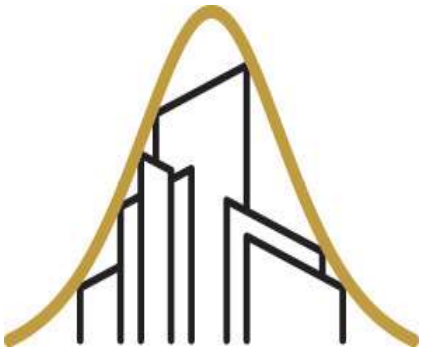
Statistics and Data Science (BA)

Undergraduate Curriculum Guide

2024-2025



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Introduction to Statistics and Data Science

This *Statistics Undergraduate Curriculum Guide* provides an outline of the curriculum and policies of the Statistics and Data Science (STAT) Bachelor of Arts degree offered by the Department of Applied Mathematics in the College of Arts and Sciences at CU Boulder. These guidelines are written primarily for students and faculty of the STAT program.

- General College of Arts and Sciences policy information:
    - www.colorado.edu/artsandsciences/student-resources/policies-and-requirements
- CU student course scheduling:
    - Log on to Buff Portal

Overview of the Department of Applied Mathematics

The Department of Applied Mathematics in the College of Arts and Sciences offers courses and degree programs for undergraduates and graduate students. The Department of Applied Mathematics currently has 21 tenured and tenure-track faculty, 12 teaching faculty, several postdoctoral associates, and maintains an active Visitor Program with researchers from around the world. Courses range from calculus to seminars in computation, mathematical biosciences, mathematical geosciences, probability and statistics, data science, nonlinear phenomena and physical applied mathematics. The departmental roots go back to the turn of the last century when it originally was the Department of Engineering Mathematics. The Department teaches thousands of students and has a major research presence in the statistical sciences, as well as in computational, physical and biological mathematics.

Introduction to the Bachelor of Arts in Statistics and Data Science (STAT-BA)

The Department of Applied Mathematics offers a Bachelor of Arts degree in Statistics and Data Science through the College of Arts and Sciences. The BA degree emphasizes inter- and cross-disciplinary training, and is intended to prepare students for a wide range of careers in areas such as statistics, data analytics, data science, business, engineering, economics, public health, epidemiology, insurance, forestry, psychology, social justice, and human rights.
Courses at the undergraduate level are designed to provide foundational skills in both traditional statistical methods and cutting-edge data analysis techniques. These skills are in high demand in the current job market and prepare students for desirable careers in statistics and data science. Statisticians and data scientists are often involved in interdisciplinary work; the BA degree requires in-depth training in some area of science, engineering, social science, or liberal arts that uses statistics to solve important problems. This knowledge prepares graduates to successfully communicate and collaborate with practitioners in these fields. A capstone course in Statistical Collaboration provides the opportunity for students to synthesize their previous coursework.

Outside Area of Emphasis/Application

Students will choose an outside area of emphasis/application to acquire knowledge in a discipline-specific area, where statistical applications are prevalent. Students will take a minimum of 18 credits in a department or certificate program outside of APPM/STAT, including a minimum of 6 credits at the upper-division level. Final course selection will be made in consultation with advisors and faculty from the departments as well as faculty advisors within the Department of Applied Mathematics.

Learning Goals for STAT-BA

Students graduating with a major in Statistics and Data Science (STAT-BA) will:

1. Develop problem-solving and modeling skills that allow them to analyze and visualize data and answer statistical questions.
2. Understand mathematical statistics, including probability, and acquire foundational mathematical knowledge, including calculus and linear algebra, as it pertains to statistics and data science.
3. Be proficient in at least two programming languages and their data science packages, and be able to write efficient, reproducible code related to data analysis
4. Acquire an in-depth knowledge of an application area, and skills to collaborate with domain experts.
5. Develop the ability to communicate statistical results clearly and concisely in oral, written, and visual forms.

Laboratory for Interdisciplinary Statistical Analysis (LISA) and Collaboration Course

After learning the communication and collaboration skills necessary to help domain experts answer their research, business, or policy questions, students have the opportunity to join LISA to gain additional practical experience. Students will collaborate with a variety of researchers around campus and in the community to apply statistics and data science to solve real problems. Students in LISA will also work with graduate students and faculty to engage in outreach activities to improve statistics and data science skills and literacy in the wider community.

STAT-BA Capstone Course

The capstone course provides students the opportunity to apply the knowledge, skills, and abilities developed throughout the Statistics and Data Science major. Working in teams, students undertake a data-driven problem proposed by domain experts from government, industry, or academia. Upon solving their assigned problem, teams formally present their solution in written and oral form. The course offers valuable project management experience for students intending to pursue analytic careers and exposure to technical communication for those preparing for graduate school.

Bachelor of Arts in Statistics Degree Requirements

To earn a BA in Statistics and Data Science, a student must complete the requirements of the College of Arts and Sciences; the following foundational courses in statistics, data science, and computing; as well as 18 credits in an outside area of emphasis, for a total of 65 credit hours.

Students must earn a grade of C- or better in all coursework applied to the major and have at least a C average for all attempted work for the major.

Minimum required courses specific to the STAT-BA degree

1. **Mathematical Foundations**
    a. APPM 1350 and APPM 1360 are introductory courses and prerequisites for Calculus 3
    b. Select one of APPM 2340 or APPM 2350 or MATH 2400 (Calculus 3). *APPM 2340 is the preferred course for Statistics majors.*
    c. APPM 3310 (Matrix Methods)

2. **Computing**
    a. APPM 1650 or CSCI 1300 or CSCI 1320. *APPM 1650 (Python with Math/Stat Applications) is the preferred course for Statistics Majors*
    b. STAT 2600 (Introduction to Data Science)

3. **Statistical Theory**
    a. STAT 3100 (Applied Probability)
    b. STAT 4520 (Introduction to Mathematical Statistics)

4. **Statistical Modeling**
    a. STAT 3400 (Applied Regression)
    b. STAT 4610 (Statistical Learning)

