The player uses a joystick to control a "snake" (a line of lit-up lights) that goes around eating pellets (other lit-up lights), growing longer as it does so, tries to prevent the snake from running into itself.
- **Nim-playing robot.** Make a robot that plays nim (or another favorite game) by sensing piece position and physically moving them with motors.
- **Visualization on a globe.** Place lights on a sphere, compute the 3D positions of the lights, and then create a visualization. There are lots of possibilities—it could be something mathematical, or something about the earth, like displaying the current weather around the world. You could control it with buttons or with position sensing in space, such as with ultrasonic distance sensors.
- **Something else.** There are many possibilities! The above are some ideas, but ideally you go through the design process to come up with an idea you are excited about.

Most of the above ideas involve some sort of math—you can bring in math you already know or learned at Mathcamp, or you can learn new math as part of the project.

This is a great project to try out Arduinos, Raspberry Pis, or programming for the first time (or the n^{th} time), to build something creative and mathematical, to design something with others, and to learn a bit of new math!

Structure and commitment: You will work through an engineering design process to generate ideas for something to build, then work with a small group to build one of those ideas. If you pick an idea involving math you don't know yet, you will spend some time learning it. You'll spend quite a bit of time on the physical construction. Programming can be a small part of the project or a large one, depending on the backgrounds of the people in your group, and what you are building. Expect 15–20 hours of work, working with your group on learning math, building, and programming, over the course of 3 weeks.

Final product: A physical, interactive construction that you can show off in Week 5 around the dorms and/or at the project fair.

Prerequisites: None. In particular, you can do this project even if you don't have programming experience.

Travis's projects

Math pedagogy. (Travis)

There's a wonderful book called *Building Thinking Classrooms in Mathematics*, which is all about practical advice to make K-12 math classrooms into places where students are engaged, curious, and excited. (I think a lot of it would transfer to teaching at math circles, too!) The book is pretty big, so we'll pick chapters of it to read and discuss based on your interests.

Structure and commitment: Reading + thinking (1–2 hours each week), plus a weekly meeting to talk about what we read

Final product: Specific ideas to implement when teaching math!

Prerequisites: Interest in math education

More graph limits. → (Travis)

You: I loved learning about graph limits this week!
Travis: Lovely! There's so much more to the story: connections to probability and measure theory and extremal graph theory and computer science...
You: Gimme! Where can I learn about all this stuff?
Travis: Right here, in a project on graph limits!

Structure and commitment: This project is like an independent study: We'll talk about what aspects of graph limits you want to learn more about, and based on that, I'll direct you to the right parts of a textbook to learn about it. We'll meet once or twice a week to discuss what you read and talk about your questions. Spending at least 3 hours a week reading is a reasonable expectation; if you want to go all in, there's really no upper limit.

Final product: Better understanding of graph limits!

Prerequisites: Travis's Week 2 class on graph limits

Rethinking education. → (Travis)

How would you redesign school if you could start from scratch? This project will give you a chance to answer that question in a detailed way. We'll use some articles by academics and education journalists to jumpstart a discussion about what school is for and what it could be. After that, we'll design a new school system, from the high-level principles to how it might actually be implemented.

Everyone has ideas and complaints about school; this is a chance to suggest something better!

Structure and commitment: We'll spend about a week and a half reading and discussing articles about education systems, and then we'll start to build a school system from scratch.

Final product: A better idea of what you think school ought to be, and a detailed plan for your dream school system!

Prerequisites: None.

To sense or non to sense? (Travis)
Go beyond making no sense by learning how to make nonsense. The sentence "A solar strawberry, stranded sumptuously by the cantankerous coast, cribbled and cravelled at its craven companions" simultaneously satisfies the formal (or "syntactical") rules of English grammar while still being completely meaningless. There's a long history of poets and authors writing nonsense—just look at Lewis Carroll and Dr. Seuss. And there are all kinds of ways to be nonsensical! We'll start this project by putting on our thinking caps and taking a scholarly look at nonsense, and then you'll use what you've learned to write fun, nonsensical poems or stories yourself!
Structure and commitment: 2.5 hours per week of reading and/or writing, with a weekly check-in meeting to talk about what we've read and share what we've written.

Final product: A collection of nonsense poems or a nonsense story.

Prerequisites: Willingness to be silly.

Zach's projects

LeetCode 75. → (Zach)
Don't let the "coding interview study plan" propaganda fool you—we're just here for fun! LeetCode and similar sites are filled to the brim with intriguing, curated puzzles, sorted by difficulty and programming proficiency. And for those of us who like watching numbers go up but suffer choice paralysis from the thousands of available questions, let's confront the 75 challenges in LeetCode 75! How far can we get? This is a great resource for learning to program, picking up a new programming language, or improving your algorithm knowledge. Can work alone or in a group.

Structure and commitment: You'll work largely independently (either alone or as a group), and I'll be available to provide feedback on solutions you're not happy with or hints on puzzles you're stuck on.

Final product: Lots of solved LeetCode problems, and improved programming skills

Prerequisites: None.

Math Sculpture from the Mundane. → (Zach)
Bring new whimsy to oft-overlooked, everyday materials by discovering their hidden patterns, structure, or symmetry. We'll choose a familiar household material (keychain rings? buttons? used covid tests? [no, ew]) and investigate new ways to attach, combine, and contort them into arrangements with mathematical precision and beauty. I used this open-minded, exploratory approach when designing the sculptures we'll build together in my Week 4 class! Participation in the class is not mandatory.

Structure and commitment: We'll meet around twice a week to choose materials, report findings, troubleshoot, and continually steer the investigation process toward an achievable and mathematically interesting result. But much of the progress will happen through your own independent effort between meetings.

Final product: A math sculpture!

Prerequisites: None.

Short Math Animation. (Zach)
Math is full of verbs—bisect, multiply, diverge, concur, integrate—so static images often fail to capture the heart of key math ideas. Let's bring them to life with short animations instead! We'll pick a theorem, algorithm, or other small and self-contained math idea, then show it in action with a short ($\leq$ 30 sec) animation in Processing (Java) or p5.js (Javascript).

Structure and commitment: We'll spend a few days brainstorming ideas for topics and visuals, then you'll work on realizing your dream on screen. We'll meet once or twice per week, initially to settle on a concrete plan and get up and running in Processing or p5.js, and then to troubleshoot and report progress. Will likely require 5 to 10 hours per week.

Final product: A math animation!

Prerequisites: Some programming experience