

# MATH 299: CHAOTIC DYNAMICAL SYSTEMS

## SYLLABUS

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**Instructor:** Dr./Prof. Subhadip Chowdhury

**Class meetings:** T/Th 1:00 PM – 2:20 PM, Taylor 200

**How to contact me:**

• **Email:** [chowdhury@wooster.edu](mailto:chowdhury@wooster.edu)

• **Phone:** 330-263-2473

• **Office:** Taylor 307

**Office Hours:** [MS Booking Link](#). Feel free to schedule an alternative time to meet if you can't make these hours. Otherwise, if my door is open, feel free to come in. You can also email me anytime.

### A. COURSE DESCRIPTION

#### Course Catalog Description

This course is an introduction to chaotic dynamical systems through theory and computer experimentation. We begin by examining discrete dynamical systems – orbits, fixed and periodic points, and bifurcations – both graphically and numerically; and transition to Devaney's definition of chaos (transitivity, dense periodic points, sensitive dependence on initial conditions). We will also build up analytic tools, including fractal geometry and a little bit of complex analysis to end the course with dynamics in the complex plane, Julia sets, and the Mandelbrot set.

#### Prerequisites

Math 125: Theory of Integral Calculus – minimum grade C-, or equivalent credit.

### B. LEARNING GOALS

The overall goal of this course is to introduce some of the spectacular new discoveries that have been made over the past thirty years in the field of Mathematics known as Dynamical Systems. By the end of the course, you will be able to

- Recognize examples of natural and artificial Dynamical Systems in various areas such as planetary motions, population, fluid dynamics, cardiac and neural dynamics, oscillator circuits, internet traffic, quantum systems, etc.
- Describe related concepts such as orbit, fixed points, periodic points, bifurcation etc.
- Use computer graphics to illustrate long term behavior of dynamical systems
- Analyze how dynamics given by precise rules can result in extremely complicated trajectories in the state-space.
- Compare various intuitive definitions of chaos (e.g., Li-Yorke vs. Devaney) that abound the literature, to clarify their relationship, if any, and to articulate an all-encompassing definition based on the concept of mixing.
- Develop various theoretical tools to identify and examine chaotic systems.

## C. COURSE CONTENT

This one-semester course is meant to serve only as an introduction to the theory of Discrete Dynamical Systems and Chaos theory, leaving opportunities for more in-depth study via Senior Independent Study. Specific topics of discussion will include **a subset of**

- Examples of Dynamical Systems from various subject areas
- Definition, examples, and classification of Orbits, Fixed points, and periodic points of discrete dynamical systems – graphical analysis using cobweb diagram and phase portraits
- Types of bifurcations – example using the Quadratic map and Logistic map
- Symbolic dynamics – the Shift map and conjugacy
- Sharkovsky’s theorem – (Li-Yorke) chaos
- Sensitive dependence on initial condition (a.k.a. the butterfly effect) – Lyapunov chaos
- Transitivity, dense periodic points – Devaney’s chaos
- Feigenbaum’s constant – universality of chaos
- The Schwarzian derivative
- Fractals and the Hausdorff dimension
- Iterated function systems – Julia set
- Complex dynamics and the Mandelbrot set
- The Lorenz attractor

Depending on time and pace, the last couple of topics might get covered through final projects only.

## D. OTHER REQUIRED MATERIALS

### Textbook

There is no specific textbook required for this course. But you may use any edition of “*A First Course in Chaotic Dynamical Systems: Theory and Experiment*” by Robert L. Devaney as a reference. Daily class notes/worksheets will be posted on Moodle to summarize regular lectures.

### Technology

Experimentation is key to understanding the nature of dynamical systems. You may use either Octave or Python for any programming needs (both are open source and free). I will use Octave for in-class demonstrations and post the code on Moodle. Note that we will have regular homework and lab exercises that will require use of some computing software.

## E. DIFFERENT TYPES OF ASSIGNMENTS

### Homework

During each class, we will intersperse the lecture with a bunch of practice problems (I will write down the problems, you do not need the book). You are encouraged to work collaboratively on these problems, and look up solutions, if necessary, to improve your understanding.