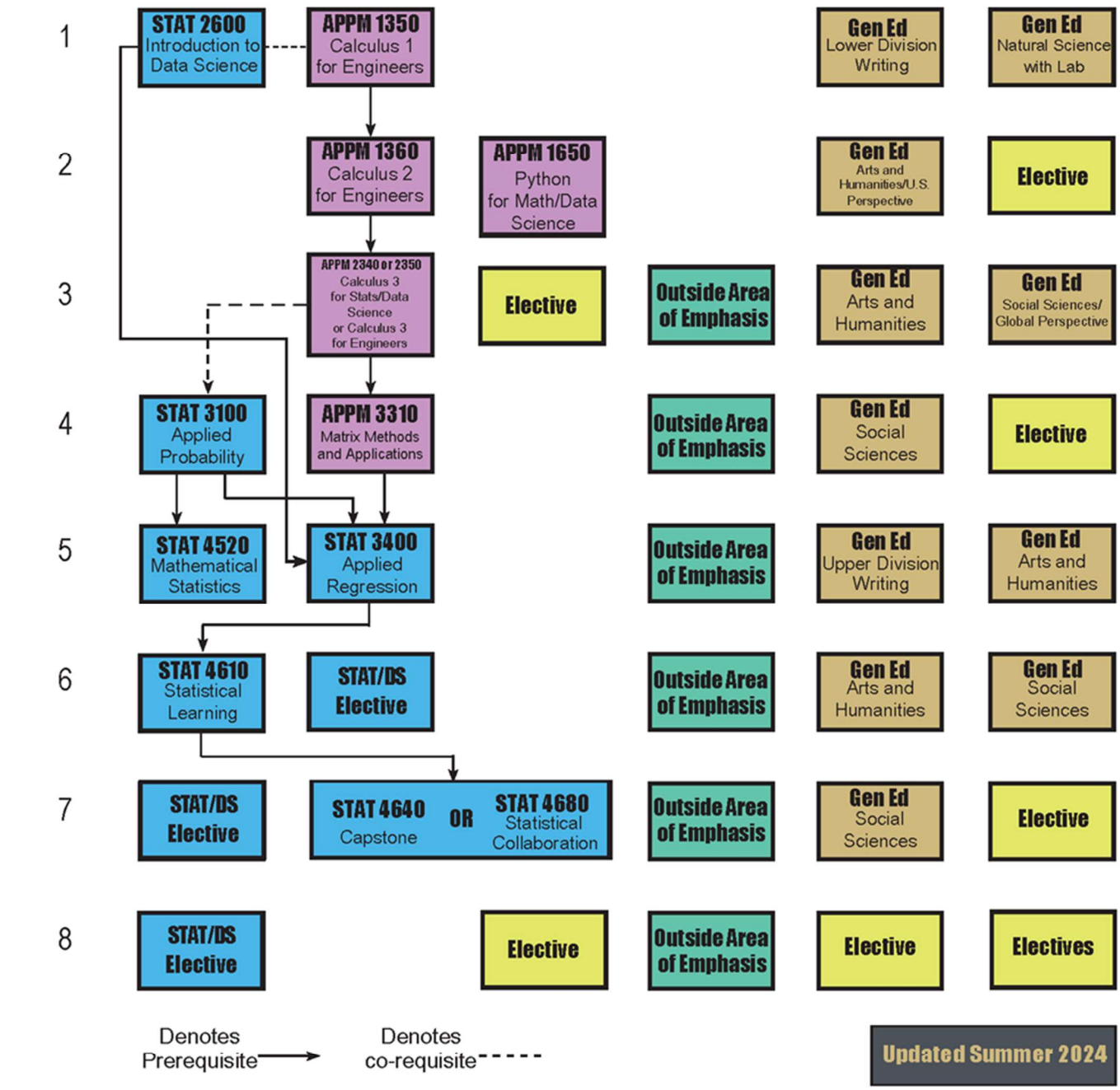
5. **Collaboration or Capstone Course, choose one**
    a. STAT 4680 (Statistical Collaboration I)
    b. STAT 4640 (STAT Capstone Course)

6. **Any 9-credit hour combination of the following courses:**
    a. STAT 4100 (Markov Processes, Queues, and Monte Carlo Simulations)
    b. STAT 4250 (Data Assimilation in High Dimensional Dynamical Systems)
    c. STAT 4350 (Applied Deep Learning 1)
    d. STAT 4360 (Applied Deep Learning 2)
    e. STAT 4400 (Advanced Statistical Modeling)
    f. STAT 4430 (Spatial Statistics)
    g. STAT 4540 (Introduction to Time Series)
    h. STAT 4630 (Computational Bayesian Statistics)
    i. STAT 4700 (Philosophical and Ethical Issues in Statistics)
    j. APPM 3650 (Algorithms and Data Structures in Python)
    k. APPM 4370 (Computational Neuroscience)
    l. APPM 4440 (Undergraduate Applied Analysis 1)
    m. APPM 4490 (Theory of Machine Learning)
    n. APPM 4515 (High-Dimensional Probability for Data Science)
    o. APPM 4530 (Stochastic Analysis for Finance)
    p. APPM 4565 (Random Graphs)

7. **Area of Application:** The area of application is a minimum of 18 credits in advisor approved courses with significant statistical content.

Statistics and Data Science Curriculum

Sample 4-Year Plan



Sample Curriculum for the Statistics and Data Science BA degree

(120 hours needed for graduation)

Year One						
Fall Semester				Spring Semester		
Course #	Course Title	Credit Hours		Course #	Course Title	Credit Hours
APPM 1350	Calculus 1 for Engineers	4		APPM 1360	Calculus 2 for Engineers	4
STAT 2600	Introduction to Data Science	4		APPM 1650	Python with Math/Stat Applications	4
	Gen. Ed. Skills course (example: Lower-division Written Communication)	3			Elective	3
	Gen. Ed. Distribution course (example: Natural Sciences with Lab)	4			Gen. Ed. Distribution/Diversity course (example: Arts & Humanities/US Perspective)	3
	Credit Hours	**15**			**Credit Hours**	**14**

