Syllabus, Fall 2023, for OIDD 5250: Thinking with Models: Business analytics for energy and sustainability (TwM) TR 3:30pm-4:59pm in JMHH 360 (8/29 to 12/11) Canvas: `https://canvas.upenn.edu/courses/1739849` GitHub: TBA

Instructor: Professor Steven O. Kimbrough
Office: 565 Jon M. Huntsman Hall
Office hours: T & R 10:00–11:30 and by appointment

August 20, 2023

Masking in class is encouraged not required until further notice. The instructor intends to wear a mask during class.

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1 Highlights

- Brought on most urgently by climate change and attendant global warming, humanity is of necessity engaged in green transitions for the sake of establishing sustainable economies and civilizations.
- The transition of most immediate import is the energy transition to "clean" energy, that is energy produced with net zero greenhouse gas (GHG) emissions.
- This course is about modeling for the energy transition and, to a lesser extent, other green transitions.
- Our focus is on commercial and policy aspects of the green transitions, in distinction to modeling for climate science.
- There are three main facets or aspects of the course:
    1. Related science and engineering necessary to understanding the modeling.

       We discuss the basics of energy science, the design and operation of large-scale electricity grids, optimization, agent-based modeling (ABM), and the elements of multi-criteria decision making theory.
    2. Maco-level policy and commercial topics.

       Examples include deep decarbonization of the electricity grid and managing in the face of variable renewable energy (VRE).
    3. Micro-level policy and commercial topics.

       Here we are concerned especially with decision making at the state and local level (whether commercial or governmental or third sector) with regard to policies and designs for effecting the green transitions.

2 Course Description

The world is engaged in a transition to clean and sustainable ("green") energy. The ensuing disruption creates opportunities for innovation on many fronts, including new social arrangements, new business models, and entrepreneurial activities of many kinds. OIDD 525X is a business analytics class that addresses these matters by surveying and introducing the main kinds of models and modeling techniques being used in the green transition. These include: (non-financial) accounting models (e.g., for calculating carbon footprints, for ESG investing, for life-cycle analysis), constrained optimization models (resource allocation using mathematical programming or AI methods in the form of metaheuristics), and system performance models (typically as simulations and often using AI methods such as agent-based modeling). There will be special emphasis on decision theoretic models and multi-criteria decision making (MCDM). These models are used to support decision making based on data and model outputs from multiple sources and domains. The problem of overcoming low data quality with proper use of modeling is a major theme in the course.

1. The Earth is experiencing global warming caused by greenhouse gas emissions.

2. "Greenhouse gas (GHG) emissions are externalities and represent the biggest market failure the world has seen."

   Stern, N. (2008). The Economics of Climate Change. American Economic Review, 98(2), 1–37. https://doi.org/10.1257/aer.98.2.1

   Hence intervention in markets is required. This very difficult and fraught with clash of interests as well as uncertainty. (Think: stranded assets.)

3. The extent and pace of global warming has created the present climate emergency. Vastly destructive consequences will ensue soon—during the lifetimes of those now living—and are already plainly in evidence. Things will only get much worse, absent necessary revisions in current practices (BAU, business as usual). Action needs to be taken proactively and with immediacy.

4. There is no credible prospect of eliminating GHG emissions without disruption of BAU. The social and economic consequences are immense, including conflict with entrenched economic interests.

5. The destructive levels of GHG emissions are due to combustion of fossil fuels (oil, gas, coal). Thus an *energy transition* is required.

6. At the same time, but with somewhat less urgency, we must undertake a sustainability transition. This is necessary even without global warming. Together—energy and sustainability—we call these the green transitions. The course will address both, with emphasis on energy.

7. The energy transition will be disruptive and transformative. Things will be different. There will be losers, but there will also be great opportunities for entrepreneurial innovation.

