Course-based Undergraduate Research Experiences: Advancing CU Boulder's Strategic Goals

THE RATIONALE

As a member of the Association of American Universities and the flagship research university of the State of Colorado, the University of Colorado (CU) Boulder is considered a benchmarking institution in Colorado and beyond. To improve and maintain its reputation for excellence, CU Boulder has set several broad goals in its Strategic Plan, including:

INCLUSION

- Serve as a nexus for innovation by facilitating collaboration and sharing of diverse perspectives,
- Build a campus characterized by diversity in all forms, giving us the opportunity to learn from our many perspectives, cultures, and backgrounds.

DISCOVERY

- Broaden and expand research, scholarship, and creative work such that half of all CU undergraduates participate in research-based activities.

RETENTION

- Recruit, matriculate, and retain students who embody the values of CU Boulder and help them develop critical thinking and creative problem solving skills,
- Achieve an eighty percent six-year graduation rate by the year 2020, which will require boosting the first-year retention rate to over ninety percent.

We, a diverse group of instructors, professors, and staff from across the university, have come together to assert that CU can continue to be a national model of STEM education supporting retention, inclusion, and discovery goals. As highlighted by Chancellor DiStefano during his state of campus speech in October 2017:

> *"We continue to have one of the highest participation rates of undergraduates conducting research and creative work, exceeding 2,000 students every year. And we are not stopping there. We feel that exposure of undergraduates to research is fundamental to our mission. Our long-term goal is to have half of our undergraduates involved in research."*

To achieve these goals, CU Boulder must continue to innovate and incorporate pedagogical strategies which have been demonstrated to achieve these goals. Each of these aims requires academic settings that foster productive student-faculty relationships and focus on innovation and research, particularly in STEM fields. Current training paradigms for students in STEM focus on apprentice-based training (i.e., a student working in a lab setting, mentored by a faculty member) as an effective means of promoting independent thinking and retention in science. Students who participate in apprentice-based research activities experience increased graduation rates and persistence in STEM careers, develop scientific identities, invest in science as a life-long learning process, and show a greater understanding of the research process relative to students who do not receive such opportunities (Lopatto, 2004; Lopatto, 2010; Seymour *et al.,* 2004; Laursen *et al.,* 2010).

However, it is not possible to scale traditional one-on-one research mentorships to serve all students. A solution to this problem is to formalize research experiences *within departmental course curricula*. **Course-based Undergraduate Research Experiences (CUREs)**, an innovative pedagogical approach, can efficiently help CU offer research opportunities to many more students. CUREs involve whole classes of students in addressing a research question that is of interest to a scientific or local community and have been shown to result in the same positive outcomes that students experience as a result of apprentice-based research (Lopatto, 2010; Corwin *et al.,* 2015a; Rodenbusch *et al.,* 2016). CUREs also increase institutions' capacity to involve *more* students in research and are accessible to students who are not afforded access to other research opportunities (Wei & Woodin, 2011; Auchincloss *et al.,* 2014). Thus, CUREs address national goals of involving more students in the *practice* of science, and specifically in research, and thus attracting and graduating more STEM majors (AAAS, 2011; NRC 2003; NRC 2013, PCAST 2012). These national goals align with CU Boulder's strategic plan.

We advocate for increased support for such course-based undergraduate research experiences (CUREs) across the CU Boulder campus.

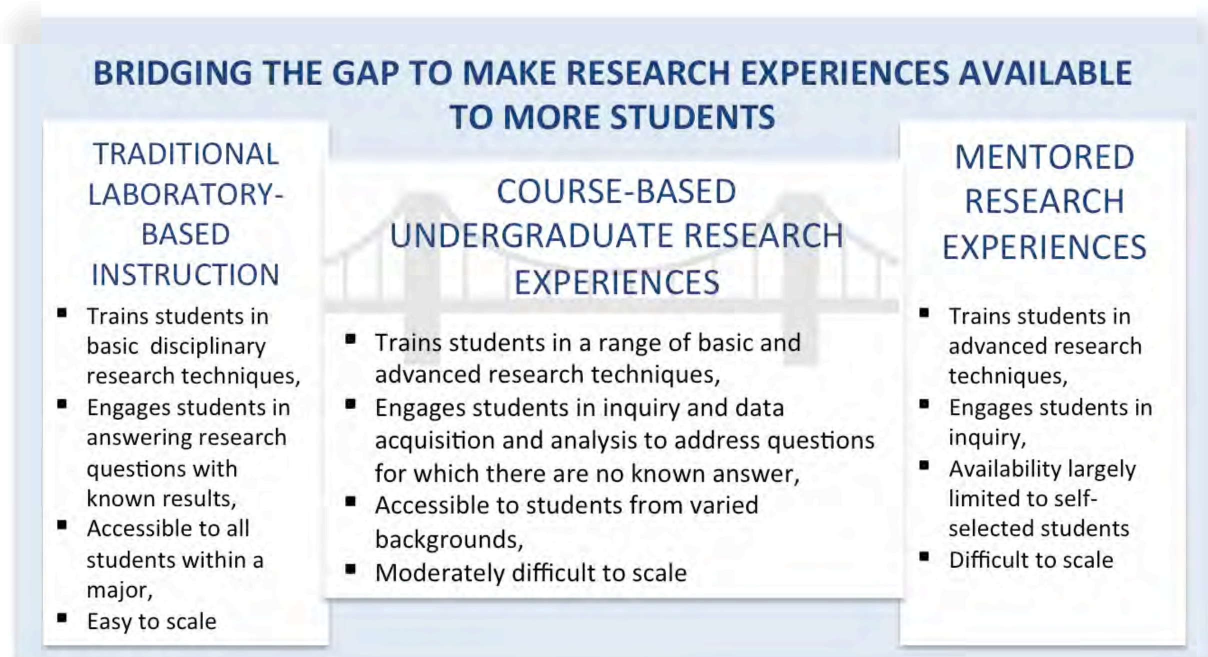
What is a CURE?

There is a broad range of successful models for CUREs. In general, CURE courses aim to:

- Study scientific problems with **RELEVANCE** to a community outside of the classroom,
- **DISCOVER** answers to scientific problems,
- **UTILIZE** established scientific practices: asking questions, building hypotheses, designing and executing experiments, iterating and troubleshooting, and communicating results,
- **COLLABORATE** within the course and with the scientific community, and
- **CRITICALLY EVALUATE** previously published work and data generated in the course.

CUREs can be implemented in **any discipline with an unknown question that requires study** to answer.

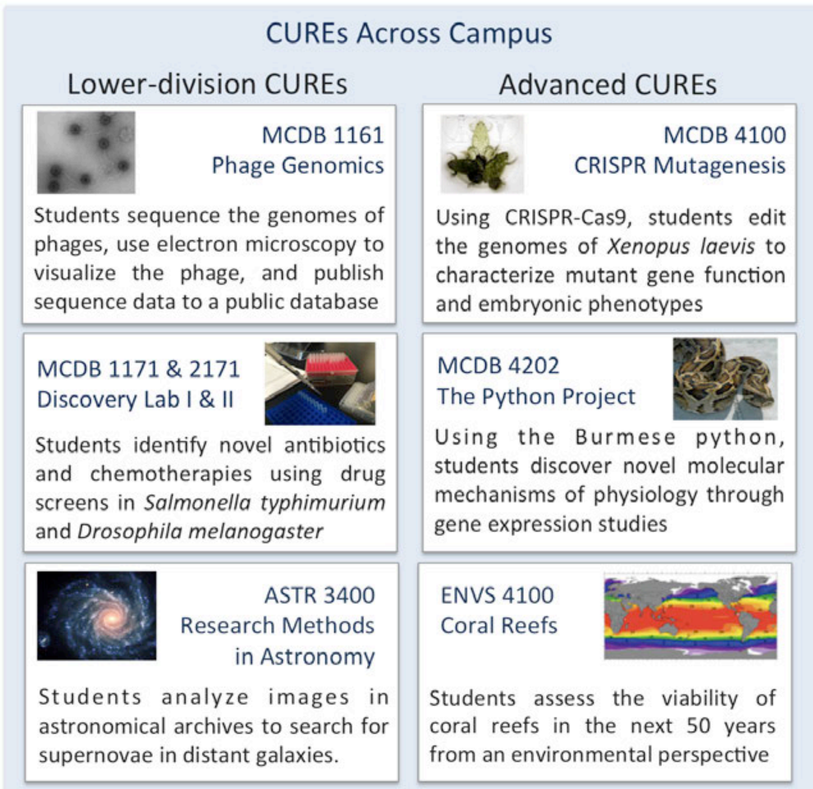
CUREs: AN EVIDENCE-BASED APPROACH TO ADVANCE CU'S STRATEGIC IMPERATIVES



Achieving the goals of CU's strategic plan requires expansion of research opportunities for students. Using current one-on-one research apprenticeship models, advisors in the Department of Molecular, Cellular, and Developmental Biology (MCDB) have reported that fewer than 20% of majors are receiving research training. CUREs in each STEM department at CU can increase this percentage up to four-fold. Unlike traditional labs offered in many CU courses (left panel), CUREs (middle panel) involve students in authentic research by engaging students in inquiries where neither the students nor the instructor know the answer and providing opportunities for genuine discovery and contribution to the scientific community. However, like traditional labs CUREs can be integrated into students' curricula. Thus, CUREs are a bridge that allows the benefits of research to be achieved in classroom environments, supporting CU Boulder's **STRATEGIC IMPERATIVES**.