Year Two						
Fall Semester				Spring Semester		
Course #	Course Title	Credit Hours		Course #	Course Title	Credit Hours
APPM 2340	Calculus 3 for Statistics/Data Science	4		APPM 3310	Matrix Methods and Applications	3
	Gen. Ed. Distribution course (example: Arts & Humanities)	3		STAT 3100	Applied Probability	3
	Gen. Ed. Distribution/Diversity course (example: Social Sciences/Global Perspective)	3			Outside Area of Emphasis course	3
	Outside Area of Emphasis course	3			Gen. Ed. Distribution course (example: Social Sciences)	3
	Elective	3			Elective	3
	Credit Hours	**16**			**Credit Hours**	**15**

Year Three						
Fall Semester				Spring Semester		
Course #	Course Title	Credit Hours		Course #	Course Title	Credit Hours
STAT 3400	Applied Regression	3		STAT 4610	Statistical Learning	3
STAT 4520	Introduction to Mathematical Statistics	3			Upper Division STAT elective	3
	Outside Area of Emphasis course	3			Outside Area of Emphasis course	3
	Gen. Ed. Skills course (example: Upper-division Written Communication)	3			Gen. Ed. Distribution course (example: Arts & Humanities)	3
	Gen. Ed. Distribution course (example: Arts & Humanities)	3			Gen. Ed. Distribution course (example: Social Sciences)	3
	Credit Hours	**15**			**Credit Hours**	**15**

Year Four						
Fall Semester				Spring Semester		
Course #	Course Title	Credit Hours		Course #	Course Title	Credit Hours
STAT 4680 or STAT 4640	Statistical Collaboration I or Capstone Course	3			Upper Division STAT elective	3
	Upper Division STAT elective	3			Outside Area of Emphasis course	3
	Gen. Ed. Distribution course (example: Social Sciences)	3			Electives	9
	Outside Area of Emphasis course or elective	3				
	Outside Area of Emphasis course or elective	3				
	Credit Hours	**15**			**Credit Hours**	**15**

Areas of Application

Statistics and Data Science majors are required to take a minimum of 18 credits in a technical area of emphasis where they could apply their statistical knowledge. At least 6 credits must be in courses numbered 3000 or above and at least 15 credits in courses numbered 2000 or above. Below are several possible options that are **suggestions** and not **requirements**. Final course selection must be made in consultation with a Statistics and Data Science advisor.

Almost any science or business minor can also count as an area of application, but almost all have more than 18 credit hours of coursework. We provide links to popular minors and certificate programs under each area of application below.

Actuarial Studies Option

- For students seeking to receive the Actuarial Studies Certificate, consult your Statistics advisor and visit http://www.colorado.edu/asqf for the full requirements and application process.

- The following courses are recommended:
  - BCOR 2203 and BCOR 2204 (prerequisite waived for Actuarial Certificate students)
  - ECON 2010** (Principles of Microeconomics – 4 cr.) and ECON 2020** (Principles of Macroeconomics – 4 cr.) (** ECON 2010, 2020 may not count toward the 18 credits of the option requirement; they are prerequisites for ECON 3070 and ECON 3080)
  - ECON 3070+ (Intermediate Microeconomic Theory – 3 cr.)
  - ECON 3080+ (Intermediate Macroeconomic Theory – 3 cr.)
  - ECON 4070 (Topics in Microeconomics - 3 cr.)
  - FNCE 3010+ (Corporate Finance – 3 cr.)
  - FNCE 3030 (Investment and Portfolio Management - 3 cr.)
  - FNCE 4040 (Derivative Securities – 3 cr.)
  - ECON 4818 (Intro to Econometrics – 3 cr.)

  Advising notes
  - The Society of Actuaries requires students to take certain college courses that will earn the Validation by Educational Experiences (VEE) credit. Courses marked with a + satisfy this requirement, provided a grade of B- or better is obtained. These courses are also required for students completing the Actuarial Certificate Program.
  - Students are strongly advised to take STAT 4540+ for the Actuarial Option.
  - Additional courses that may be useful include ACCT 3220, 3230, and BCOR 3000. These courses can be taken only if space is available on the first day of the semester.
  - The first actuarial examination, Exam P/1, can be taken after completing STAT 3100.
  - The second actuarial examination, Exam FM/2, can be taken after completing ECON 3070, ECON 3080, FNCE 3010 and self-study in interest theory.
  - The third actuarial examination, Exam MFE/3, can be taken after completing STAT 4100, FNCE 4040, and self-study.
  - The fourth actuarial examination, Exam C/4, can be taken after completing: STAT 4520+, STAT 4540+, STAT 4100, and self-study.
  - **Students wishing to take courses in the College of Business *must*** apply for admittance to the Actuarial Studies and Quantitative Finance Certificate Program which requires grades of B+ or better in their three semesters of Calculus. Students accepted into this program receive preferential treatment with respect to other non-business students when registering for business courses.
  - Students desiring to sign up for an actuarial exam should visit: http://www.soa.org

Computational Biology and Bioinformatics Option

- For students seeking to receive a Computational Biology Minor consult your Statistics advisor, and check the link for full requirements and the application process.

- The following selected courses from computer science, biology, and chemistry provide the foundation for work in mathematical biology, computational biology, and/or bioinformatics:
    - CSCI 2270 (Data Structures – 4 cr.) (Note: CSCI 1300 is a prerequisite for CSCI 2270)
    - CHEM 3311 & 3321 (Organic Chemistry 1 and Lab – 5 cr.)
    - MCDB 1150 & 1151 (Introduction to Cellular and Molecular Biology and Lab – 4 cr.)
    - MCDB 2150 & 2151 (Principles of Genetics and Lab – 4 cr.)
    - MCDB 3135 & 3140 (Molecular Cell Biology 1 and Lab - 5 cr.)
    - CSCI 3104 (Algorithms – 4 cr.) (prereq.: CSCI 2824 or APPM 3170)
    - CSCI 4314 (Algorithms for Molecular Biology - 3 cr.)

  Advising notes
    - Students selecting this option are advised to take APPM 4390 and STAT 4540 as part of their Statistics coursework. Other recommended courses include CSCI 3287 (Database and Information Systems).

Computer Science Option

- For students seeking to receive a Computer Science minor consult your Statistics advisor, and check the link for full requirements and the application process.