What are the grand challenges for business analytics and modeling for the green transitions? There are two main categories:

A. <u>Choice of alternatives</u>: Choosing alternatives and portfolios of alternatives from among the very large number alternatives available for making the transitions. Alternatives may be technologies, systems, policies, rules, . . . anything material for the green transitions. Which should be implemented? In what form? Under what timing? What mix of public, commercial and non-profit sector involvement? What mixes of technologies and where are they best? Etc. This is also a portfolio problem with immense complexities, all operating in the civil analog of the fog of war. Here the main modeling tools come from decision theory. The course will be particularly interested in multi-criteria decision making (MCDM) for exploring design tradeoffs. This class of models is practised widely, independent of the energy transition. Examples include: selection of a portfolio of R&D projects, selection of a collection of policies to meet a diverse set of goals.

B. Understanding system configuration and performance: Broadly speaking, these are design optimization problems, for which many different kinds of modeling techniques prove useful. Because of the extent of change needed, there is nearly unlimited need for system configuration and performance modeling. Example areas include: Capacity planning, transit oriented development (TOD), building design, urban design, services design.

The course will have particular focus on (and across) these topics:

i. Accommodating intermittency of variable sources of renewable energy (wind, solar, etc.). This is a special and important topic for system configuration and performance modeling as well as an important area of policy design and choice.

ii. Risk assessment related to intermittency, fuel prices, risk imposition, system performance, and much else.

iii. Modeling in the presence of uncertainty, making good decisions with imperfect data and models and in the face of great uncertainty. This is a theme that suffuses everything in the course.

iv. Services design and the green transitions, e.g., for new services, such as district geothermal, as well as existing services, such a food rescue programs and walkability design.

The overall aim of the course is to teach facility with modeling and to use real-world applications in doing so. As a means to this end, we will study key material elements of the green transition, including where greenhouse gas emissions (GHGs) originate, how electric power systems ("the grid") function and are organized, renewable energy systems (RES), and social design ideas (such as Transit Oriented Development and Complete Streets). Students with interests in entrepreneurial investment, policy analysis, activism, or administration in the energy sphere will find the course useful. The modeling problems and techniques that we study in the context of the green transition are entirely transferable to other domains.

3 Prerequisites

The essential prerequisite is interest in the subject. Students should comfortable with spreadsheet modeling and with using provided computational tools, executing them and configuring them to do analyses. The instructor will provide support as needed. Basic instruction in NetLogo will be given for the purpose of working with and understanding agent-based models (ABMs) as they apply to energy and sustainability. Students interested in implementing computational models will have opportunity and support for doing so, but this is not a requirement.

4 Required Texts

- Our main text will be Randolph and Masters (2018), *Energy for Sustainability: Foundations for Technology, Planning, and Policy, 2nd ed.* This will be available as an ebook, through the library and Canvas. We will use it as a source for information on energy and sustainability.
- *Multi-criteria analysis: a manual* Great Britain and Department for Communities and Local Government (2009), available on Canvas.
- NetLogo. Software tool for agent-based modeling. Available for free at `https://ccl.northwestern.edu/netlogo/`.
- *Lecture Notes* for most classes will be posted on Canvas. These notes are required or suggested readings, as indicated.
- Other readings and handouts will be freely available on Canvas.

5 Class Schedule

5.1 First class: Introduction

Main topics:

- Course overview
- The climate change imperative

  A quick overview of climate science and why it makes the energy transition imperative. Relying on the IPCC.

  Slide deck: 2021 Global Virtual Training PowerPoint English Short.zip, courtesy of The Climate Reality Project.
- Local policy making

  Slide deck: Opportunities in Municipal Climate Transitions.pdf

Assigned reading(s):

a. IPCC AR6 Working Group III report, *Climate Change 2022: Mitigation of Climate Change*. Read the "Summary for Policymakers" IPCC (2022).

Reference material:

a. The Energy Gang podcast Gang (2022)

b. Good article about the transition to EVs:

   Wallace-Wells, D. (2023, January 11). Electric Vehicles Keep Defying Almost Everyone's Predictions. The New York Times. `https://www.nytimes.com/2023/01/11/opinion/electric-vehicles-sales-growth-tesla.html`

5.2 Fundamentals of Energy Science, 1

Main topics:

1. Energy science

   Slide deck: Chapter 4 RandM.pptx

Assigned reading(s):

a. *Energy for Sustainability* (Randolph and Masters, 2018, chapter 4, pages 95–113), “Fundamentals of Energy Science.”