Specifically, scaling-up of existing CUREs and creation of new CUREs have the potential to make research opportunities available to students who do not typically access research, including those with lower GPAs and students from backgrounds historically underserved in STEM (Bangera & Brownell, 2014) **(INCLUSION).** Through participation in CUREs at CU, more students will experience novel research in a supportive setting, and the innovative potential of CU Boulder will increase **(DISCOVERY)**. By involving more hands and minds in research, CUREs have potential to tap diverse perspectives to solve problems and innovate in new directions **(DISCOVERY and INCLUSION)**. Finally, based on outcomes at other large universities, incorporation of CUREs can help achieve the goal of an eighty percent graduation rate at CU (Rodenbusch *et al.,* 2016) **(RETENTION).** At the same time, CUREs help students develop problem-solving skills, creativity, and innovation, hallmarks of CU Boulder's values.

BUILDING UPON SUCCESS AT CU BOULDER.

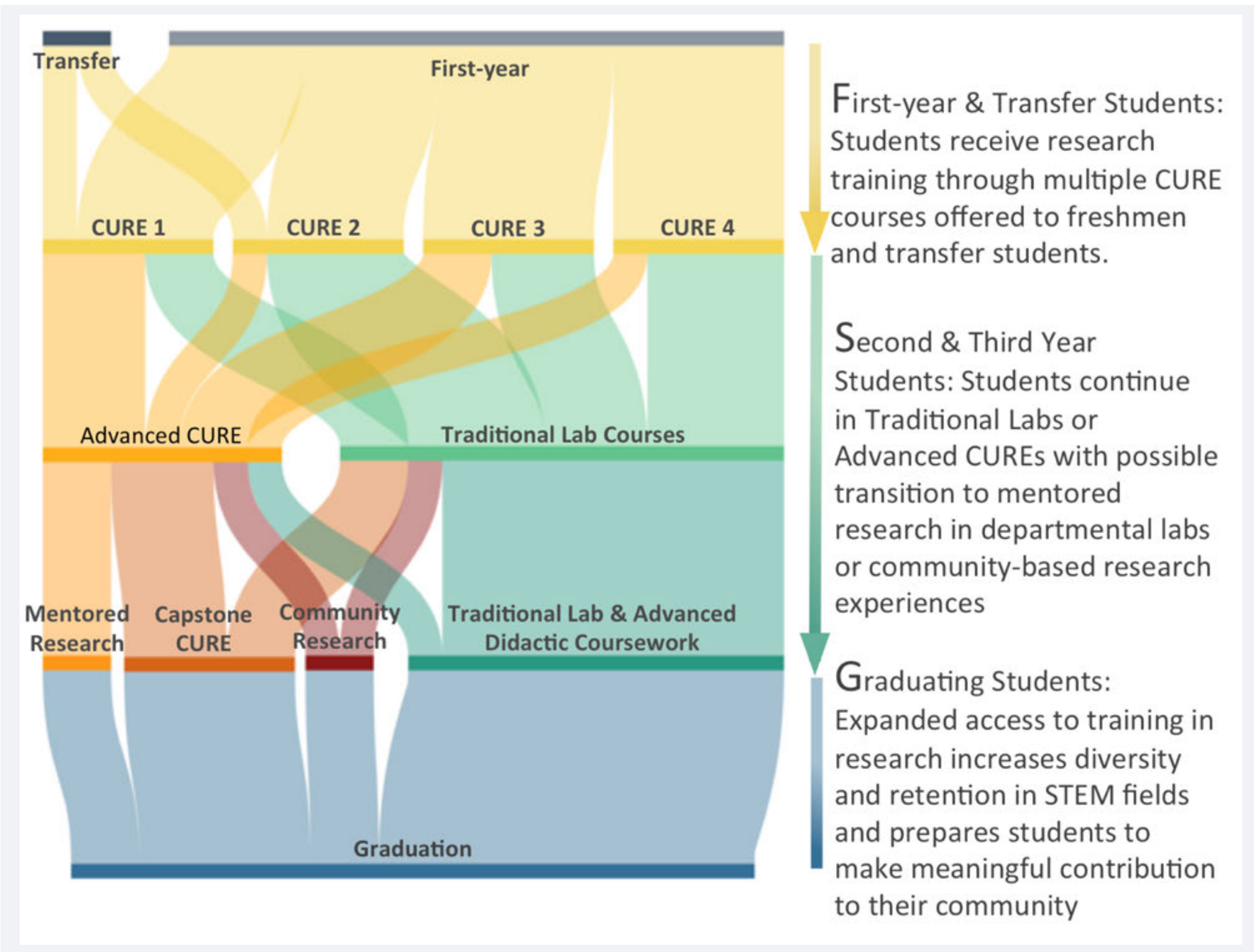


Current CU Boulder courses provide evidence that, when sufficiently supported, CUREs can be broadly implemented in STEM departments at CU Boulder. For example, the Department of Molecular, Cellular, and Developmental Biology (MCDB) has committed to offering research experiences to all undergraduates in the major (Supplementary Materials). This has been made possible not only by the dedication of MCDB faculty and personnel, but also by catalytic efforts and funding of external sources (e.g., HHMI in collaboration with CUB's Biological Sciences Initiative). University funding from the Dean's Office of the College of Arts and Sciences and the Provost's Office has also provided additional instructional support and renovation of space. Over the past three years, two courses (MCDB 1171 and MCDB 2171) were created to complement a lower-division CURE (MCDB 1161) already offered in the department. Students who declare MCDB as their major upon admission to CU are now required to take one of these courses as part of the curriculum. Students completing the course are able to enter departmental laboratories, albeit with a small number of opportunities that allow fewer than 40 students to pursue apprentice-based research training. Two upper division CUREs are also offered (MCDB 4100 and MCDB 4202) for upper division students who remain interested in obtaining more research experience. This innovative example illustrates that scaling of CUREs is feasible for large departments at CU Boulder and provides a model upon which other departments may build.

New CUREs are also being developed in diverse departments. Recently in Fall 2018, faculty in Astronomy and Environmental Studies worked to create new CURE courses (ASTR 3400 and ENVS 4100), and the development and refinement of other CUREs is occurring across campus (Supplementary Materials). This demonstrates the interest in incorporating CUREs across campus and further illustrates the potential of CUREs at CU Boulder.

OUR PROPOSAL: A Vision for CUREs at CU BOULDER

CUREs offer a way to scale high-quality learning experiences that target outcomes critical to advancing CU Boulder's Strategic Plan and are efficacious across disciplines. Thus, we propose a broad vision for CURE implementation at CU Boulder designed to serve multiple departments while accomplishing CU Boulder's broad goals. In our vision, students progress through their undergraduate career (downward through the diagram) with multiple options and opportunities to engage in research via CUREs or other opportunities (solid bars) throughout their tenure at CU Boulder.



Our vision has seven core elements:

1. **Early introduction to research for *all* STEM students.** In accordance with best practices for retention in STEM, CU students would benefit from entering into a CURE early in their undergraduate career, within the first three semesters or upon transfer to CU Boulder. Early exposure to research would:

- Allow students who might not otherwise pursue research to explore research, develop interest and potentially continue in STEM, diversifying the pool of CU Boulder students pursuing STEM education,
- Provide the opportunity to evaluate their interest in research and either continue or develop alternative plans for their education,
- Provide opportunities for greater involvement in the university through teaching, research, or local-community related endeavors.

By offering early participation for and removing barriers to research opportunities, entry-level CUREs will help CU students to enter upper-division courses with greater direction and more opportunities.

2. **Multiple advanced opportunities for research.** After the entry-level CURE experience, students will be better able to evaluate their interests and post-graduation goals. By providing several types of advanced opportunities, CU would ensure students strategically work towards their goals. Such opportunities could involve becoming a learning assistant for the CURE they recently completed, entering a research lab, enrolling in an upper-division CURE, or pursuing an internship with local partners outside of the university. Participation in these more advanced opportunities could provide access to future partnerships with industry and the local community.

3. **A central location for students to explore and access next steps after completing entry-level CUREs.** We propose that students completing entry-level CUREs interact with a central support system of advisors and resources created to help them evaluate their interests and strategically access opportunities that align with their post-graduation goals. A central location for this support could be housed in advising offices or a center for undergraduate research and would be a place where students could work with trained staff to find, explore, and access a myriad of opportunities outlined above (see #2). This location would also provide a community resource for individuals, agencies, or companies seeking research support (see #5).

4. **Enhanced participation in research through teaching.** Undergraduates who have participated in CUREs would be given the opportunity to continue their involvement in the courses through paid and credit-based teaching assistantships in which they assist faculty with instruction of the next generation of CURE students while also receiving pedagogical training and experience. Programs like the Colorado Learning Assistant (LA) Program at CU Boulder and MCDB 3010, offered in conjunction with the CUREs in MCDB, are popular options for undergraduate students. These programs attract more than 100 students annually and could be scaled or modeled within departments. Scaling the number of available CUREs could also provide increased opportunities to train graduate students and postdocs in innovative pedagogies through a combination of

CURE involvement as TAs or instructors and formal teaching training. This training would provide a valuable experience for the next generation of educators and researchers, helping them build a competitive teaching portfolio and improve broader impacts for those interested in outreach.