- Recommended courses:
    - CSCI 2270 (Data Structures – 4 cr.) (Note: CSCI 1300 is a prerequisite)
    - CSCI 3104 (Algorithms – 4 cr.)*
    - CSCI 3287 (Design & Analysis of Data Systems – 3 cr.)
    - Additional CSCI courses that have been pre-approved by your STAT advisor to complete the 18 credit requirement for the outside area of application

  Advising notes
    * CSCI 3104 has APPM 3170 or CSCI 2824 as a prerequisite.

Creative Design and Technology (CTD)

- For students seeking to receive a Creative Design and Technology minor consult your Statistics advisor, and check the link for full requirements and the application process.

- The following CTD courses are especially well-suited for Statistics majors, and can form the core of a creative design area of application:
    - ATLS 1100 (Design Foundations – 3 cr.), ATLS 2000 (The Meaning of Information Technology – 3 cr.), ATLS 3150 (Universal Design for Digital Media – 3 cr.), ATLS 4140 (Game Development – 3 cr.), ATLS 4151 (Flow Visualization – 3 cr.), ATLS 4519 (Data Storytelling – 3 cr.)
    - Other ATLS classes can be substituted for these classes depending on your interests. They should be approved by your STAT advisor prior to enrolling.

Quantitative Finance Certificate Option

- For students seeking to receive the Quantitative Finance Certificate, consult your Statistics advisor and visit http://www.colorado.edu/asqf for the full requirements and application process.

- Recommended courses
  - BCOR 2203 and BCOR 2204
  - FNCE 3010 (Corporate Finance – 3 cr.)
  - ECON 2010**, 2020**, 3070 and 3080 (** ECON 2010, 2020 may not count toward the 18 credits of the option requirement; they are prerequisites for ECON 3070 and ECON 3080)
  - ECON 4818 (Econometrics) - 3 cr.
- At least any two of the following (all must be taken for the Quantitative Finance Certificate Program):
  - ACCT 3220 (Corporate Financial Reporting 1 - 3 cr.)
  - FNCE 3030 (Investment and Portfolio Management - 3 cr.)
  - FNCE 4040 (Derivative Securities - 3 cr.)
  - FNCE 4820 (Topics in Finance: Mathematical Finance - 3 cr.)
  - FNCE 4070 (Financial Markets and Institutions - 3 cr.)
- Additional courses as time permits:
  - ACCT 3230 (Corporate Financial Reporting 2 - 3 cr.)
  - FNCE 4000 (Financial Institutions Management - 3 cr.)
  - FNCE 4020 (Applied Business Finance - 3 cr.)
  - FNCE 4050 (Capital Investment Analysis - 3 cr.)
  - FNCE 4060 (Special Topics in Finance - variable)

Advising notes

- **Students wishing to take courses in the College of Business** must apply for admittance to the Actuarial Studies and Quantitative Finance Certificate Program which requires grades of B+ or better in their three semesters of Calculus. Students accepted into this program receive preferential treatment with respect to other non-business students when registering for business courses. For more information, please see your Statistics advisor and visit http://www.colorado.edu/asqf

Geographic Information Science Option

- For students seeking to receive an Undergraduate Certificate in GIS and Computational Science, consult your Statistics advisor and check the link for full requirements and application process.

- Required courses
  - GEOG 3023 (Statistics and Geographic Data – 4 cr.)
  - CSCI 2270 (Data Structures – 4 cr.)
  - GEOG 3053 (Cartography Visualization & Information Design – 4 cr.) **or** GEOG 4103 (Introduction to GIS – 4 cr.) (Prereqs: GEOG 3023 & GEOG 3053)
- Recommended courses
  - GEOG 4023 (GIS Modeling Applications – 4 cr.)
  - GEOG 4303 (Spatial Programming in GIScience – 4 cr.)
  - GEOG 4403 (Space-Time Analytics – 3 cr.)
  - GEOG 4503 (GIS Project Management – 3 cr.)
  - GEOL 3050 (GIS for Geologists – 2 cr.)

Geological Sciences Option

- For students seeking to receive a Minor in Geological Sciences, consult your Statistics advisor and check the link for full requirements and application process.

- One of the following as an introductory course
    - GEOL 1010 & 1020 (Introduction to Geology + Geology 2 – 6 cr.)
    - GEOL 1010 & 1040 (Introduction to Geology + Geology of Colorado – 6 cr.)
    - GEOL 1010 & 1060 (Introduction to Geology + Global Change – 6 cr.)
- Required laboratory
    - GEOL 1030 (Introduction to Geology Laboratory – 1 cr.)
- Recommended courses
    - GEOL 2700 (Introduction to Field Geology – 2cr.)
    - GEOL 3010 (Introduction to Mineralogy – 3 cr.)
    - GEOL 3023 (Statics for Earth Sciences – 3 cr.)
    - GEOL 3120 (Structural Geology – 4 cr.)
    - GEOL 3410 (Paleobiology – 3 cr.)
    - GEOL 3430 (Sedimentology and Stratigraphy – 4 cr.)
    - GEOL 4130 (Principles of Geophysics – 3 cr.)
    - GEOL 4093 (Remote Sensing of the Environment – 4 cr.)
    - GEOL 4241 (Principles of Geomorphology – 4 cr.)

College of Media, Communication and Information (CMCI) option

- There are many combinations of courses available through CMCI. Please consult your Statistics advisor to choose courses that meet your academic and professional goals.
- Please check https://www.colorado.edu/cmci/academics for examples of courses and minors.

Public Health Certificate Option

- For students seeking to receive a Public Health Certificate, consult your Statistics advisor and check the link for full requirements and application process.

- Suggested courses include:
    - GEOG 2692/IPHY 2692 (Foundations in Public Health – 3 credits)
    - GEOG 3692 (Introduction to Global Public Health – 4 credits)
    - IPHY 3490 (Introduction to Epidemiology – 3 credits)
    - ECON 4646 (Topics in Health Economics – 3 credits)
    - GEOG 4732 (Population Geography – 3 credits)
    - SOCY 3032 (Social Epidemiology – 3 credits)

Business Minor and Economics Option

- Students seeking a Minor in Business, consult your Statistics advisor and check the link for full requirements and application process.
- The business minor is only 12 credits, you will need to find an additional 6 credits that meet your academic and professional goals. As always, consult your Statistics advisor when choosing these courses.

Many other options are possible!