Reference material:

a. Smil Smil (2006)

5.3 Fundamentals of Energy Science, 2

Main topics:

1. Energy science

   Slide deck: Chapter 4 RandM.pptx

Assigned reading(s):

a. *Energy for Sustainability* (Randolph and Masters, 2018, chapter 4, pages 113–131), “Fundamentals of Energy Science.”

Reference material:

a. Smil Smil (2006)

b. “Is a Transition to Renewable Energy on the Verge of Being Unstoppable?” Kimbrough and McElfresh (2018)

5.4 Electric Energy Systems, 1

Main topics:

1. Centralized Electric Power Systems

   Slide deck: Chapter 09 annotated.pptx

Assigned reading(s):

a. *Energy for Sustainability* (Randolph and Masters, 2018, chapter 9)

5.5 Electric Energy Systems, 2

Main topics:

1. Distributed Energy Resources (DER)

   Slide deck: Chapter 10 annotated.pptx

Assigned reading(s):

a. *Energy for Sustainability* (Randolph and Masters, 2018, chapter 10)

Reference material:

a. Vernon, A. (July 6, 2022). Is the Smart Grid All Hot Air? - Austin Vernon's Blog. Retrieved January 6, 2023, from `https://austinvernon.site/blog/smartgrid.html`

   Informative at least of debates going on. Many of the assertions are contested. The other shoe drops at the end. I would not endorse all the views on display, but they are contenders in the present environment. The issues are real and in play.

b. Lazard. (2021). Levelized Cost Of Energy, Levelized Cost Of Storage, and Levelized Cost Of Hydrogen. Lazard.Com. `http://www.lazard.com/perspective/levelized-cost-of-energy-level`

   lazards-levelized-cost-of-energy-version-150-vf.pdf on Canvas

5.6 Variability and intermittency

Main topics:

- The grand challenge of accommodating variable renewable energy (VRE).
- Energy storage systems
- Batteries: electrical, thermal
- PJM production and load data
- Analyzing production shortfall

Assigned reading(s):

a. Readings in the *Class Notes*.

b. m *Energy for Sustainability* (Randolph and Masters, 2018, chapter 10, pages 327–332)

Reference material:

a. Geocaris, M. (2022, September 12). On the Road to 100% Clean Electricity: Six Potential Strategies To Break Through Last Few Percent. `https://www.nrel.gov/news/program/2022/on-the-road-to-100-clean-electricity-six-potential-strategies-to-break-thro` `html` https://www.nrel.gov/news/program/2022/on-the-road-to-100-clean-electricity-six-potential-strategies-to-break-through-the-last-few-percent.html

b. EIA. (n.d.). U.S. Natural Gas Electric Power Price (Dollars per Thousand Cubic Feet). Retrieved January 10, 2023, from `https://www.eia.gov/dnav/ng/hist/n3045us3m.htm`

5.7 Risk and Pricing

Main topics:

- Risk shifting, burden shifting
- Fuel price risk as an example
- Pricing fuel price risk

Assigned reading(s):

a. *Class Notes*

Reference material:

a. Bolinger (2017)

5.8 Quiz 1

In class, written, closed book. One crib sheet (two sides) permitted. Quiz will be aimed at 50–60 minutes.