5. **Horizontal integration of CURE efforts with the Colorado community and industry partners.** Involvement of interested Colorado citizens or industry partners has potential for mutual benefit to CU Boulder and the local community. Projects relevant to local interests can increase students' investment in their research (Demarest 2014), while local partners may be able to gather data to inform their interests and endeavors. Students, CURE instructors, and local partners may also form lasting relationships that lead to increased student employment after graduation, more targeted workforce training at CU, and mutually beneficial and appreciative relationships with CU Boulder and the surrounding community. Such horizontal integration would increase the strength of ties between Boulder and the university and result in greater local support and CURE sustainability.

Off-campus Partnerships

Through CUREs, students can partner with community and industry partners for locally-relevant and targeted research experiences. For instance, an upper-division course in EBIO partners with professional ecologists at Boulder Open Space to research issues related to restoration in the community. Students learn workforce skills, feel engaged by work that has immediate application, and build a network that can lead to employment after graduation.

6. **Capstone CUREs for greater access to post-graduate opportunities.** Many post-graduate programs require or strongly encourage students to participate in research prior to acceptance. We envision university support to departments for the creation of capstone courses that reflect specific requirements of competitive graduate training programs (e.g., medical, architecture, or engineering) and in-demand jobs. Offering capstone CUREs also has the benefit of allowing greater flexibility in CURE topics, thus encouraging professors to engage in undergraduate education that aligns with their research interests.

7. **Continual formative evaluation of CURE efficacy in achieving CU Boulder's goals.** The hallmark of true innovation and advancement is that it never ceases. We envision a program with built-in formative evaluation that continually examines whether the goals of retention (e.g., longitudinal examination of graduation rates), job placement, and satisfaction are met for *all* students, including those historically

underserved by traditional models of education. Thus, we propose that this program be evaluated and improved regularly to meet its stated goals.

CUREs AT CU BOULDER - A NATIONAL MODEL OF STEM EDUCATION

Our team, drawing members from two colleges, eight departments, and multiple roles within the university (instructors, assistant, associate, and full professors, and administrators), advise the *Academic Futures* leaders to consider the elements described above in their broader strategic vision and act to support instructors and department heads in accomplishing one or more of these elements over the next five years. While many existing campus structures may be leveraged to support CUREs (e.g., the Learning Assistant program), other supports and structures will need modification or redesign to accomplish these goals. Compared to other lab classes, CUREs are likely to require more effort during development, increased instructional time during implementation, and flexible space due to their innovative and discovery-orientated nature. Campus leaders can support this by allowing flexibility and experimentation with alternative instructional models, especially during CURE development, and by gathering input from multiple departments and individuals serving in diverse campus roles in steering this effort.

The vision we present serves the goals of the university to expand research opportunities to undergraduates. There already exists evidence, both from diverse units across campus (See Supplement) and from similar institutions, that our vision is tenable. By providing multiple opportunities for engagement in research through CUREs, providing opportunities for community engagement, and exposing students to diverse opportunities for professional development, CU Boulder can continue to be a leader in innovative education and achieve the goal of incorporating discovery and critical analysis into the experiences of all undergraduates.

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Acknowledgements

This work was conducted by a Transforming Education, Stimulating Teaching and Learning Excellence (TRESTLE) Scholars Group and supported by the TRESTLE Project, a 7-institution NSF-Funded project to support improvements in undergraduate STEM education (NSF-DUE 1525331).

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Supplementary Materials

Examples of CUREs offered at CU Boulder:

In EBIO 4600, students work in small team (3-4 students) to conduct a greenhouse experiment that evaluates plasticity in dispersal traits in the annual herb *Lasthenia fremontii*. The project is designed to evaluate students' progress towards several of the course learning goals, and to provide experience designing, implementing, and evaluating your own research progress. The project involves writing a proposal, conducting the experiment, managing and analyzing data, and writing up the final results. If the project is appropriately designed and carefully implemented, it will likely be incorporated into a scientific paper that will ultimately be submitted for publication. Particularly motivated students have the opportunity to be co-authors on the manuscript.

EBIO 4600/5600: Evolutionary Ecology

Course Syllabus

Week 01

Aug. 29 / Tuesday, 12:30 – 1:45 PM: Class in RAMY N183
Topic: Course overview, learning goals, and expectations
In-Class Activities: Peer interviews, scientific thinking pre-assessment

Aug. 31 / Thursday, 12:30 – 5 PM: Combined class/lab - **FIELD TRIP to the CU Mountain Research Station** (meet in KTCH 1B17)
Topic: The Nature of Science and Science of Nature
Assignments Due: Pre-assessment (D2L), Pre-class quiz on reading assignments, field trip forms (due before class)
In-Class/Lab Activity: Scientific observations and discussion

Week 02

Sept. 05 / Tuesday, 12:30 – 1:45 PM: Class in RAMY N183
Topic: Sources of variation – G, E, and G x E; proximate & ultimate drivers of variation
Assignment: Pre-class quiz on reading assignment
In-Class Activity: Group challenges - disentangling G and E

Sept. 07 / Thursday, 12:30 – 5 PM: Combined class/lab – KTCH 1B17
Topic: Developing hypotheses from observations / Introduction to dispersal ecology
Assignment Due: Team summary of seed observations (due before class)
In-Class/Lab Activity: Team presentations of observations; group challenge – generate testable (draft) hypotheses for seed variation; using Web of Science and EndnoteOnline

Week 03

Sept. 12 / Tuesday, 12:30 – 1:45 PM: Class in RAMY N183 - Guest instructor: Dr. Raffica La Rosa
Assignment Due: Two papers and associated summaries
Topic: Evaluating and refining hypotheses by reviewing the literature
In-Class Activity: Work session - team literature repositories

Sept. 14 / Thursday, 12:30 – 5 PM: Combined class/lab – KTCH 1B17, then **30th street greenhouses**
Assignment Due: Team literature repositories, literature summaries, one outstanding hypothesis
Topic: Hypotheses to predictions to experimental design
In-Class/Lab Activity: Team (10-minute) presentations of literature repositories; formulate predictions based on robust hypotheses; visit 30th street greenhouses

Week 04

Sept. 19 / Tuesday, 12:30 – 1:45 PM: Class in RAMY N183

Assignments Due: (1) Team summary of proposed greenhouse experiment
(2) Equipment list (due AFTER CLASS, by 5 pm)

Topic: Designing a manipulative experiment (**Class research project**)

In-Class Activity: Jigsaw presentations of proposed greenhouse experiments

Sept. 21 / Thursday, 12:30 – 5 PM: Combined class/lab – **30th street greenhouses**

Assignment Due: Final summary of greenhouse experimental design

Topic: Implementing a manipulative experiment (**Class research project**)

In-Class/Lab Activity: Set up greenhouse experiments!

Week 05

Sept. 26 / Tuesday, 12:30 – 1:45 PM: Class in RAMY N183

Assignment Due: Proposed data collection for observational study in Milkweed

Topic: Designing an observational study (**Milkweed project**)

In-Class Activity: Jigsaw discussions & presentations of proposed data collection in Milkweed

Sept. 28 / Thursday, 12:30 – 5 PM: Combined class/lab **FIELD TRIP (various local locations)**

Assignment Due: Write-up of Methods for greenhouse experiment set-up

Topic: Implementing an observational study I – field data collection (**Milkweed project**)

In-Class/Lab Activity: Milkweed fieldwork - data collection & seed harvest

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Week 06

Oct. 03 / Tuesday, 12:30 – 1:45 PM: Class in RAMY N183 – *Guest lecture by Matthew Oh*

Topic: Cross-cutting concepts – dispersal and cancer

In-Class Activity: Group challenge – use dispersal hypotheses to design cancer experiments

Oct. 05 / Thursday, 12:30 – 5 PM: Combined class/lab – KTCH 1B17

Assignment due: Write-up of Methods from Milkweed field lab

Topic: Implementing an observational study II – lab data collection (**Milkweed project**)

In-Class/Lab Activity: Dispersal Olympics! Lab-based analysis of Milkweed dispersal traits

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Week 07

Oct. 10 / Tuesday, 12:30 – 1:45 PM: Class in RAMY N183

Assignment Due: Pre-class quiz on statistical thinking

Topic: The statistical mindset – how to tackle a data set

In-Class Activity: Group challenge to analyze a simple data set

Oct. 12 / Thursday, 12:30 – 5 PM: Combined class/lab - KTCH 1B17

Assignment due: Visualization of predicted results

Topic: Analyzing the results of an observational study (**Milkweed project**)

In-Class/Lab Activity: Milkweed data crunching session

Week 08

Oct. 17 / Tuesday, 12:30 – 1:45 PM: Class in RAMY N183
Assignment Due: pre-class quiz on reading assignments
Topic: Measuring natural selection in the wild – fitness components & fitness functions
In-Class Activity: Case studies in fitness functions – survival, reproduction, and fitness