The rest of the questions from the lecture notes will be assigned as homework problems (around 5-7) each week that must be turned before class on next week Thursday. These problems must be completed as **independent** assignments, but I welcome you to come and discuss your attempts during my office hours. Solutions to your homework should include a statement of the problem, and all statements you make should be in complete sentences.

**Note:** While a big part of this course emphasizes computer experimentation, you will be required to understand and explain all the definitions, theorems, proofs, and so forth. Solutions to your homework should include a statement of the problem, and all statements you make should be in complete sentences. Where appropriate, you should end the problem with a statement summarizing the solution. You are at the point in your mathematical education where we want to start looking at how you are communicating.

Homework problems will be graded on a 3-point scale. 3 points is like 95%, 2 points is like 85%, 1 point is like 75%. Anything below 75% will be scored as 0.

### Tests

There will be two in-class timed midterm exams about one-thirds and two-thirds way through the course. Most problems on the tests will be computational in nature (i.e., no proof questions). There is no final exam (but there is a final project, see below). A portion of the exam may be take-home.

### Lab Projects

There will be around five or six lab projects built around understanding dynamical systems through computer experimentations. I will provide mostly completed codes for the programs, and you will be asked to modify and use the program to generate a lab report detailing the investigations that you have conducted. This lab report must be typed, preferably using a Word processing program such as LaTeX (I will provide a template) and will usually consist of three types of answers.

- **Collected data.** You should present the data you have collected when necessary. This may consist of a list or table of orbits, a collection of graphs, or a series of pictures. Be reasonable about the amount of data you include. If you are asked only for the fate of orbits, we do not need to see the entire orbit; all we need is the end result.
- **An essay describing your conclusions, conjectures, or problems derived from this data.** I expect that these essays will be carefully written and readable with correct spelling and grammar. You will be graded not only on the mathematical content of your findings but also on the presentation. Please feel free to include graphs and pictures in your essays, using distinguishable for the illustrations if that helps.
- **Answers to certain questions that relate to each experiment.** Sometimes, there is no precise answer to these questions, or the correct answer is not known by anyone. These questions are meant to stimulate you to further thought about the subject of the lab.

During lab days,

- You may pair up with another student to work in groups of two. **One write-up for your entire team will suffice. But both students must submit it individually to Moodle for grading purposes.**
- You may not work with the same partner more than once during the semester.

### Final Project

You will be asked to write and present an expository paper on a final topic in place of your final exam. The due date will be the same as the timeslot reserved for the final exam according to the college schedule. I will announce more details about this halfway through the semester. Both the paper and the presentation will be graded according to a rubric specified after Spring break.

## F. HOW YOUR LETTER GRADE IS DETERMINED

The individual course components are scored with the following weights:

- Lab Projects – 20%
- Midterms – 30%
- Homework – 30%
- Final Project – 20%

Final grade cutoffs will be set as follows:

**A:** 90-100, **A-:** 87-89.9, **B+:** 84-86.9, **B:** 80-83.9, **B-:** 77-79.9, ..., **C-:** 67-69.9, **D:** 60.0-66.9, **F:** 0-59.9

**These grade cutoffs are subject to change during the semester.**

## **G. ACADEMIC POLICIES, PROCEDURES & SUPPORT SERVICES**

### **Academic Resource Center: Academic Support and Disabilities**

**Contact:** Amber Larson, [al Larson@wooster.edu](mailto:al Larson@wooster.edu), (330)263-2595, [ARC Website](#)

The Academic Resource Center, which is in APEX (Gault library) offers a variety of academic support services, programs and 1:1 meetings available to all students. Popular areas of support include time management techniques, class preparation tips and test taking strategies. In addition, the Academic Resource Center coordinates peer-tutoring for several academic departments. Students are encouraged to schedule an appointment.

An additional support that the Academic Resource Center offers is English Language Learning. Students can receive instruction or support with English grammar, sentence structure, writing, reading comprehension, reading speed, vocabulary, listening comprehension, speaking fluency, pronunciation, and American culture through 1:1 meetings with the Academic Resource Center staff, ELL Peer Tutoring, ELL Writing Studio courses, and other programming offered throughout the year.