5.9 Optimization

Main topics:

- Constrained optimization
- Exact solver methods
- Heuristic solver methods; metaheuristics
- Energy storage optimization

Slides: optimization-math-prog-beamer.pdf, intro-metaheuristics-beamer.pdf
Assigned reading(s):

a. (Kimbrough and Lau, 2016, chapters 1–2)

5.10 Optimization and deep decarbonization

Main topics:

- Capacity planning models and deep decarbonization
- Other optimization models for energy and sustainability

Assigned reading(s):

a. (Kimbrough and Lau, 2016, chapter 3)

b. Yilmaz, H. Ü., Kimbrough, S. O., van Dinther, C., & Keles, D. (2022). Power-to-gas: Decarbonization of the European electricity system with synthetic methane. Applied Energy, 323, 119538. https://doi.org/10.1016/j.apenergy.2022.119538

Reference material:

a. Hobbs, B. F. (1995). Optimization methods for electric utility resource planning. European Journal of Operational Research, 83(1), 1–20. https://doi.org/10.1016/0377-2217(94)00190-N Hobbs (1995)

b. Hansen, K., Breyer, C., & Lund, H. (2019). Status and perspectives on 100% renewable energy systems. Energy, 175, 471–480. https://doi.org/10.1016/j.energy.2019.03.092 Hansen et al. (2019a)

5.11 Energy Analysis, 1

Main topics:

- Data resources
- Accounting models, in which we add things up. (Not financial accounting.)
- Energy Analysis
- EU green taxonomy
  - Protocol for measuring GHG emissions
  - Modeling tools and use

Assigned reading(s):

a. *Class Notes* Appendix A.

b. *Energy for Sustainability: Foundations for Technology, Planning, and Policy* (Randolph and Masters, 2018, chapter 5, pages 133–148), "Energy Analysis and Life-Cycle Assessment."

c. EU green taxonomy: Union (2022),

Reference material:

a. TEG (2022)

b. `https://ec.europa.eu/info/business-economy-euro/banking-and-finance/sustainable-finance/eu-taxonomy-sustainable-activities_en`

5.12 Energy Analysis, 2

Main topics:

- Energy Analysis and Life-Cycle Assessment
- Carbon footprinting
- The GHG Protocol

Assigned reading(s):

a. *Energy for Sustainability: Foundations for Technology, Planning, and Policy* (Randolph and Masters, 2018, chapter 5, pages 148–167), "Energy Analysis and Life-Cycle Assessment." Read for general understanding.

b. Greenhouse Gas Protocol Protocol (2022)

c. "Value for the calorie? - Corporate social responsibility and benchmarking analysis of calorie efficiency in food retailing" Jensen et al. (2019)

5.13 Cost-Benefit Analysis (CBA) & its discontents

Main topics:

- Cost-benefit analysis: principles, pluses and minuses
- Cost-benefit analysis: examples

Assigned reading(s):

a. *Class Notes*

b. "Cost benefit analysis of composting and anaerobic digestion in a community: a review" Zulkepli N.E. et al. (2017)

Reference material:

a. *Business Analytics for Decision Making* (Kimbrough and Lau, 2016, chapter 1)

b. DeMartino, G. F. (2022). The Tragic Science: How Economists Cause Harm (Even as They Aspire to Do Good). The University of Chicago Press.

5.14 ABM, 1: Introduction: ABM & NetLogo

For the NetLogo classes, come to class with a laptop and NetLogo installed on it. Main topics:

In-class NetLogo exercise.

- Introduction to agent-based modeling
- Introduction to NetLogo programming

Assigned readings for introduction to agent-based modeling:

a. *Agent-Based Evolutionary Game Dynamics* (ABEGD) (Izquierdo et al., 2019, pages 14–20) "0.2. Introduction to agent-based modeling."[1]

b. PNbook: preface and chapter 1.

Assigned readings for introduction to NetLogo programming:

a. *NetLogo Users Manual* Learning NetLogo:
Tutorial #1: Models
Tutorial #2: Commands
Tutorial #3: Procedures

b. *Agent-Based Evolutionary Game Dynamics* (ABEGD) (Izquierdo et al., 2019, pages 21–31) "0.3. Introduction to NetLogo" and into "0.4. Fundamentals of NetLogo." `https://wisc.pb.unizin.org/agent-based-evolutionary-game-dynamics/`

c. PNbook: chapter 2.

d. "NETLOGO 6.0 — QUICK GUIDE"
`http://luis.izqui.org/resources/NetLogo-6-0-QuickGuide.pdf`

