A Portfolio of Data Analytics Classes at University of Oklahoma

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Genesis / Motivation

- **Genesis**
  - I wrote an NSF Astronomy and Astrophysics Grant proposal to develop an analysis methodology for broad absorption-line quasar spectra in 2014.
  - The methodology involved *machine learning techniques.*
  - The ***broader impacts*** focused on developing a ***graduate-level course on machine learning*** in astrophysics.
- **The second step**
  - I wrote an NSF renewal proposal in 2019.
  - We decided to add ***undergraduate data analytics classes*** to the portfolio

Machine Learning

- Astronomy and Physics graduate students and advanced undergraduates
- Used AstroML – accompanying materials for “Statistics, Data Mining and Machine Learning in Astronomy”
- Taught in 2015, 2017, 2020

Introduction to Python

Statistics Introduction / Review

Markov Chain Monte Carlo

Histograms and Kernel Density Estimation

K-means Clustering / Gaussian Mixture Models

Regression and Principal Components Analysis

Classification / Neural Nets / Deep Learning

Time Series and Spatial Analysis

Successes

- All students improved their Python programming skills
- Several students fully embraced machine learning techniques
  - **Alex Kerr** – Enhanced genetic algorithms with neural nets to find better molecular designs, used manifold learning and clustering techniques to identify topological quantum phase transitions
  - **Collin Dabbieri** – FeLoNET – convolutional neural net methodology to classify quasar spectra

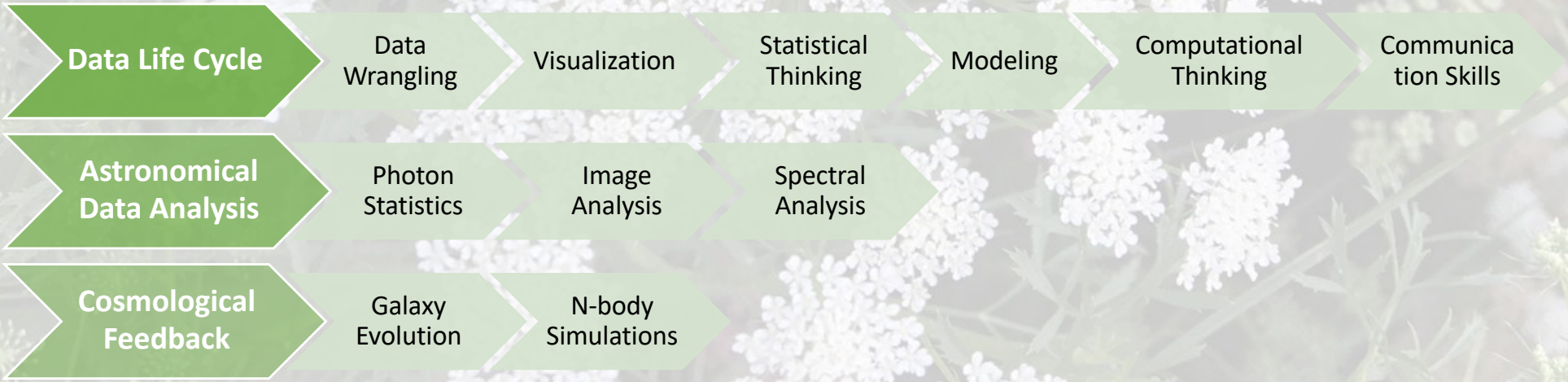
- *Several students who obtained data analysis jobs at Boeing, the FAA, and elsewhere cited this class as instrumental in their hiring.*

Improvements for Next Time (?)

- Improved homework
  - Frequent (daily) “try this” exercises
  - Longer project-like problems (less recipe based) for 1-2 week HW assignments

Introduction to Research

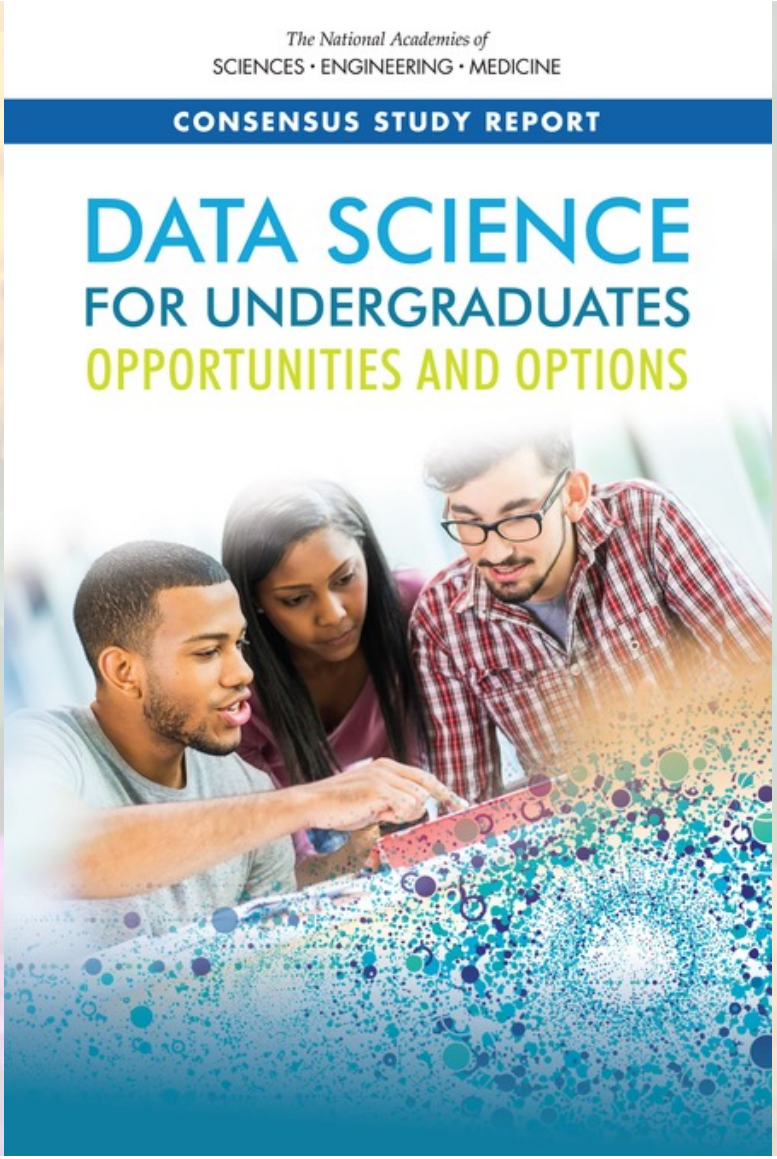
- Sophomore and junior astronomy and astrophysics majors
- Developed during 2019 PICUP Summer Faculty Development Workshop
- Taught Spring 2020