The Academic Resource Center also coordinates accommodations for students with diagnosed disabilities. At the beginning of the semester, students should contact the Academic Resource Center to make arrangements for securing appropriate accommodations. Although the Academic Resource Center will notify professors of students with documented disabilities and the approved accommodations, students are encouraged to speak with professors during the first week of each semester. If a student does not request accommodations or does not provide documentation to the Academic Resource Center, faculty are under no obligation to provide accommodations.

### **The College Libraries and the Research Help Desk**

**Contact:** [library@wooster.edu](mailto:library@wooster.edu), 330-263-2493, [Libraries website](#)

Your librarian for this course is Ian McCullough. You can ask your librarian for help with research in this class and can make an appointment with them using the [research consultation form](#) for help with your research and information needs, including finding and using items we have in the Libraries; learning expert tips to refine your search for articles in magazines, journals, and newspapers; making an appointment with a librarian for help on a project; and learning how to evaluate the information you discover.

### **Active Participation & Engagement**

For aspiring young scholars and professionals, consistent effort is a necessary starting point. Full engagement will be expected in your future college courses and in a professional setting, so they are also expected here. The active participation of every student in all activities (whether whole class, small

group, or individual) leads to the best learning environment for everyone. Some ways in which engagement can be demonstrated include the following:

- Completing optional Moodle quizzes (graded based on completion only).
- participating in collaborative group work and labs
- giving constructive feedback during in-class discussions
- asking relevant questions in class, during office hours, or through email
- creating an inclusive & welcoming class environment for peers

### **Attendance and Absence**

Attendance is crucial to success in this class. Your best chance to discuss new material, ask questions, and avoid confusion is during class. So, don't miss class! You are responsible for all material and announcements from class, even in case of absence. Much of this information will be available on Moodle. Please check in with me and with your classmates when you are back.

That said, life happens. We get the flu (or COVID!). Relatives need your help. When this happens, do what you need to do. I trust that you are an adult and will make the best choices that you can. I appreciate it if you can notify me in advance of an absence, if possible.

It is College of Wooster policy that a student may not miss more than 25% of class meetings (e.g. about 6-7 classes for a full-credit course in spring semesters), through any combination of excused and unexcused absences. If you think you will miss more than one class in a row, you should contact me beforehand to let me know, and meet me afterward to discuss how you can catch up and move forward in the course. If you miss three classes in a row, I will send out an academic alert. If you miss more than 7 classes, you should contact Dean Jen Bowen and/or Amber Larson, Director of the Academic Resource Center. They can help you consider options for dropping the course.

### **Course Withdrawal Options (for 2022-23 Academic Year)**

*Students may withdraw from a course after the 6th-week drop deadline until the last day of classes (Tuesday, May 9, 2023 in Spring 2023).* Students may withdraw from one course, up to 1.25 credits, at any time through the last day of classes, as long as their total remaining credits are 3.0 or above. This may be done without documentation of extenuating circumstances. Requests to drop enrollment below 3.0 credits will require additional documentation through a [Petition for an Exception to an Academic Policy](#).

Note that because federal government guidelines define courses as 'attempted' after 6 weeks, if a student withdraws from a course after 6 weeks, it will be noted as a 'W' on their transcript.

### **Diversity and Inclusion**

The College of Wooster is committed to inclusive excellence in undergraduate education, and our department seeks to actively foster a welcoming learning environment in which diversity and individual differences are valued, respected, and celebrated. Diversity comes in many forms, including but not limited to, race, color, national origin, ancestry, sex, gender identity and expression, sexual orientation, socioeconomic status, religion, age, and physical and/or mental abilities. The diversity that students and staff bring to the classroom is an invaluable resource, strength, and benefit to everyone at the College of Wooster. As such, we remain vigilant and attentive about issues of diversity, equity, and inclusion in the classroom. Expressions or actions disparaging others are contrary to the mission of the department and will not be tolerated.

It is also important that we all be respectful of everyone's privacy around health concerns, vaccination status, and any accommodations that are necessary for the classroom. It is not appropriate to question why someone requests physical distancing, chooses to wear a mask, or requires any other accommodations. As part of our participation together in this class, we commit to showing respect to

each other as individuals, to working together to create a learning environment that fosters a sense of belonging and inclusion to all members, and to understanding that our differences are also strengths. Your suggestions are encouraged and appreciated, and please contact me—via email, office hours, or after class—if you have any concerns or questions.