Statistics, Data Science and Applied Mathematics Courses

Statistics and Data Science Courses

All Courses Require a C- Grade or higher to advance to the next course in sequence

STAT 2600 **Introduction to Data Science**
Introduces students to importing, tidying, exploring, visualizing, summarizing, and modeling data and then communicating the results of these analyses to answer relevant questions and make decisions. Students will learn how to program in R using reproducible workflows. During weekly lab sessions students will collaborate with their teammates to pose and answer questions using real-world datasets. Semester Offered: Spring

STAT 3100 **Applied Probability**
Studies axioms, counting formulas, conditional probability, independence, random variables, continuous and discrete distribution, expectation, joint distributions, moment generating functions, law of large numbers and the central limit theorem. Credit not granted for this course and ECEN 3810 or MATH 4510. Same as APPM 3570. Semester Offered: Fall and Spring

STAT 3400 **Applied Regression**
Introduces methods, theory, and applications of linear statistical models, covering topics such as estimation, residual diagnostics, goodness of fit, transformations, and various strategies for variable selection and model comparison. Examples will be demonstrated using statistical programming language R.
Prerequisites: STAT 2600 and STAT 3100 Semester Offered: Spring

STAT 4000 **Statistical Methods and Application I**
Introduces exploratory data analysis, probability theory, statistical inference, and data modeling. Topics include discrete and continuous probability distributions, expectation, laws of large numbers, central limit theorem, statistical parameter estimation, hypothesis testing, and regression analysis. Considerable emphasis on applications in the R programming language. Same as STAT 5000.
Corequisite: APPM 1360. Semester Offered: Fall and Spring
NOTE: STAT 4000 does not apply to the STAT-BA course requirements.

STAT 4010 **Statistical Methods and Application II**
Expands upon statistical techniques introduced in STAT 4000. Topics include modern regression analysis, analysis of variance (ANOVA), experimental design, nonparametric methods, and an introduction to Bayesian data analysis. Considerable emphasis on application in the R programming language. Same as STAT 5010.
Prerequisite: STAT 4000 or Instructor Consent. Semester Offered: Spring
NOTE: STAT 4010 does not apply to the STAT-BA course requirements.

STAT 4100 **Markov Processes, Queues, and Monte Carlo Simulations**
Brief review of conditional probability and expectation followed by a study of Markov chains, both discrete and continuous time, including Poisson point processes. Queuing theory, terminology and single queue systems are studied with some introduction to networks of queues. Uses Monte Carlo simulation of random variables throughout the semester to gain insight into the processes under study. Same as STAT 5100, APPM 4560 and APPM 5560.
Prerequisites: APPM 3570 or STAT 3100 or MATH 4510. Semester Offered: Fall and Spring

STAT 4230 **Stochastic Analysis for Finance**
Studies mathematical theories and techniques for modeling financial markets. Specific topics include the binomial model, risk neutral pricing, stochastic calculus, connection to partial differential equations and stochastic control theory. Same as APPM 4530, APPM 5530 and STAT 5230.
Prerequisites: APPM 3310 and APPM 3570 or STAT 3100 or MATH 4510.

STAT 4250 Data Assimilation in High Dimensional Dynamical Systems
Develops and analyzes approximate methods of solving the Bayesian inverse problem for high-dimensional dynamical systems. After briefly reviewing mathematical foundations in probability and statistics, the course covers the Kalman filter, particle filters, variational methods and ensemble Kalman filters. The emphasis is on mathematical formulation and analysis of methods. Same as APPM 4510, APPM 5510 and STAT 5250.
Prerequisites: APPM 3310 and APPM 3570 or STAT 3100 or MATH 4510.

STAT 4350 Applied Deep Learning 1
Introduces students to state-of-the-art deep learning techniques employed in the industry. This course will focus on training neural networks and computer vision, including image classification and transformation, object detection, and facial recognition. Advanced topics will include domain adaptation and learning techniques. There will be an emphasis on reading current literature.
Prerequisites: APPM 3570 or STAT 3100; STAT 3400 or STAT 4520; APPM 4650 or APPM 4600.

STAT 4360 Applied Deep Learning 2
Introduces students to state-of-the-art deep learning techniques employed in the industry. This course will focus on training neural networks and computer vision, including image classification and transformation, object detection, and facial recognition. Advanced topics will include domain adaptation and learning techniques. There will be an emphasis on reading current literature.
Prerequisites: APPM 3570 or STAT 3100; STAT 3400 or STAT 4520; APPM 4650 or APPM 4600.

STAT 4400 Advanced Statistical Modeling
Introduces methods, theory and applications of modern statistical models, from hierarchical linear models, to generalized hierarchical linear models, including hierarchical logistic and hierarchical count regression models. Topics such as estimation, residual diagnostics, goodness of fit, transformations, and various strategies for variable selection and model comparison will be discussed in depth. Examples will be demonstrated using statistical programming language R.
Prerequisites: STAT 3400 and STAT 4520. Semester Offered: Spring

STAT 4430 Spatial Statistics
Introduces the theory of spatial statistics with applications. Topics include basic theory for continuous stochastic processes, spatial prediction and kriging, simulation, geostatistical methods, likelihood and Bayesian approaches, spectral methods and an overview of modern topics such as nonstationary models, hierarchical modeling, multivariate processes, methods for large datasets and connections to splines. Same as STAT 5430.

STAT 4520 Introduction to Mathematical Statistics
Examines point and confidence interval estimation. Principles of maximum likelihood, sufficiency, and completeness: tests of simple and composite hypotheses, linear models, and multiple regression analysis if time permits. Analyzes various distribution-free methods. Same as STAT 5520 and MATH 4520 and MATH 5520. Prerequisites: APPM 3570 or STAT 3100 or MATH 4510

STAT 4540 Introduction to Time Series
Studies basic properties, trend-based models, seasonal models, modeling and forecasting with ARIMA models, spectral analysis and frequency filtration. Same as STAT 5540 and MATH 4540 and MATH 5540.