Oct. 19 / Thursday, 12:30 – 5 PM: Combined class/lab - KTCH 1B17
Assignment Due: Milkweed paper draft
Topic: Collecting data to quantify selection (**Gall project**)
In-Class/Lab Activity: Gall dissections & data collection

Week 09

Oct. 24 / Tuesday, 12:30 – 1:45 PM: Class in RAMY N183
Assignment Due: pre-class quiz on reading assignments
Topic: Measuring natural selection in the wild – direct and indirect selection
In-Class Activity: Case study: selection differentials & gradients in Bumpus' sparrows

Oct. 26 / Thursday, 12:30 – 5 PM: Combined class/lab - KTCH N1B17
Assignment Due: Peer reviews of Milkweed papers (due before class; bring hard copies to class)
Topic: Statistical approaches to measuring selection (**Gall project**)
In-Class/Lab Activity: Gall data crunching session

Week 10

Oct. 31 / Tuesday, 12:30 – 1:45 PM: Class in RAMY N183
Assignment Due: Pre-class quiz on reading assignments
Topic: Gene flow, hybridization, and conservation
In-Class Activity: Group challenge – sampling design for cattail lab

Nov. 02 / Thursday, 12:30 – 5 PM: Combined class/lab - **FIELD TRIP to CU South Campus**
Assignment Due: Final draft of Milkweed paper
Topic: Testing for hybrids using molecular tools (**Cattail project**)
In-Class/Lab Activity: Tissue & trait collection

Week 11

Nov. 07 / Tuesday, 12:30 – 1:45 PM: Class in RAMY N183
Assignment Due: Pre-class quiz on reading assignment
Topic: Crash course in molecular markers
In-Class Activity: Predicting patterns of molecular variation

Nov. 09 / Thursday, 12:30 – 5 PM: Combined class/lab - KTCH 1B17
Assignment Due: Gall paper draft
Topic: Molecular techniques for measuring gene flow and testing for hybrids (**Cattail project**)
In-Class/Lab Activity: DNA extraction from cattail leaves

Week 12

Nov. 14 / Tuesday, 12:30 – 1:45 PM: Class in RAMY N183
Assignment Due: Gall paper peer reviews
Topic: Greenhouse project check-in
In-Class Activity: Team updates on greenhouse projects / gall paper peer review discussions

Nov. 16 / Thursday, 12:30 – 5 PM: Combined class/lab - KTCH 1B17
Topic: Implementing a manipulative experiment, con'd (**Class research project**)
In-Class/Lab Activity: Dispersal Olympics part II!

Week 13 - *Thanksgiving Break - No Class or Lab*

Week 14

Nov. 28 / Tuesday, 12:30 – 1:45 PM: Class in RAMY N183
Assignment Due: Final draft of gall paper
Topic: TBD (flex)
In-Class Activity: TBD (flex)

Nov. 30 / Thursday, 12:30 – 5 PM: Combined class/lab - KTCH 1B17
Topic: Molecular analysis of hybridization (**Cattail project**)
In-Class/Lab Activity: Microsatellite data analysis

Week 15

Dec. 05 / Tuesday, 12:30 – 1:45 PM: Class in RAMY N183
Topic: TBD (flex)
In-Class Activity: TBD (flex)

Dec. 07 / Thursday, 12:30 – 5 PM: Combined class/lab - KTCH 1B17
Topic: Implementing a manipulative experiment con'd (**Class research project**)
In-Class/Lab Activity: HARVEST GREENHOUSE EXPERIMENT

Week 16

Dec. 12 / Tuesday, 12:30 – 1:45 PM: Class in RAMY N183
Assignment Due: Final draft of cattail paper
Topic: Implementing a manipulative experiment con'd (**Class research project**)
In-Class/Lab Activity: Greenhouse experiment data crunching session (con'd)

Dec. 14 / Thursday, 12:30 – 5 PM: Combined class/lab - KTCH 1B17
Topic: Implementing a manipulative experiment con'd (**Class research project**)
In-Class/Lab Activity: Greenhouse experiment data crunching session (con'd)

Monday, Dec. 18: Final papers due for class research project

Course description of ENVS 4100-003: Coral Reefs, Instructor: Atreyee Bhattacharya

In the Spring of 2017, I piloted a special topics course in Environmental Studies (ENVS 4100-003) exploring environmental aspects of global coral reefs; via this course, I expected students to assess the viability of coral reefs in the next 50 years from an environmental perspective.

ENVS 4100 Coral reefs was a research based-course, in which about 17 undergraduate students and the instructor (myself) explored the state of the union of coral reefs (and threats) from a marine environmental perspective. The outcome of the course was to produce new research (tables, figures and captions) using meta-analysis of published data to inform a follow-up report seeking an environmental classification of coral reefs, which would assist in coral reef conservation efforts. The learning goals of this seminar style course was for students use this course to learn the steps required in producing a well-researched report, a common expectation in several careers involving environmental studies. The process of producing a report usually takes three months (the length of a semester), and involves several critically reading peer-reviewed manuscripts, analyzing published data using meta-analytical techniques, figure making, lively group discussions to analyze and synthesize the information. The class progressed according to the pace set between instructor and the students.

In the course, we achieved till 'lively group discussions', which is essentially a synthesis of analyses and research findings produced in the course during the semester. At the end of the semester (Spring, 2018), based on the analysis and synthesis we conducted in class, three students took up the work of developing a full manuscript for peer-review over one year. The three students also got the research (conducted in the class) accepted as an abstract in the prestigious American geophysical Union (AGU) Fall meeting of 2017 in New Orleans (Abstract ID: 299863). The presentation date is December 11, 2017. The three students also presented the AGU poster in the ESSS poster session here on campus (Date: December 1, 2017 at SEEC auditorium).

Based on the feedback that the students receive at the two conferences, they will draft the manuscript during Spring 2018 (the manuscript outline is already in place). We expect to submit the manuscript to the Journal Anthropocene in the late spring of 2018 (the students have committed to conduct follow up work through the year 2018 to address review comments). It is important to note that following this class, all three students are working to continue their research education into graduate school (two students are interested in PhD programs and one student is interested in a Master's program).

MCDB 1161 - Phage Genomics Laboratory I

Course Information
Lecture: W 3:00-3:50pm, GOLD A2B70
Lab Section 011: T/R 10-11:50 MUEN E0040
Lab Section 012: T/R 12-1:50 MUEN E0040
Lab Section 013: T/R 2-3:50 MUEN E0040
Lab Section 014: T/R 10-11:50 PORT B0026
Lab Section 015: T/R 12-1:50 PORT B0026
Lab Section 016: T/R 2-3:50 PORT B0026
Open Lab: W 4-6pm, F 12-2pm

Course Description
This course integrates molecular biology topics and basic laboratory techniques while allowing students the opportunity to participate in a real scientific research project. This course provides students with laboratory experience working on a bacteriophage genomic research project. Students will study novel bacteriophage they isolate from the environment. Topics covered include phage biology, bacteria and phage culturing and amplification, DNA isolation, restriction digestion analysis, agarose gel electrophoresis, and electron microscopy.

Instructors

	Office	Phone	Email
Dr. Christy Fillman	Porter B142A	303-492-8559	Christy.Fillman@Colorado.edu
Dr. Nancy Guild	Porter B113A	303-492-5054	Nancy.Guild@Colorado.edu

Lab Coordinator

Megan Greening	GOLD A1B52	303-492-1618	Megan.Greening@Colorado.edu

Instructor Office Hours
Dr. Fillman: Tuesday 4pm, Wednesday 11am
Dr. Guild: Tuesday 4pm, Wednesday 4pm

Teaching Assistants
Six per semester

Lab Assistants
Six per semester

Required Text: Phage Genomics I Lab Manual, laboratory notebook with carbonless copies (at least 50 pages).

Day – Date	Topic	Reading	Due
Week 1 T – 8/29	Lab Safety and Pipetting	Pipetting Video 7-10	Introduction Activity
W – 8/30	Course Information Enrichment and Direct Isolation	5-6, 20, Appendix 1	
R – 8/31	Sterile Technique Lab Calculations	11-12	Sterile Technique Activity Phage Lab Calculations
Week 2 T – 9/5	Enrichment and Direct Isolation	33	
W – 9/6	Phage Lifecycles	Bacteriophage Video, 13-20	Problem Set 1
R – 9/7	Phage Therapy article discussion Plaque Assay Technique	Phage therapy article (D2L see media links), 35-36	Phage Therapy Discussion Phage Therapy Activity
Week 3 T – 9/12	Purification Streak Technique	37-38	Lab Notebook 1
W – 9/13	Phage Titer Assay Archiving	21, 39-40, 55	Problem Set 2
R – 9/14			Phage Lifecycles Activity
Week 4 T – 9/19	Phage Titer Technique		Lab Notebook 2
W – 9/20	Scientific Presentations Diverse Uses for Phage	Appendix 3, 41	Problem Set 3
R – 9/21	High Titer Lysate Technique		Titer Assay Activity
Week 5 T – 9/26			Lab Notebook 3
W – 9/27	Reading Scientific Literature Restriction Analysis Agarose Gel Electrophoresis	23-28, 43-46	Problem Set 4
R – 9/28	DNA Isolation Technique		Restriction Digestion Activity
Week 6 T – 10/3	Restriction Digestion Technique		Lab Notebook 4
W – 10/4	Scientific Writing Journal Article	Appendix 2, 47-48, Journal article 1 (D2L)	Problem Set 5
R – 10/5	Agarose Gel Electrophoresis Technique, Practice Gels		Journal Article Activity
Week 7 T – 10/10			Lab Notebook 5
W – 10/11	Phage Clustering PCR Phage Therapy Research	29-31, 49-50, Phage clustering article (D2L)	Problem Set 6 Materials and Methods Draft*
R – 10/12			Phage Clustering Activity
Week 8 T – 10/17			Lab Notebook 6