No student is required to take an examination or fulfill other scheduled course requirements on recognized religious holidays. Please declare your intention to observe these holidays at the beginning of the semester.

### **Names, Pronouns & Pronunciation**

All people have the right to be addressed and referred to as they prefer. I will do my best to address and refer to all students by the names and pronouns that they share in class, regardless of what is listed on the roster, and I support classmates in doing so as well. I would like for you to refer to me as Dr./Professor Chowdhury. I use he/him/his pronouns. Please share the name you prefer to be called and pronouns you wish to use in this class with me via classroom introductions or privately.

If you are interested in changing your chosen name and/or including your pronoun(s) in The College of Wooster system, [you can find additional information here](#). What appears in The College of Wooster system is what will display in all platforms across Microsoft Teams. At present, there is no alternative way to change your name or to add pronouns in Teams, but you can add a background that includes these for any video platform (see [instructions for Microsoft Teams here](#)).

I encourage everyone in this classroom to create a space of mutual respect and support by also giving each other some grace around pronouns, pronunciation of names, etc., if or when we make mistakes. This is not at all to absolve anyone of responsibility for using correct pronouns, names, and pronunciations. But I find it useful to acknowledge that even with the best of intentions, sometimes we can all still make mistakes.

### **Academic Honesty and the Code of Academic Integrity**

The academic program at the College seeks to promote the intellectual development of each student and the realization of that individual's potential for creative thinking, learning, and understanding. In achieving this, each student must learn to act rigorously, independently, and imaginatively.

The College's understanding and expectations in regard to issues of academic honesty are fully articulated in the Code of Academic Integrity as published in [The Scot's Key](#) and form an essential part of the implicit contract between the student and the College. The Code provides framework at Wooster to help students develop and exhibit honesty in their academic work. You are expected to know and abide by these rules.

Dishonesty in any of your academic work is a serious breach of the Code of Academic Integrity and is grounds for serious penalties. Such violations include turning in another person's work as your own, copying from any source without proper citation, violating expectations for a group project, submitting an assignment produced for a course to a second course without the authorization of all the instructors, and dishonesty in connection with your academic work. You will be held responsible for your actions. Particular attention should be directed to the appropriate use of materials available online. Whether intentional or not, improper use of materials is a violation of academic honesty. If you are unsure as to what is permissible, please contact your course instructor.

### **College Policy on Final Exams**

No final examinations are to be given during the last week of classes or on reading days. Students who wish to reschedule a final exam must submit a petition to the Dean for Curriculum and Academic Engagement in advance of the examination. The student must confer with the instructor before

submitting a petition, and the instructor should indicate to the Dean if they support the petition. Normally, such petitions are granted only for health reasons. If other reasons necessitate a request for a change in a final exam, the request must be submitted three weeks in advance of the examination. [Find electronic petition forms on the Registrar's website.](#)

### **Conflicts with Academic Responsibilities**

The College of Wooster is an academic institution, and its fundamental purpose is to stimulate its students to reach the highest standard of intellectual achievement. As an academic institution with this purpose, the College expects students to give the highest priority to their academic responsibilities. When conflicts arise between academic commitments and complementary programs (including athletic, cultural, educational, and volunteer activities), students, faculty, staff, and administrators all share the responsibility of minimizing and resolving them.

As a student you have the responsibility to inform the faculty member of potential conflicts as soon as you are aware of them, and to discuss and work with the faculty member to identify alternative ways to fulfill your academic commitments without sacrificing the academic integrity and rigor of the course.

### **Basic Needs, Food Security & Access to Course Materials**

**Contact:** Dean of Students Office, [dos@wooster.edu](mailto:dos@wooster.edu), 330-263-2545, Galpin Hall

We learn as whole people. To learn effectively you must have basic security: a roof over your head, a safe place to sleep, enough food to eat. If you have trouble with any of those things or need assistance obtaining the course materials for this or other classes, please talk with me or with staff in the Dean of Students office. Together we can work to make sure those needs are met. There is a [Technology Assistance Application](#) (Wooster login required) and Wooster alums have created a fund to assist students who encounter a personal financial crisis during their time at the College; find out more about this [Emergency Funding](#) through the DoS office.