Reference material:

a. Wilensky and Rand (2015). Wilensky, U., & Rand, W. (2015). An Introduction to Agent-Based Modeling. The MIT Press. Available on JSTOR as a series of PDFs: `http://www.jstor.org/stable/j.ctt17kk851`

b. Romanowska, I., Wren, C. D., & Crabtree, S. A. (2021). Agent-Based Modeling for Archaeology: Simulating the Complexity of Societies. SFI Press. (Romanowska et al., 2021, chapters 1 and 2) [2] File: ABMA_color_version.pdf posted on Canvas.

c. AIMES (2022). AIMES (Director). (2022, March 23). Episode 1: Agent Based Modeling of Land Use Change. `https://www.youtube.com/watch?v=w_q2yJlDwDQ`

d. Complexity Explorer (2018). Complexity Explorer (Director). (2018, June 26). Agent-Based Modeling: An Introduction from Uri Wilensky. `https://www.youtube.com/watch?v=ocp3OdOvrZM`

[1] `https://wisc.pb.unizin.org/agent-based-evolutionary-game-dynamics/`

[2] `https://www.santafe.edu/news-center/news/new-book-agent-based-modeling-archaeology` Has free PDF at this location.

5.15 ABM, 2: NetLogo

We will have an in-class exercise. Come to class with a laptop and NetLogo installed on it.

In-class NetLogo exercise.

Main topics:

- Programming in NetLogo

Assigned reading(s):

a. *Agent-Based Evolutionary Game Dynamics* (ABEGD) (Izquierdo et al., 2019, pages 35–40) "0.4. Fundamentals of NetLogo."
`https://wisc.pb.unizin.org/agent-based-evolutionary-game-dynamics/`

b. "NETLOGO 6.0 — QUICK GUIDE"
`http://luis.izqui.org/resources/NetLogo-6-0-QuickGuide.pdf`

c. "The Fire Model," (Wilensky and Rand, 2015, chapter 3, pages 101–118). Wilensky, U., & Rand, W. (2015). An Introduction to Agent-Based Modeling.

Reference material:

a. *NetLogo User Manual* (read it)
  Reference
    Interface Guide
      Interface Tab Guide
      Info Tab Guide
      Code Tab Guide
    Programming Guide

   And the NetLogo Dictionary should be your constant companion while programming.

b. Romanowska, I., Wren, C. D., & Crabtree, S. A. (2021). Agent-Based Modeling for Archaeology: Simulating the Complexity of Societies. SFI Press. Romanowska et al. (2021)
`https://www.santafe.edu/news-center/news/new-book-agent-based-modeling-archaeolo`
   Or tiny URL: `https://tinyurl.com/329azsje`. (Has free PDF at this location. File ABMA_color_version.pdf posted on Canvas.)

5.16 ABM, 3: NetLogo

Main topics:

- Conventional programming in NetLogo

Assigned reading(s):

a. PNbook: skim programming material after chapter 3.

Reference material:

a. NetLogo User Manual

5.17 ABM, 4: NetLogo

Main topics:

- BehaviorSpace
- Pivot tables in Google Sheets
- Plotting in NetLogo

Assigned reading(s):

a. PNbook: chapter 3, appendix A.

Slide deck: ABM-4-beamer.pdf.
Recommended readings (before class):

a. (Wilensky and Rand, 2015, Chapter 6), especially pages 288–296.

b. (Kimbrough and Lau, 2016, chapter 1), file Chapter1BAbook.pdf on Canvas.

Reference material:

a. NetLogo User Manual

b. `https://support.google.com/docs/answer/1272900?hl=en&co=GENIE.Platform%3DDesktop` pivot table Google Sheets

5.18 ABM Cases in Energy and Sustainability, 1

Homework exercise handed out. Due November 16, 2023, 11:59 p.m.