Day – Date	Topic	Reading	Due
W – 10/18	Lysogens and Immunity Quality Control	53, Immunity video, immunity assay example (D2L)	Problem Set 7 Results Draft*
R – 10/19			Immunity Activity
Week 9 T – 10/24	Presentations		Lab Notebook 7
W – 10/25	Lab Midterm exam		Discussion Draft* No Problem Set Due
R – 10/26	Presentations		
Week 10 T – 10/31			Lab Notebook 8
W – 11/1	Central Dogma	Central Dogma (D2L)	Problem Set 8
R – 11/2			Central Dogma Activity
Week 11 T – 11/7			Lab Notebook 9
W – 11/8	Scientific Posters, CURE Symposium Power of Genomics Genomics Research	Appendix 4	Problem Set 9 Abstract and Introduction Draft*
R – 11/9			Poster Review
Week 12 T – 11/14	Last Day for Experiments		Lab Notebook 10
W – 11/15	Sequencing Presentations		Phage Biology Paper* Hard Copy and D2L No Problem Set
R – 11/16			Archiving Report Phages db
11/20-11/24	Fall Break		
Week 13 T - 11/28	Poster Work Day		
W – 11/29	Positional and Functional Annotation	DNA Master Guide 9-10, 64-35 (D2L)	Problem Set 10 Digital Poster Draft (D2L) 1/group
R – 11/30	Peer Review		Final Poster Draft (D2L) 1/group PowerPoint file 11:59PM
Week 14 T – 12/5	Genomics Activity Day 1 Poster Presentations		Poster Voice Recording
W – 12/6	Symposium Practice Talk Comparative Genomics	DNA Master Guide 105-108 (D2L)	Problem Set 11
R – 12/7	Genomics Activity Day 2 Poster Presentations		Genomics Activity
Week 15 M – 12/11	CURE Symposium 5:30-9:00PM UMC Ballroom		

Date	**Topic**	Reading	Due
T – 12/13	Final Presentations		
W – 12/14	Power of Genomics: The Human Genome Project, Microbiomes, and the Future of Genomics		Problem Set 12
R – 12/15	Final Presentations Surveys, Lab Clean-up		
T – 12/19	Final Exam (Gold A2B70) 7:30-10:00 PM		

*Assignments noted with a star are due at the beginning of class. Problem Sets are due by 11:59pm on D2L Wednesdays. All other assignments are due at the end of class.

Course Grading
Your grade will be calculated out of 506 points as shown in the chart below

Clicker Points and Lecture Participation	25
Problem Sets	70
Lab Notebook	50
Lab Activities	111
Writing Drafts	15
Phage Biology Lab Paper	50
Presentations	25
CURE Symposium 10 Voice recording + in class presentation 20 Poster 20 Symposium Attendance (10 photo, 10 eval)	50
Archiving Report	20
Mid-term assessment	25
Final Exam	40
Participation	25
Total Maximum Extra Credit (6pts)	506

Clicker Points and Lecture Participation

Clicker points will be recorded using iClicker response pads. Points will be awarded for participating regardless of whether the answer is correct. To earn the maximum of 15 points for clicker participation you must answer 80% of the available clicker questions over the semester. Clicker points are only recorded electronically; you cannot get clicker points for writing down answers during a class if you forget your clicker or if your clicker is not working. Ten lecture participation points will be for in-class activities and for your group responding when called on during class.

Problem Sets

Problems based on the reading and lecture material will be due weekly on Wednesdays at 11:59pm (see syllabus). Each problem set is worth 7 points, and your 10 best problem set scores count towards your grade (2 problem sets are dropped).

Lab Activities

Most lab activities are to be completed in class and turned in at the end of that lab period (see the syllabus). Lab activities can be completed as a group, but each group member must participate and must write their own answer in their own words. Copying activity answers from another student is a violation of the Honor Code. Lab activities are in the activities section of your lab manual.

Phage Biology Paper

Each student will write a lab report about the discovery and characterization of their phage. Drafts of each section of the paper will be assigned, so you can get feedback on your writing before you turn in your final report. You must turn in two copies of your final paper: a digital copy must be uploaded to the dropbox on D2L, and a hard copy must be turned in to the instructor. The drafts of the paper must be turned in with the final copy (for points). For more information about writing scientific papers, see appendix 2 of your lab manual.

Participation and improvement

Participation is an important part of the learning experience in this course. How far your project will go depends on how much work you are willing to put into it. You will not be graded based on how many "successful" experiments you complete but rather by your effort and your ability to critically trouble shoot your experiments and make the appropriate changes when you repeat the experiment. You will work with a lab partner for the experiments in this class. Both partners are expected to participate in all aspects of the experiment. If you find it necessary to repeat a procedure, you should discuss your revised procedure with an instructor first.

Participation points may be earned by: following lab etiquette, being helpful in the lab, sharing equipment, etc. Participation points may be lost by: being late to class, not helping your lab partner, not cleaning up after yourself, not following directions or safety protocols, leaving class early when there is still work to be done, or not following other lab etiquette procedures.

Late Work Policy

All lab assignments that are due at the beginning of class must be turned in before class starts. Late work that is turned in the same day it was due will be marked down 10%. You will lose an additional 10% for each additional day the assignment is late. Work that is more than one week late will not be accepted. If you have an excused and documented absence, your work is due at the next lab period or at an earlier date as determined by your instructor. Please note that turning in your work late is much better than not turning it in at all (a 10% deduction is minor in comparison to a 0 grade).

Attendance Policy

A large portion of this course requires your attendance. Every student is allowed to make up one unexcused absence. Every further unexcused and/or undocumented absence results in a 10 point deduction from your final grade and lost points for all late assignments that were due that day. Excused absences require documentation (*i.e.,* a note from a doctor for illness related absences). Excused absences can be made up by attending open lab time on Friday. No more than 6 excused absences are allowed. If you miss more than 6 class, please speak with an instructor about your options for withdrawing from the course.

Open Lab Policy

Open lab times are optional times that you can work in the lab on your experiments or lab activities. Open labs will be held on Wednesdays and Fridays check the syllabus for times. LAs will be available during open lab time to assist you and answer questions. Instructors have office hours at the times noted on the front page of the syllabus. Office hours and open lab time are also a great time to ask questions about activities and problem sets and to get help with your writing.

Spring 2016
Porter B0046

MCDB 2171

Drug Discovery Through Hands-on Screens II

Pamela Harvey, PhD
E-Mail: pamela.harvey@colorado.edu
Phone: 617-501-4175 (emergencies)
Lab: 303-492-7191
Office Hours: by appointment

Overview

Students will work in pairs as some of the activities such as pouring food and adding drugs are best done with two sets of hands. Based on prior experience, we expect each pair of students to screen through and analyze data from approximately 100 compounds per batch. Screening through each batch, from embryo collection to data analysis, will take about two weeks (collect embryos on day 0, irradiate larvae on day 5, count survival on day 15). Done on a rolling basis, each pair of students is expected to screen four batches of compounds from weeks 1-12, for a total of 400 molecules.

Course Objectives

The overriding goal of MCDB 2171 is for students to become familiar with a number of biology concepts and techniques including model systems, genetics, approaches to screening for new therapeutics, statistical analyses, and compound validation. Unlike laboratory exercises that are designed to reinforce concepts that may accompany lecture topics, there is no certainty that any one particular project will succeed, which mirrors the inherent risks of novel research. The goal-oriented nature of this research effort means that validation of findings will also need to be performed.

1. Understand how your data contributes to the research being performed in the Su lab and also in drug discovery in general,
2. Obtain experience in Drosophila maintenance and husbandry,
3. Participate in drug screen experiments to identify compounds with potential therapeutic value,
4. Statistically evaluate experimental data,
5. Successfully present your data to a panel during the final exam period,
6. Understand and be able to describe previous research on your compound(s).

Co-requisite

MCDB 2150 – Principles of Genetics

Evaluation

	Weight
Lab participation	10%
Quizzes & worksheets	35%
Lab notebook	15%
Final report	20%
Oral presentation	20%

Materials:

1. Fly Pushing: The Theory and Practice of Drosophila Genetics, by Ralph J Greenspan. Cold Spring Harbor Laboratory Press.

2. The Development of Drosophila melanogaster, by Michael Bates. Cold Spring Harbor Laboratory Press.

3. Radiobiology for the Radiologist, by Eric Hall and Amato Giaccia. Lippincott, Williams and Wilkins Publishers.

(specific chapters will be assigned as required reading and the books will be available as reference)

1. M. Gladstone & T. T. Su. Screening radiation sensitizers of Drosophila checkpoint mutants. Methods Mol Biol 2011;782:105-17.