Useful Reference

- National Academies Report published in 2018
- Useful for grant proposals, administrators, and convincing your colleagues this is a good idea.

”Data Science for Undergraduates Opportunities and Options”



Data Life Cycle - Course Design

- ***Data Wrangling*** – Accessing & cleaning data; preliminary data analysis
- ***Visualization*** – Graphical representation of data; characteristics of effective graphical displays
- ***Statistical Thinking*** – the recognition that all data is influenced by statistics and the effect of underlying assumptions (e.g., normal distribution)
- ***Modeling*** – fitting physical or empirical models to data; what constitutes a good fit
- ***Computational Thinking*** – expressing problems and their solutions in a way that a computer could execute
- ***Communication Skills*** – Sharing the results with your peers and the public; scientific and technical writing
- (***Attitudes towards Research and Science***)

Lecture 1 - Introduction	Lecture 18 – Galaxy Evolution
Lecture 2 – SciServer and Jupyter Notebook Intro	Lecture 19 – Introduction to Convolution
Lecture 3 – Python Fundamentals	Lecture 20 – Reverberation Mapping
Lecture 4 - Plotting	Lecture 21 – Sherpa (Spectral Fitting Software)
Lecture 5 - Functions	Lecture 22 – Black Hole Masses
Lecture 6 – Loading Data	Lecture 23 – Astronomical Publications
Lecture 7 – Filter Photometry	Lecture 24 – Writing a Paper
Lecture 8 – Interpolation, Integration, Weighted Mean	Lecture 25 – Image Analysis
Lecture 9 – Colors and Distances	Lecture 26 – Radial Profile
Lecture 10 - Uncertainty	Lecture 27 – More Radial Profile
Lecture 11 - Histograms	Lecture 28 – Velocity Dispersion
Lecture 12 - Errors	Lecture 29 – Cosmological Simulations
Lecture 13 – Galaxy Spectra	Lecture 30 – Falling Sphere
Lecture 14 – Cumulative Distributions	Lecture 31 – Simple Hanging Harmonic Oscillator
Lecture 15 – Linear Least Squares	Lecture 32 – Introduction to Rebound
Lecture 16 – The Hubble Law	Lecture 33 – Jupiter Trojan Asteroids
Lecture 17 - SQL	Lecture 34 - Classes

Successes

- All students improved their Python programming skills
- Used the SciServer platform
  - Free access to python computation / Jupyter notebooks
  - Internal integration with SDSS SkyServer
  - Reliable
- Used nearly daily ”try this” exercises to explore concepts
- Converted to online (Zoom) delivery more or less seamlessly

Improvements

- Streamline content
- Reduce / eliminate quizzes and projects

An Ambitious Goal

- Collaborative research:
  - Don Terndrup - Ohio State University
  - Bruce Mason - University of Oklahoma
- Goal: ***Develop data analytics pre-post assessment tests***
  - Like the ”Force Concept Inventory”
- ***Challenging***, since they should cover the data life cycle, e.g.,
  - Statistical thinking
  - Computational thinking
  - Modeling
  - Visualization skills
- No progress yet – perhaps a draft version for Spring 2023?

Universal Challenge I

- ***Range of backgrounds*** – graduate class
  - Students with a background in Python can focus on the material.
  - Students without a background in Python struggle and have less time to learn the concepts
- ***Range of skills*** – undergraduate class
  - Some students already have hypothesis-testing skills.
  - Others struggle with the idea that they may have to try more than one method to successfully solve a problem.

Universal Challenge II

- ***Can data analytics be taught?*** I have my doubts.
- Students who want to work on my research project need to have excellent:
  - ***Attention to detail***
  - ***Trouble-shooting skills***
- Are these skills innate? Or developed by other creative activities?

Summary and Future

- We are developing a portfolio of data analytics courses at University of Oklahoma and Ohio State University.
- OU's contribution:
  - *Machine Learning in Astrophysics* – graduate class taught Fall 2015, 2017, 2020
  - *Introduction to Research* – sophomore-level course taught Spring 2020 and to be taught Spring 2023
- Plans to develop assessment tools for the development of data analytics skills in the undergraduate classes at both OU and OSU.