Main topics:

1. Examples of ABMs in energy and sustainability
2. Hand out and discussion ABM exercise.

Assigned reading(s):

a. Instructor handouts

Reference material:

a. Castro, J., Drews, S., Exadaktylos, F., Foramitti, J., Klein, F., Konc, T., Savin, I., & Bergh, J. van den. (2020). A review of agent-based modeling of climate-energy policy. WIREs Climate Change, n/a(n/a), e647. https://doi.org/10.1002/wcc.647

5.19 ABM Cases in Energy and Sustainability, 2

Continuation of ABM Cases in Energy and Sustainability, 1.

5.20 Quiz #2

Quiz #2. In-class. Closed book but with one two-sided crib sheet.

Quiz #2. In-class.

5.21 Simulation Other Than ABM, 1

Main topics:

- Discrete event simulation
- Building energy simulation. Slides: building-energy-simulation-beamer.pdf.
- Energy analysis: LCA and carbon footprinting. Slides: energy-analysis-2-beamer.pdf.
- IAMs (integrated assessment models)

Assigned reading(s):

a. Instructor handout

Reference material:

a. Mawson, V. J., & Hughes, B. R. (2019). The development of modelling tools to improve energy efficiency in manufacturing processes and systems. Journal of Manufacturing Systems, 51, 95–105. https://doi.org/10.1016/j.jmsy.2019.04.008

b. Hussain, J., Lee, C.-C., & Chen, Y. (2022). Optimal green technology investment and emission reduction in emissions generating companies under the support of green bond and subsidy. Technological Forecasting and Social Change, 183, 121952. https://doi.org/10.1016/j.techfore.2022.121952

c. Integrated Assessment Models (IAMs) and Energy-Environment-Economy (E3) models — UNFCCC. (n.d.). Retrieved December 18, 2022, from https://unfccc.int/topics/mitigation/workstreams/response-measures/modelling-tools-to-assess-the-impact-of-the-implementation-of-response-measures/integrated-assessment-models-iams-and-energy-environment-economy-e3-models

d. Integrated Assessment Models (IAMs) for Climate Change. (n.d.). Obo. Retrieved December 18, 2022, from `https://www.oxfordbibliographies.com/display/document/obo-9780199363445/obo-9780199363445-0043.xml`

e. Wikipedia `https://en.wikipedia.org/wiki/Integrated_assessment_modelling` "All numerical models have shortcomings. In 2021, the integrated assessment modeling community examined gaps in what was termed the 'possibility space' and how these might best be consolidated and addressed.[42] In an October 2021 working paper, Nicholas Stern argues that existing IAMs are inherently unable to capture the economic realities of the climate crisis under its current state of rapid progress."

5.22 Decision theory (DT), 1

Main topics:

- Utility and preference
- Risk
- Uncertainty

Assigned reading(s):

a. *Class Notes*

Reference material:

a. Hansson, S. O. (2005). Decision Theory: A Brief Introduction. `https://people.kth.se/~soh/decisiontheory.pdf`

5.23 Decision theory, 2: MCDM, MAUT

Main topics:

- Multiple criteria decision making
- MAUT and SMARTER
- Example applications

Assigned reading(s):

a. *Lecture Notes*

b. (Kimbrough and Lau, 2016, chapter 16), "Multiattribute Utility Modeling."

Reference material:

a. "SMARTS and SMARTER: Improved Simple Methods for Multiattribute Utility Measurement" Edwards and Barron (1994)

b. Read quickly for general understanding. Kimbrough (2019)

c. *Multi-criteria analysis: a manual* Great Britain and Department for Communities and Local Government (2009), available on Canvas.

5.24 Decision theory, 3: MCDM, AHP

Main topics:

- Continuation of MCDM and SMARTER
- AHP
- Examples, case studies

Assigned reading(s):

a. *Class Notes*

Reference material:

a. Teknomo, K. (n.d.-a). Analytic Hierarchy Process (AHP) Tutorial. `https://mathsci2.appstate.edu/~wmcb/Class/5340/ClassNotes141/AHP/AHP%20Tutorial%20Teknomo.pdf`

b. *Multi-criteria analysis: a manual* Great Britain and Department for Communities and Local Government (2009), available on Canvas.