2. M. Gladstone & T. T. Su. Chemical genetics and drug screening in Drosoph cancer models. J. Genetics and Genomics, 2011 Oct 20;38(10):497-504

3. A. Edwards, et al. Combinatorial effe of maytansinol and radiation in Drosophila and human cancer cells, Disease Models and Mechanisms. 2011 Jul;4(4):496-503. Epub 2011 Apr 18.

4. M. Gladstone, B. Frederick, et al. A translation inhibitor identified in a Drosophila screen enhances the effect o ionizing radiation and taxol in mammalian models of cancer. Disease Models and Mechanisms. 2012 May;5(3):342-50.

Numerical Grade	*Letter Grade*
≥ 92.5	A
≥ 90.0	A-
≥ 87.5	B+
≥ 82.5	B
≥ 80.0	B-
≥ 77.5	C+
≥ 72.5	C
≥ 70.0	C-
≥ 67.5	D+
≥ 62.5	D
≥ 59.5	D-
< 59.5	F

Late assignments

Assignments are due at the beginning of class. Electronic submission is preferred. If an assignment is received after the due date/time, a zero will be entered in the grade book. Late assignments will be accepted with a 10% deduction for each class it is late. When a late assignment is received, the grade will replace the zero in the grade book. If you miss an assignment, you should *always* consider submitting it late. A zero can greatly affect your final grade.

Attendance policy

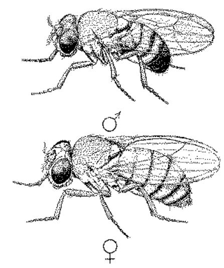
Attendance is mandatory. Because lab courses are participatory, your physical presence is required. You will be allowed one unexcused absence without adversely affecting your grade. Each additional unexcused absence will result in the dropping of a full letter grade. An unexcused absence will be defined as failure to notify the course instructor prior to your absence. Notification can be in the form of personal communication, email or contact by cell phone (text or voice mail). However, the onus will be on the student to inform the instructor that he or she will be absent. This includes potential conflicts with other courses that schedule exams when during the time our class meets.

Make-up Policy

If you anticipate an excused absence will conflict with a laboratory period, please contact an instructor **before** the scheduled class to ensure that your excuse is acceptable (typically medical emergencies, catastrophic loss of a family member, religious holidays, etc.). If you miss a class, it is your responsibility to contact Pamela Harvey to arrange a make-up. The student is responsible for providing satisfactory evidence within one week of the end of the absence to document the necessity of the absence.

Laboratory Conduct

Students and faculty each have responsibility for maintaining an appropriate learning environment. Those who fail to adhere to such behavioral standards may be subject to discipline. Professional courtesy and sensitivity are especially important with respect to individuals and topics dealing with differences of race, color, culture, religion, creed, politics, veteran's status, sexual orientation, gender, gender identity and gender expression, age, disability, and nationalities. Class rosters are provided to the instructor with the student's legal name. The instructors will gladly honor your request to address you by an alternate name or gender pronoun. Please advise the instructors of this preference early in the semester so that we may make appropriate changes to my records. See policies at http://www.colorado.edu/policies/classbehavior.html and at http://www.colorado.edu/studentaffairs/judicialaffairs/code.html#student_code



Course Milestones

- Set up Drosophila population cage
- Embryo collection
- Embryo culture to larvae
- Larvae irradiation
- Larvae treatment with drug compounds
- Quantify survival
- Calculate average and standard deviation of potential hits
- Validate candidate compounds

Students with Disabilities

If you qualify for accommodations because of a disability, please submit to us a letter from Disability Services in a timely manner so that your needs may be addressed. Disability Services determines accommodations based on documented disabilities. Contact: 303-492-8671, Willard 322, and htp://www.Colorado.edu/disabilityservices.

Disability Services' letters for students with disabilities indicate legally mandated reasonable accommodations. The syllabus statements and answers to Frequently Asked Questions can be found at http://www.colorado.edu/disabilityservices.

Religious Observances

Campus policy regarding religious observances requires that faculty make every effort to reasonably and fairly deal with all students who, because of religious obligations, have conflicts with scheduled exams, assignments or required attendance. See full details at: http://www.colorado.edu/policies/fac_relig.html

Discrimination and Harassment

The University of Colorado Boulder (CU-Boulder) is committed to maintaining a positive learning, working, and living environment. The University of Colorado does not discriminate on the basis of race, color, national origin, sex, age, disability, creed, religion, sexual orientation, or veteran status in admission and access to, and treatment and employment in, its educational programs and activities. (Regent Law, Article 10, amended 11/8/2001). CU-Boulder will not tolerate acts of discrimination or harassment based upon Protected Classes or related retaliation against or by any employee or student. For purposes of this CU-Boulder policy, "Protected Classes" refers to race, color, national origin, sex, pregnancy, age, disability, creed, religion, sexual orientation, gender identity, gender expression, or veteran status. Individuals who believe they have been discriminated against should contact the Office of Discrimination and Harassment (ODH) at 303-492-2127 or the Office of Student Conduct (OSC) at 303-492-5550. Information about the ODH, the above referenced policies, and the campus resources available to assist individuals regarding discrimination or harassment can be obtained at http://hr.colorado.edu/dh/

Honor Code

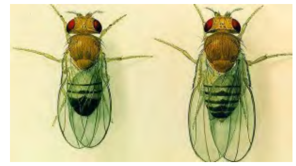
All students of the University of Colorado at Boulder are responsible for knowing and adhering to the academic integrity policy of this institution. Violations of this policy may include: cheating, plagiarism, aid of academic dishonesty, fabrication, lying, bribery, and threatening behavior. All incidents of academic misconduct shall be reported to the Honor Code Council (honor@colorado.edu; 303-735-2273). Students who are found to be in violation of the academic integrity policy will be subject to both academic sanctions from the faculty member and non-academic sanctions (including but not limited to university probation, suspension, or expulsion). Other information on the Honor Code can be found at http://www.colorado.edu/policies/honor.html and at http://honorcode.colorado.edu

Plagiarism and Copyrights

As commonly defined, plagiarism consists of passing off as one's own, the ideas, words, or writings that belong to another. In accordance with this definition, you are committing plagiarism if you copy the work of another person and turn it in as your own, even if you have the permission of that person. Plagiarism is one of the most serious forms of academic misconduct.

Course Schedule

(Subject to change at any time due to progression of the research)



Week	Class	Lecture	Lab		Experimental set - 700 compounds
Week of January 16	Class 1		NO CLASS		
	Class 2	Course Introduction and Experimental Design, Pipetting Technique and Exercise Overview & Lab Notebook Overview	Course and pipetting exercise overview		
Week of January 23	Class 1	Individual Student Pipetting Results Review, Day 1	Pipetting Exercise - Day 1		
	Class 2	Experimental Protocol Overview, Radiation Safety	Food protocol review, practice pouring food, add yeast to vials, move adult flies from bottle to bottlel, continue pipetting exercise		Practice with each step of the experimental protocol in an accelerated schedule
Week of January 30	Class 1	Model Organisms and Fly Biology	Grape juice plates and population cage setup, continue pipetting exercise		
	Class 2	Fly Development and Husbandry	Embryo observation and collection, different time points for collection tested		
Week of February 6	Class 1	Fly Genetics I - chromosomes, balancer chromosome, and maternal effects	New Lab Tour and Safety Overview?, Irradiate and expose flies to positive and negative controls (1 vial per student)		
	Class 2	Fly Genetics II - checkpoint proteins and grapes mutation	Mark GFP-negative pupae, quantify survival, average, and standard deviation		
Week of February 13	Class 1	Lab Meeting & Bioethics and Animal Use	Add yeast to new culture bottles		Experimental Set #1- 100 drugs (5 per st
	Class 2	Biostatistics	Transfer adults to new culture bottles		
Week of February 20	Class 1	Evolution of Drug Resistance in Cancer	Set up small population cage	**Add yeast to new culture bottles**	Experimental Set #2 - 200 d
	Class 2	Drug Development & Clinical Trials	Egg collection and culture to larval stage	**Transfer adults to new culture bottles**	
Week of February 27	Class 1	NCI-Developmental Therapeutics Program	Drug/food preparation. larvae collection, and irradiate	**Set up population cage**	
	Class 2	PubMed and Google Scholar		**Egg collection and culture to larval stage**	
Week of March 6	Class 1	Tin Tin Research Lecture		**Drug/food preparation, larvae collection, and irradiate**	
	Class 2	Lab Meeting	Mark GFP and eclosed/not eclosed Thursday evening to Friday morning - (9-10 days after irradiation)		