### **Title IX Reporting Policy Regarding Sexual Misconduct, Harassment, Relationship Violence, and Stalking**

**Contact:** Joe Hall, [jhall@wooster.edu](mailto:jhall@wooster.edu), [Title IX website](#)

The College of Wooster is committed to fostering a campus community based on respect and nonviolence. To this end, we recognize that all Wooster community members are responsible for ensuring that our community is free from discrimination, gender bias, sexual harassment, and sexual assault. In accordance with Title IX, Wooster is legally obligated to provide supportive options for all reports of sexual harassment and sexual assault that occur on our campus. Faculty who become aware of an incident of sexual violence, including harassment, rape, sexual assault, relationship violence, or stalking, are mandated reporters at the College and are required to notify Wooster's Title IX Coordinator. The purpose of this disclosure is to ensure that students are made aware of their reporting options and resources for support. For more information about your rights and reporting options at Wooster, including confidential and anonymous reporting options, please visit <https://inside.wooster.edu/title-ix/>

### **Discriminatory or Bias-Related Harassment Reporting Policy**

**Contact:** Visit the [Bias Reporting website](#)

The College of Wooster is committed to promoting its mission of inclusivity and equity in all aspects of the educational enterprise. This commitment extends to all rights, privileges, programs and activities, including housing, employment, admissions, financial assistance, and educational and athletic programs at the College. The College's Bias Incident Reporting Process is designed to effectively respond to bias

concerns raised by faculty, students, staff, alumni and visitors to the College. If you or someone you know are the victims of bias, you can:

- [File a report online](#) (where you may choose to identify yourself or not)
- Contact Campus Safety: 2590 (from campus phone) or 330-263-2590
- Call the Anonymous Tip Line: 2337 (from campus phone) or 330-263-2337
- Contact the Dean of Students Office: 2545 (from a campus phone) or 330-263-2545
- Contact the Vice President for Equity, Inclusion, and Diversity Cheryl Nuñez at 330-263-2356

### Well-being at Wooster

**Contact (24/7):** (330) 263-2319, or visit the [Wellness Center website](#)

The College of Wooster is committed to supporting the wellbeing of our students. During the course of their academic careers, students experience challenges that may interfere with their learning & health (both physical and mental), including but not limited to: strained relationships, adjusting to a new environment, chronic worrying, persistent sadness or loss of interest in enjoyable activities, family conflict, grief and loss, domestic violence, unwanted sexual experiences, difficulty concentrating, drug/alcohol problems, significant changes in eating and sleeping patterns, microaggressions, challenges with organization, procrastination and/or lack of motivation. Counseling Services at the Longbrake Student Wellness Center is a free and confidential resource providing short-term counseling and connections to community agencies for students needing longer term or specialized resources. You can make an appointment by calling 330.263.2319 between 8:30am-4:30pm during weekdays or by emailing Lori Stine ([lstine@wooster.edu](mailto:lstine@wooster.edu)). You can also find helpful resources on the Counseling Services website at <https://inside.wooster.edu/health/counseling/>.

Students also have free access to TimelyCare, a telehealth service providing scheduled medical and counseling appointments as well as 24/7 crisis consultation with licensed professionals. Students use their Wooster email to establish an account at [TimelyCare: Telehealth for Scots](#). TimelyCare also provides students access to nutritionists and health coaches about issues of sleep and exercise, and psychiatry (with a referral from doctor or counselor).

If you or a friend is in crisis, please call Campus Safety at 330-287-3333 or the Suicide and Crisis Lifeline (988, available 24 hours) or connect with the Crisis Text Line by Texting “4HOPE” to 741-741.

**For financial concerns:** Dean of Students Office, [dos@wooster.edu](mailto:dos@wooster.edu) (330) 263-2545, [DoS website](#)

**For safety concerns:** Campus Safety 330-263-2590 or [cw-security@wooster.edu](mailto:cw-security@wooster.edu), [Campus Safety website](#). **In the care of an emergency, call: 330-287-3333.**

## H. SYLLABUS CHANGES

I reserve the right to make changes to this syllabus, if needed. Any changes will be announced to the class in a timely manner.