STAT 4610 Statistical Learning
Consists of applications and methods of statistical learning. Reviews multiple linear regression and then covers classification, regularization, splines, tree-based methods, support vector machines, unsupervised learning and Gaussian process regression.
Prerequisite: STAT 3400

STAT 4630 Computational Bayesian Statistics
Introduces Bayesian statistics, normal and non-normal approximation to likelihood and posteriors, the EM algorithm, data augmentation, and Markov Chain Monte Carlo (MCMC) methods. Additionally, introduces more advanced MCMC algorithms and requires significant statistical computing. Examples from a variety of areas, including biostatistics, environmental sciences, and engineering, will be given throughout the course. Same as STAT 5630.
Prerequisites: APPM 4560 or STAT 4100; STAT 3400; STAT 4520 or MATH 4520

STAT 4680 **Statistical Collaboration**
Educates and trains students to become effective interdisciplinary collaborators by developing the communication and collaboration skills necessary to apply technical statistics and data science skills to help domain experts answer research questions. Topics include structuring effective meetings and projects; communicating statistics to non-statisticians; using peer feedback, self-reflection and video analysis to improve collaboration skills; creating reproducible statistical workflows; working ethically. Prereqs., STAT 4520. Same as APPM 5500. Semester offered: Fall

STAT 4690 **Advanced Statistical Collaboration** (2 cr.)
Educates and trains students to become advanced interdisciplinary collaborators by developing and refining the communication, collaboration and technical statistics and data science skills necessary to collaborate with domain experts to answer research questions. Students work on multiple projects. Discussions center on technical skills necessary to solve research problems and video analysis to improve communication and collaboration skills. Prereqs., APPM 4500 or APPM 5500. Same as APPM 5505. Semester offered: Spring

STAT 4700 **Philosophical and Ethical Issues in Statistics**
Introduces students to philosophical issues that arise in statistical theory and practice. Topics include interpretations of probability, philosophical paradigms in statistics, inductive inference, causality, reproducible, and ethical issues arising in statistics and data analysis. Same as STAT 5700.

STAT 4720 **Open Topics in Statistics and Data Science**
Provides a vehicle for the development and presentation of new topics that may be incorporated into the core courses in statistics and data science. Department enforced prerequisite: variable, depending on the topic, see instructor. May be repeated up to 15 total credit hours. Same as STAT 5720.

STAT 4840 **Reading and Research in Statistics**
Introduces undergraduate students to the research foci of the Statistics and Data Science faculty. May be repeated up to 9 total credit hours. Semester offered: Fall, Spring and Summer.

Applied Mathematics Courses

All Courses Require a C- Grade or higher to advance to the next course in sequence

APPM 1235 **Pre-calculus for Engineers**
Prepares students for the challenging content and pace of the calculus sequence required for all engineering majors. The course covers algebra, trigonometry and selected topics in analytical geometry. It prepares students for the calculus courses offered for engineering students. It requires students to engage in rigorous work sessions as they review topics that they must be comfortable with to pursue engineering course work. The course is structured to accustom students to the pace and culture of learning encountered in engineering math courses. Requires placement into pre-calculus based on your admissions data and/or CU Boulder coursework. Credit not granted for this course and MATH 1150.

APPM 1340 **Calculus 1 with Algebra, Part A.**
Studies selected topics in analytical geometry and calculus: rates of change of functions, limits, derivatives and their applications. APPM 1340-1345 together are equivalent to APPM 1350. The sequence APPM 1340-1345 is specifically designed for students whose manipulative skills in the techniques of high school algebra and precalculus may be inadequate for APPM 1350. Requires prerequisite course of APPM 1235 or MATH 1021 or MATH 1150 or MATH 1160, or placement into pre-calculus based on your admissions data and/or CU Boulder coursework. Semester offered: Fall

APPM 1345 **Calculus 1 with Algebra, Part B**.
Continuation of APPM 1340. Studies selected topics in calculus: derivatives and their applications, integration, differentiation and integration of transcendental functions. Algebraic and trigonometric topics are studied throughout, as needed. Prereq., APPM 1340. Credit not granted for this course and APPM 1350 or MATH 1300 or ECON 1088 or MATH 1081 or MATH 1310 or MATH 1330. Semester offered: Spring

APPM 1350 Calculus 1 for Engineers
Topics in analytical geometry and calculus including limits, rates of change of functions, derivatives and integrals of algebraic and transcendental functions, applications of differentiations and integration. ***Note:*** APPM 1351, a 1-credit workgroup, is available for students who would like more practice working calculus problems in a group learning environment. Requires prerequisite course of APPM 1235 or MATH 1021 or MATH 1150 or MATH, or placement into calculus based on your admissions data and/or CU Boulder coursework. Students with credit in APPM 1350 may not receive credit for MATH 1080, 1081, 1090, 1100, 1300, 1310, or ECON 1088 or APPM 1345. Approved for arts and sciences core curriculum: quantitative reasoning and mathematical skills.

APPM 1351 Calculus 1 Work Group
Provides problem-solving assistance to students enrolled in APPM 1350. Student groups work in collaborative learning environment. Student participation is essential. Semester offered: Fall and Spring

APPM 1360 Calculus 2 for Engineers
Continuation of APPM 1350. Focuses on applications of the definite integral, methods of integration, improper integrals, Taylor's theorem, and infinite series. Students may not receive credit for both APPM 1360 and MATH 2300. Prereq., APPM 1350 or APPM 1345 or MATH 1300.

APPM 1361 Calculus 2 Work Group
Provides problem solving assistance for students enrolled in APPM 1360. Conducted in a collaborative learning environment. Student work groups solve calculus problems with assistance of facilitator. Semester offered: Fall and Spring

APPM 1390 A Game for Calculus
1 credit course coaches students to implement study strategies geared specifically toward APPM Calculus in a structured, supportive, small group environment. APPM department consent required.
Repeatable: Repeatable for up to 3.00 total credit hours.

APPM 1650 Python for Mathematical and Statistical Applications
Uses Python to teach the fundamentals of computer programming with an emphasis on mathematical and statistical applications. Topics will include data types, data structures, iteration, visualization, and simulations. Techniques covered will be applicable to many scientific and technical fields. No prior programming experience is required.

APPM 2350 Calculus 3 for Engineers
Covers multivariable calculus, vector analysis, and theorems of Gauss, Green, and Stokes. Students may not receive credit for APPM 2350 and MATH 2400. Prereq., APPM 1360 or MATH 2300.