Week of March 13	Class 1	Fly Genetics & Experimental Protocol review - students generate on white board	Quantify survival (vials rechecked Monday evening)		udent)	ugs (10 per student)
	Class 2	Lab Meeting & Grapes Mutation Exercise	Lab meeting	**Mark GFP and eclosed/not eclosed Wednesday to Friday morning - (9-10 days after irradiation)**		
Week of March 20	Class 1		Add yeast to new culture bottles	**Quantify survival (vials rechecked Monday evening)**	Experimental Set #3 - 200 drugs (10 per student)	
	Class 2	Lab Meeting	Transfer adults to new culture bottles	Lab Meeting		
Week of March 27	**Spring Break**		Egg collection and culture to larval stage (Pam)	**Add yeast to new culture bottles (Pam)**		Experimental Set #4 - 200 drugs (10 per student)
Week of April 3	Class 1		Drug/food preparation, larvae collection, and irradiate	**Transfer adults to new culture bottles**		
	Class 2			**Set up population cage**		
Week of April 10	Class 1	Scientific Reporting and Ethics		**Egg collection and culture to larval stage**		
	Class 2	Anatomy of a Research Article	Mark GFP and eclosed/not eclosed Thursday evening to Friday morning - (9-10 days after irradiation)	**Drug/food preparation, larvae collection, and irradiate**		
Week of April 17	Class 1	Lab Meeting & Poster Session Presentation	Quantify survival (vials rechecked Monday evening)			
	Class 2	Punctuation and Grammar Review, Guidelines for results & discussion sections -	Lab Meeting			
Week of April 23	Class 1	Guidelines for Introduction Section		**Mark GFP and eclosed/not eclosed Thursday evening to Friday morning - (9-10 days after irradiation)**		
	Class 2	Guidelines for Methods Section		**Quantify survival (vials rechecked Monday evening)**		
Week of April 30	Class 1	Lab Meeting & Grammar Review, Guidelines for Results and Discussion sections				
	Class 2	Open Lab				

MCDB 4202

The Python Project

Fall 2017
TTH 1-4 pm, Gold A1B18

Instructor: Pamela Harvey, PhD
Office: Gold B318
E-Mail: pamela.harvey@colorado.edu
Phone: 617-501-4175 (emergencies)
Lab: 303-492-7191
Office Hours: by appointment

TA: Kiley Hartigan
E-Mail: kiley.hartigan@colorado.edu

Overview

The Python Project is a three-credit laboratory course designed to help upper division students engage in an authentic laboratory experience. During the class, students design experiments to examine the molecular mechanisms of organ growth in the Burmese python. To this end, students will:

- **Use modern molecular biology and bioinformatic techniques** to isolate RNA, synthesize cDNA, design primers, measure expression of candidate molecules of the python genome, and present data in the context of the research project,
- **Generate novel data** that will contribute to an ongoing research project in the Leinwand lab.

Course Objectives

The overriding goal of The Python Project is to provide students with sufficient training & guidance to become proficient in a number of molecular biology techniques including but not limited to gel electrophoresis, isolation of RNA from tissue, cDNA synthesis, PCR, and real time PCR. Unlike laboratory exercises that are designed to reinforce concepts that may accompany lecture topics, there is no certainty that any one particular project will succeed, which somewhat mirrors the inherent risks of novel research. The linear, goal-oriented nature of this research effort means that repetition of some steps will be required to get things to work optimally.

1. Understand how your data contributes to the research being performed in the Leinwand lab,
2. Obtain expertise in real time PCR experiments from beginning to end,
3. Design experiments that address specific scientific questions,
4. Successfully present a poster describing your data in a public poster session to be held during the final exam period,
5. Understand and be able to describe previous research on your gene of interest.

Suggested Prerequisites

MCDB 3120 and 3500, or MCDB 3135 and 3145, and CHEM 4711 and 4731.

Evaluation

Quizzes and worksheets:
Quizzes and worksheets will be completed approximately weekly. Paper submissions will not be accepted. All quizzes and worksheets must be submitted on D2L. Late assignments will be allowed, but 10% will be deducted for each class it is late.

Midterm Exam:
The midterm exam for the Fall 2017 semester is scheduled for Thursday, October 26th at 1:00 pm, location to be announced. This date is provided beforehand so students can plan their schedules accordingly. In an effort to be fair to all students taking the course, every effort should be made to attend this exam. A rescheduled exam results in a delay in the other students' exams being returned. The exam will be a cumulative review of laboratory

Materials

There is **no** textbook for this course. All required materials will be posted on D2L.

Course Milestones

RNA Isolation

RNA Integrity & Purity

Primer Design

cDNA Synthesis

PCR Validation of Primers

Production of a Standard Curve

Quantitative PCR

Data Analysis

Data Presentation

techniques and information covered in the first half of the semester. It should take about two hours to complete.

Make-up Exam Policy:
If you anticipate an excused absence will conflict with an exam, please contact me **before** the scheduled exam. If you unexpectedly miss an exam, it is your responsibility to contact me to arrange a make-up. The student is responsible for providing satisfactory evidence within one week of the end of the absence to document the necessity of the absence.

Final Exam:
There is no final exam for this course. Final review papers, abbreviated summaries, and completed laboratory notebooks are due at the end of our final exam period. You do not need to be present in lab on that day.

Point Distribution:

	Weight
Quizzes & worksheets	15%
Review article	10%
Oral presentation	10%
Midterm written exam	25%
Abbreviated summary	5%
Lab notebook	10%
Final research paper	15%
Poster presentation	10%

Numerical Grade	*Letter Grade*
≥ 92.5	A
≥ 90.0	A-
≥ 87.5	B+
≥ 82.5	B
≥ 80.0	B-
≥ 77.5	C+
≥ 72.5	C
≥ 70.0	C-
≥ 67.5	D+
≥ 62.5	D
≥ 59.5	D-
< 59.5	F

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politics, veteran's status, sexual orientation, gender, gender identity and gender expression, age, disability, and nationalities. Class rosters are provided to the instructor with the student's legal name. I will gladly honor your request to address you by an alternate name or gender pronoun. Please advise me of this preference early in the semester so that I may make appropriate changes to my records. See policies at

http://www.colorado.edu/policies/classbehavior.html and at
http://www.colorado.edu/studentaffairs/judicialaffairs/code.html#student_code

Students with Disabilities

If you qualify for accommodations because of a disability, please submit to me a letter from Disability Services in a timely manner so that your needs may be addressed. Disability Services determines accommodations based on documented disabilities. Contact: 303-492-8671, Willard 322, and http://www.Colorado.edu/disabilityservices.

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The University of Colorado Boulder (CU-Boulder) is committed to maintaining a positive learning, working, and living environment. The University of Colorado does not discriminate on the basis of race, color, national origin, sex, age, disability, creed, religion, sexual orientation, or veteran status in admission and access to, and treatment and employment in, its educational programs and activities. (Regent Law, Article 10, amended 11/8/2001). CU-Boulder will not tolerate acts of discrimination or harassment based upon Protected Classes or related retaliation against or by any employee or student. For purposes of this CU-Boulder policy, "Protected Classes" refers to race, color, national origin, sex, pregnancy, age, disability, creed, religion, sexual orientation, gender identity, gender expression, or veteran status. Individuals who believe they have been discriminated against should contact the Office of Discrimination and Harassment (ODH) at 303-492-2127 or the Office of Student Conduct (OSC) at 303-492-5550. Information about the ODH, the above referenced policies, and the campus resources available to assist individuals regarding discrimination or harassment can be obtained at http://hr.colorado.edu/dh/

Honor Code

All students of the University of Colorado at Boulder are responsible for knowing and adhering to the academic integrity policy of this institution. Violations of this policy may include: cheating, plagiarism, participating in academic dishonesty, fabrication, lying, bribery, and threatening behavior. All incidents of academic misconduct shall be reported to the Honor Code Council (honor@colorado.edu; 303-735-2273). Students who are found to be in violation of the academic integrity policy will be subject to both academic sanctions from the faculty member and non-academic sanctions (including but not limited to university probation, suspension, or expulsion). Other information on the Honor Code can be found at:
http://www.colorado.edu/policies/honor.html and at http://honorcode.colorado.edu

Plagiarism and Copyrights

As commonly defined, plagiarism consists of passing off as one's own, the ideas, words, or writings that belong to another. In accordance with this definition, you are committing

plagiarism if you copy the work of another person and turn it in as your own, even if you have the permission of that person. Plagiarism is one of the most serious forms of academic misconduct.

All lectures, exams, handouts and other materials used in this course (including those provided in D2L) are copyrighted. Because these materials are copyrighted, you do not have the right to reproduce, transmit, provide or receive these materials without explicit permission of the instructor/authors. Any other use of these materials is considered "unauthorized" and is thus a form of academic dishonesty and an honor code violation.

Projected Schedule of Experiments

Note: The nature of the course requires some flexibility in the progression of the semester. Research is unpredictable. We will do out best to adhere to this schedule in terms of experimental procedures. For planning purposes, lecture and assignment due dates will not change.