5.25 Decision theory, 4: MCDM, outranking methods; Well-being and Objective list theories

Main topics:

- ELECTRE
- PROMETHEE
- Examples

Assigned reading(s):

a. *Class Notes*

Reference material:

a. "Stakeholder-driven multi-attribute analysis for energy project selection under uncertainty" Read et al. (2017)

b. *Multi-criteria analysis: a manual* Great Britain and Department for Communities and Local Government (2009), available on Canvas

5.26 Risk and uncertainty: Concepts, examples

Main topics:

- Risk versus uncertainty
- Probability of exceedance
- DMDU: Decision Making under Deep Uncertainty, and related concepts

Readings & background material:

a. (Bolinger, 2017)

b. (Boholm et al., 2015)

c. *Lecture Notes*

Reference material:

a. "A General, Analytic Method for Generating Robust Strategies and Narrative Scenarios" (Lempert and Trujillo, 2018)

b. "We are almost certainly underestimating the economic risks of climate change" Link

c. *Catastrophe Modeling: A New Approach to Manage Risk*, (Grossi and Kunreuther, 2005) is a good source for practical application of probability of exceedance concepts.

d. "Risk" (Hansson, 2018)

5.27 Quiz #3

Quiz #3. In-class. Closed book but with one two-sided crib sheet.

Quiz #3. In-class.

5.28 Last class

- Topics from (Randolph and Masters, 2018, chapters 16–18)
- *Informing Decisions on Climate Change* National Research Council (2009).
- Pichert, D., & Katsikopoulos, K. V. (2011). Green Defaults: Information Presentation and Pro-environmental Behaviour. In G. Gigerenzer, R. Hertwig, & T. Pachur (Eds.), Heuristics: The Foundations of Adaptive Behavior (pp. 712–724). Oxford University Press.
- Course summary

6 Grades and Conduct of Class

Attendance: Mandatory. Please email me in advance if you have a good reason not to attend a particular session.

Electronics: No phones, laptops, tablets or other electronics, unless specifically directed otherwise.

Grading will be based on several components, as follows.

15% Homework assignment, with NetLogo, done in self-formed groups of two. Due 11/21/23 at 11:59 p.m.

60% Three quizzes, 20% each. Classes 8 (9/21/23), 20 (11/07/23), and 27 (12/05/23).

15% End of term essay/project, due Thursday, December 21, 2023, 11:59 p.m. Groups of two, self-organized.

10% Class participation (including attendance, comments, in-class exercises).

Most of all, I want to see you engaged and involved in the class. I'll prepare lectures for the classes, but much prefer to conduct class with lots of interactive, give and take, and discussion.

Two further items/requirements:

- Every student should come chat with me at least once during (online) office hours. If my posted hours conflict with your schedule, let me know and we'll make arrangements. Also, you need not come alone. It's fine to come with a group of up to four.
- You will occasionally need your laptop in class. I'll let you know ahead of time. However, during lectures and similar periods when we are not actively using them, use of laptops, PDAs, etc. are forbidden.

7 Calendar, fall 2023

Last class is on Thursday, December 8, 2022.

	0	1	2
0	—	R: 2023-09-28	T: 2023-11-07
1	T: 2023-08-29	T: 2023-10-03	R: 2023-11-09
2	R: 2023-08-31	R: 2023-10-05	T: 2023-11-14
3	T: 2023-09-05	T: 2023-10-10	R 2023-11-16
4	R: 2023-09-07	T: 2023-10-17	T: 2023-11-21
5	T: 2023-09-12	R: 2023-10-19	T: 2023-11-28
6	R: 2023-09-14	T: 2023-10-24	R: 2023-11-30
7	T: 2023-09-19	R 2023-10-26	T: 2023-12-05
8	R: 2023-09-21	T: 2023-10-31	R: 2023-12-07
9	T: 2023-09-26	R: 2023-11-02	—

Table 1: Class number :: date correlation, for Tuesday (T) and Thursday (R) classes, fall 2023. Penn academic calendar `https://almanac.upenn.edu/penn-academic-calendar`

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