APPM 2351 Calculus 3 Work Group
Provides problem solving assistance to students enrolled in APPM 2350. Conducted in a collaborative learning environment. Student work groups solve calculus problems with the assistance of a facilitator. Semester offered: Fall and Spring

APPM 2360 Introduction to Differential Equations with Linear Algebra
Introduces ordinary differential equations, systems of linear equations, matrices, determinants, vector spaces, linear transformations, and systems of linear differential equations. No credit is awarded to students already having credit in both MATH 2130 and MATH 3430, both APPM 3310 and MATH 3430.
Prereq., APPM 1360 or MATH 2300.

APPM 2361 Differential Equations Work Group
Approval pending - Provides problem solving assistance to students enrolled in APPM 2360. Conducted in a collaborative learning environment. Student work groups solve differential equations and linear algebra problems with the assistance of a facilitator. Semester offered: Fall and Spring

APPM 2460 Differential Equations: Computer Lab
Selected topics include differential equations and linear algebra, with a focus on symbolic computation using Matlab. Coreq., APPM 2360. Grading basis: Satisfactory/Unsatisfactory

APPM 2720 Open Topics in Lower Division Applied Mathematics
This course provides a vehicle for the development and presentation of new topics that are accessible to lower division Applied Mathematics students. These topics have the potential to be incorporated into the core APPM curriculum. Prereqs., Calc 1. Semester offered: Varies

APPM 3010 Chaos in Dynamical Systems
Introduces undergraduate students to chaotic dynamical systems. Topics include smooth and discrete dynamical systems, bifurcation theory, chaotic attractors, fractals, Lyapunov exponents, synchronization and networks of dynamical systems. Applications to engineering, biology and physics will be discussed. Department enforced requisite, knowledge of a programming language.
Prerequisites: APPM 2360 or MATH 3430. Semester offered: Fall.

APPM 3050 Scientific Computing in Matlab
Topics covered include: approximations in computing, computer arithmetic, interpolation, matrix computations, nonlinear equations, optimization, and initial-value problems with emphasis on the computational cost, efficiency, accuracy of algorithms. The problem sets are application-oriented with examples taken from orbital mechanics, physics, genetics and fluid dynamics.
Prerequisites: APPM 2360 or MATH 3430. Semester offered: Spring.

APPM 3170 Discrete Applied Mathematics
Introduces students to ideas and techniques from discrete mathematics that are widely used in science and engineering. Mathematical definitions and proofs are emphasized. Topics include formal logic notation, proof methods; set theory, relations; induction, well-ordering; algorithms, growth of functions and complexity; integer congruencies; basic and advanced counting techniques, recurrences and elementary graph theory. Other selected topics may also be covered.
Prerequisites: APPM 1360 or MATH 2300. Semester offered: Fall and Spring

APPM 3310 Matrix Methods and Applications
Introduces linear algebra and matrices, with an emphasis on applications, including methods to solve systems of linear algebraic and linear ordinary differential equations. Discusses computational algorithms that implement these methods. Some applications in operations research may be included as time permits. Prereq., APPM 2350 or MATH 2400 or APPM 2360. Semester offered: Fall and Spring.

APPM 3350 Advanced Engineering Calculus
Extends the treatment of engineering mathematics beyond the topics covered in Calculus 3 and differential equations. Topics include non-dimensionalization, elementary asymptotics and perturbation theory, Reynold's transport theorem and extensions of Leibnitz's rule, as applied to continuum conservation equations. Hamiltonian formulations, Legendre and Laplace transforms, special functions and their orthogonality properties. Prereq., (APPM 2350 or MATH 2400) and APPM 2360. Semester offered: usually in Fall.

APPM 3570 Applied Probability
Studies axioms, counting formulas, conditional probability, independence, random variables, continuous and discrete distribution, expectation, moment generating functions, law of large numbers, central limit theorem, Poisson process, and multivariate Gaussian distribution. Coreq., APPM 2350 or MATH 2400. Students may not receive credit for both APPM 3570 and either ECEN 3810 or MATH 4510. Same as STAT 3100. Semester offered: Spring and Fall.

APPM 3650 Algorithms and Data Structures in Python
Covers data structures (stacks, queues, linked lists, hash tables, heaps), algorithms (divide and conquer, sorting, greedy, graph, dynamic programming), and asymptotic complexity with an emphasis on applied math topics. Assignments will include programming projects written in Python. Semester offered: Spring

APPM 4120 Introduction to Operations Research
Studies linear and nonlinear programming, the simplex method, duality, sensitivity, transportation and network flow problems, some constrained and unconstrained optimization theory and the Kuhn-Tucker conditions as time permits. Prereqs., APPM 3310. Same as APPM 5120 and MATH 4120/5120. Semester offered: Spring.

APPM 4320 Introduction to Dynamics on Networks
Introduces modern approaches to model and analyze dynamical processes on complex networks. Many dynamical processes such as epidemic propagation, opinion formation, synchronization, and cascading processes take place on complex social or technological networks. This course will introduce the tools to understand the interplay between network structure and the outcome of these dynamical processes. Previously offered as a special topics course. Same as APPM 5320.

APPM 4350 Methods in Applied Mathematics: Fourier Series and Boundary Value Problems
Reviews ordinary differential equations, including solutions by Fourier series. Physical derivation of the classical linear partial differential equations (heat, wave, and Laplace equations). Solution of these equations via separation of variables, with Fourier series, Fourier integrals, and more general eigenfunction expansions. Prereqs., (APPM 2350 or MATH 2400) and APPM 2360. Coreq., APPM 3310. Same as APPM 5350. Semester offered: Fall.

APPM 4360 Methods in Applied Mathematics: Complex Variables and Applications
Introduces methods of complex variables, contour integration and theory of residues. Applies solving partial differential equations by transform methods, Fourier and Laplace transforms, Riemann-Hilbert boundary-value problems. Also applies conformal mapping to ideal fluid flow and/or electrostatics. Prereqs., (APPM 2350 or MATH 2400) and APPM 2360. Coreq., APPM 3310 or MATH 3130. Same as APPM 5360. Semester offered: Spring.

APPM 4370 Computational Neuroscience
Applies mathematical and computational methods to neuroscience. Techniques from linear algebra, differential equations, introductory dynamical systems, probability, stochastic processes, model validation, and machine learning will be learned and used. Neuroscience topics include neural spiking, network dynamics, probabilistic inference, learning, and plasticity. Will learn how the brain uses computational principles to enact decision making, vision, and memory. Recommended background includes linear algebra, differential equations, probability, and programming. Students will hone programming skills in MATLAB/Python and TensorFlow. Recommended prerequisite: APPM 3570/STAT 3100, STAT 2600 or CSCI 3022. Same as APPM 5370. Semester offered: varies

APPM 4380 Modeling in Applied Mathematics
An exposition of a variety of mathematical models arising in the physical and biological sciences. Students' modeling projects are presented in class. Topics can vary: GPS navigation, medical imaging, ocean waves, computerized facial recognition. Prereqs., APPM 2350 or MATH 2400 and 2360. Recommended prereqs., APPM 3310, 4350, and 4650. Same as APPM 5380. Semester offered: Fall.

APPM 4390 Modeling in Mathematical Biology
Investigates how complex systems in biology can be studied using applied mathematics. Examines several case studies which include topics from microbiology, enzyme reaction kinetics, neuroscience, ecology, epidemiology, physiology, and bioengineering. Coreq., APPM 2360 and (APPM 3310). Same as APPM 5390. Semester offered: Spring.

APPM 4440 Undergraduate Applied Analysis 1
Provides a rigorous treatment of topics covered in Calculus 1 and 2. Topics include convergent sequences, continuous functions, differentiable functions, Darboux sums, Reimann sums, and integration, Taylor and power series and sequences of functions. Prereq., (APPM 2350 or MATH 2400) and APPM 2360. Prereq or coreq., APPM 3310. Semester offered: Fall

APPM 4450 Undergraduate Applied Analysis 2
Continuation of APPM 4440. Study of multidimensional analysis including n-dimensional Euclidean space, continuity and uniform continuity of functions of several variables, differentiation, linear and nonlinear approximation, inverse function and implicit function theorems, and a short introduction to metric spaces. Prereq. APPM 4440 or MATH 3001. Semester offered: Spring

APPM 4490 Theory of Machine Learning
Presents the underlying theory behind machine learning in proofs-based format. Answers fundamental questions about what learning means and what can be learned via formal models of statistical learning theory. Analyzes some important classes of machine learning methods. Specific topics may include the PAC framework, VC-dimension and Rademacher complexity. Recommended prerequisite: CSCI 5622 (minimum grade C-). Semester offered: Varies

APPM 4510 Data Assimilation in High Dimensional Dynamical Systems
Develops and analyzes approximate methods of solving the Bayesian inverse problem for high-dimensional dynamical systems. After briefly reviewing mathematical foundations in probability and statistics, the course covers the Kalman filter, particle filters, variational methods and ensemble Kalman filters. The emphasis is on mathematical formulation and analysis of methods. Prereqs., APPM 3310 and APPM 3570. Same as APPM 5510. Semester offered: Typically fall of odd years

APPM 4515 High-Dimensional Probability for Data Science
Provides students with an exposition of the most recent methods of high-dimensional probability for the analysis of high dimensional datasets. Applications include randomized algorithms and high-dimensional random models of datasets. Same as APPM 5515. Semester offered: varies

APPM 4530 Stochastic Analysis for Finance
Studies mathematical theories and techniques for modeling financial markets. Specific topics include the binomial model, risk neutral pricing, stochastic calculus, connection to partial differential equations and stochastic control theory. Prereqs., APPM 3310 and APPM 3570. Prereq or Coreq of APPM 4350. Same as APPM 5530. Semester offered: Fall

APPM 4560 Markov Processes, Queues, and Monte Carlo Simulations
Brief review of conditional probability and expectation followed by a study of Markov chains, both discrete and continuous time. Queuing theory, terminology, and single queue systems are studied with some introduction to networks of queues. Uses Monte Carlo simulation of random variables throughout the semester to gain insight into the processes under study. Prereq., APPM 3570 or MATH 4510. Same as APPM 5560. Semester offered: Spring.

APPM 4565 Random Graphs
Introduces mathematical techniques, including generating functions, the first- and second-moment method and Chernoff bounds to study the most fundamental properties of the Erdos-Renyl model and other celebrated random graph models such as preferential attachment, fixed degree distribution, and stochastic block models. Same as APPM 5565. Semester offered: varies

APPM 4600 Numerical Methods and Scientific Computing
Provides an introduction to numerical analysis and scientific computing. Numerical analysis topics include root finding, interpolation, quadrature, linear system solution techniques, and techniques for approximating eigenvalues. Scientific computing topics include code development and repository management in addition to an introduction to shared and distributed memory computing. Involves hands-on learning with weekly group interactions and a final project including a report and in-class presentation. Recommended prerequisite: knowledge of a programming language such as Python, and C++. Semester offered: Fall, Spring, and (occasionally) Summer

APPM 4610 Numerical Differential Equations
Continuation of 4600. Provides an introduction to the most commonly used techniques for numerically solving boundary value problems and time dependent problems and the corresponding linear systems. Topics include finite difference methods, the finite element method, the spectral method, spectral collocation methods, Euler and Runge-Kutta methods. Scientific computing skills such as advanced code and memory management will be developed. Involves hands-on learning with weekly group interactions and a final project. Prereq., APPM 2360 and APPM 4600, both with C- grades or higher. Semester offered: Spring

APPM 4720 Open Topics in Applied Mathematics
Provides a vehicle for the development and presentation of new topics that may be incorporated into the core courses in applied mathematics. Prereqs., variable, depending on topic -- see instructor. Same as APPM 5720. Semester offered: Varies.

APPM 4840 Reading and Research in Applied Mathematics
Introduces undergraduate students to the research foci of the Department of Applied Mathematics. May be repeated up to 9 total credit hours. Semester offered: Fall, Spring and Summer.

APPM 4950 Seminar in Applied Mathematics
Introduces undergraduate students to the research foci of the Department of Applied Mathematics. It is also designed to be a capstone experience for the program's majors. Semester offered: Fall and Spring.