Date	Experimental Procedure	Lecture Topic
August 29, 2017	**NO CLASS**	
August 29, 2017		
September 5, 2017		Lab Orientation, Introduction to the Python Project
September 7, 2017	Primer Design Part I	Python Transcriptome and WGS
September 12, 2017	Primer Design Part II	
September 14, 2017	Primer Design Part III	
September 19, 2017	Primer Design IV	
September 21, 2017	RNA Isolation	RNA Transcription and Splicing Review, RNA Isolation Protocol
September 26, 2017	RNA gel electrophoresis	RNA to cDNA – qPCR Introduction, Review of Procedure to Date, RNA Concentration, Purity, and Integrity
September 28, 2017	cDNA Synthesis	Conventional PCR, General Chemistry Review
October 3, 2017	PCR Primer Test – Reference Genes	Burmese Python Research
October 5, 2017	Gel electrophoresis & Imaging	Cardiac Physiology I
October 10, 2017	PCR Primer Test – GOI primer set 1, 10 Minute Talks 1	
October 17, 2017	Gel electrophoresis, 10 Minute Talks 2	Cardiac Physiology II

October 17, 2017	PCR Primer Test – GOI primer set 2, 10 Minute Talks 3	
October 19, 2017	Gel electrophoresis, 10 Minute Talks 4	
October 24, 2017	10 Minute Talks 5, Bioneer PCR Kit	Review Session for Midterm
October 26, 2017	**Midterm Exam**	
October 31, 2017	Protein Assays	Review Paper Overview, Introduction to Standard Curves & Protein Assays
November 2, 2017	Protein Assays	
November 7, 2017	Protein Assays	qPCR I
November 9, 2017	Protein Assays, qPCR – standard dilution set up	qPCR II
November 14, 2017	qPCR GOI plate 1	
November 16, 2017	qPCR GOI plats 2	qPCR III
November 21, 2017	**Fall Break – no class**	
November 23, 2017		
November 28, 2017	qPCR GOI plate #3	Biostatistics, Poster Presentation Details
November 30, 2017	Data analysis – CFX96 software, qPCR GOI plate #4	CFX96 Data Analysis
December 5, 2017	qPCR, Conventional PCR, Poster Practice	Online Research Resources
December 7, 2017	qPCR, Conventional PCR, Poster Practice	Review of Poster Presentation Details & CURE Symposium
December 11, 2017	**CURE Symposium 5:30-9 pm**	
December 12, 2017	Plan for Spring 2018, Finalize data	Anatomy of a Research Publication, Python Research Paper Introduction Review
December 14, 2017	Open Lab	Python Methods Review, Expectations for Final Assignments Review
Final Exam Day (TBD)	Lab Notebooks, Abbreviated Summary, and Final Research Paper Due at end of final exam period	

Schedule of Due Dates

Assignment	Due Date & Time
Primer Design I	9/12/2017, 1 pm
Primer Design II	9/14/2017, 1 pm

Primer Design III	9/19/2017, 1 pm
Primer Design IV	9/21/2017, 1 pm
Primer Design Worksheet	9/26/2017, 1 pm
RNA Transcription & Translation Worksheet	9/28/2017, 1 pm
Conventional PCR & General Chemistry Worksheet	10/3/2017, 1 pm
Python Research Worksheet	10/5/2017, 1 pm
Cardiac Physiology I	10/10/2017, 1 pm
Cardiac Physiology II	10/17/2017, 1 pm
qPCR I & II Worksheet	11/14/2017, 1 pm
Review Paper	11/16/2017, 1 pm
qPCR III & Biostatistics	11/30/2017, 1 pm
Final Poster PowerPoint	12/1/2017, 5 pm
Final Research Paper	End of final exam period (to announced by CU)
Abbreviated Summary	End of final exam period (to announced by CU)
Final Laboratory Notebooks	End of final exam period (to announced by CU)

Course realization Example 1: Time-domain analysis of large Imaging databases (Ellingson, Bally)

Provides students hands-on experience with analyzing large imaging databases from the Las Cumbres Global Telescope Network to search for transient or variable phenomena. Time-domain analysis and data-mining are expanding fields in astronomy and elsewhere, and this project will align student skills with these new opportunities. Research methods are designed to provide general skills in assessment, calibrations, statistical analysis, creative troubleshooting, teamwork and written and oral presentations on scientific topics.

Weeks	**Instruction 2 hours per week**	**Lab work** **2 hours per week + outside independent work**
1 -2	Scientific motivation, data and databases: telescope networks, large databases and data-mining, space and ground-based observations. star formation and stellar rotation, supernovae, massive stars.	Background reading assignments, scientific literature searches and identification of scientific themes, key areas of research and methods. Introduction to data structures and the pipeline interfaces. Target and dataset selection and downloads.
3-4	Detectors and detector characteristics Initial oral presentations on scientific topics and data assessment.	Examples and practice using the pipeline. Finish a first data assessment.
5	Coordinate systems and Transformations. Linear and non-linear transformations, model fitting. Progress reports and troubleshooting.	Practice with coordinate transformation software in class; continue with dataset analysis.
6-7	Photometric measurements and algorithms. Testing results that depend on multiple variables. Progress reports and troubleshooting.	Setting and testing photometric measurement parameters. Practice with software and assessment of results for different parameter choices.

8-9	Calibrations: methods and systematic uncertainties. Progress reports and troubleshooting.	Calibration of datasets; accuracy of calibrations, handling outliers
10-11	Producing and characterizing Light curves. Model fitting, statistical inference and hypothesis testing. Detection limits and sampling biases.	Production and inspection of light curves (hundred per research group). Identification of transient and variable objects.
12	Proposal writing and peer-review	Mock proposal review and re-writing exercise.
13-14	Independent work in data analysis, programming applications or further research.	Analysis of light curves for scientific results. Advanced techniques, additional programming, incorporating other datasets.
15	Student presentations of results	Student oral reports, significance of the results in the context of the scientific research program.

2	Travel to Sunspot, NM Meets daily for 1 hour. 1. Facility orientation (1 hour) 2. Project reviews and Team formation -- roles and responsibilities (1 hour) 3. Elements of an observing proposal and proposal writing (1 hour) 4. Introductory data analysis : correcting for instrumental effects (2 hours)	Observations on the Dunn Solar Telescope (10 hours lab work). Includes working with non-CU solar physicists on site. Initial data assessment and analysis (5 hours supervised lab work) Observing proposal development. Data analysis.
		Written observing proposal (20% of grade)
3	Return to CU Meets daily for 1 hour. 1. Data analysis techniques and statistical inference (3 hours) 2. Peer review of written proposals (1 hour) 2. Student presentations of research results (1 hours)	Finish data analysis to meaningful scientific result. Guided lab work (meets with instructor 3 hours daily for guided lab work) Prepare final results and reports.
		Student oral reports focusing on significance of the results in the context of the proposed scientific research program. Research analysis, oral and written presentations (40% of grade)

Course realization Example 2: Solar Observations at the NSO Dunn Telescope (M. Rast)

Provides students hands-on experience designing and executing a solar observational program and analyzing solar data. Focuses on the multi-wavelength solar spectropolarimetric instrumentation, observations, and data analysis techniques. Includes preparatory class work, observing proposal development, observation, analysis and both oral and written presentations. Students will work in groups under trained graduate student mentors to develop, execute, analyze and report research projects using high resolution telescopic observations of the Sun. Requires extended travel to non-local telescope site.

Maymester Schedule
A 3 credit hour class (2 lecture credits plus one lab credit), taught over the three week Maymester term, 20 hours/week. The first week focuses on classroom activities on the CU Boulder campus and the second and third weeks are devoted to development and execution of an observing proposal on the Dunn Solar Telescope in Sunspot, NM. Travel costs for students are covered via an external grant.

<table>
<tr><th rowspan="2">Weeks</th><th rowspan="2">Instruction</th><th>Lab and Outside work</th></tr>
<tr><th>Assessment</th></tr>
<tr><td rowspan="2">1</td><td rowspan="2">Meet daily for 2 x 2-hour lecture sessions.

1. The Sun: An introduction to the Sun as a magnetically active star (4 hours)

2. How we observe the Sun: High resolution multi-wavelength spectroscopy and spectropolarimetry (5 hours)

3. Principles of the Dunn Solar Telescope (DST) design and operations (5 hours)

4. The SDST instrument suite, design and capabilities (5 hours)

5. Student oral presentations (1 hour)</td><td>Scientific definition (guided independent work outside of class, based on current scientific literature). Scientific background and motivation report.</td></tr>
<tr><td>Daily homework assignments to emphasize lecture topics (20% of grade)

Both written component and 5min oral presentation, which will be assessed via video and anonymous peer commentary (20% of grade).</td></tr>
</table>

Course Realization Example 3: Exoplanet with TESS + SBO/LCO/APO
(Berta-Thompson, with lots of consultation from Ellingson)

The class provides students with hands-on experience analyzing light curves of transiting exoplanets, as well as designing and gathering their own photometric observations. Through the specific topical foci of the physics of eclipsing systems and the techniques broadband time-series photometry, this Classroom Undergraduate Research Experience will provide a studio setting in which students can practice original research, develop technical expertise, make new discoveries, and establish a sense of identity and belonging as astronomers.

The Transiting Exoplanet Survey Satellite (TESS) mission is scheduled to launch in Spring 2018, finish commissioning by summer, and start science observations by Fall 2018. TESS will produce photon-limited photometric time-series for roughly 100,000 new stars *each month*. Students will work in groups to visualize and inspect a fraction of these light curves, develop algorithms to select variable sources, fit models to extract physical system parameters, identify targets that would benefit from additional follow-up, write proposals for telescope time, and conduct their own new observations. Students will be exploring newly discovered systems in real-time, as part of the TESS scientific community.

Week	Learning Goals	Instruction	Lab Work (In + Out of Class)
1	Asking questions. Identifying ones you can answer.	Background scientific motivation, how to read a paper.	Reading scientific papers, exploring the literature with ADS.
2	Visualizing data. Telling signal from noise.	Basic principles of data visualization, the concept of uncertainty, binning.	Plotting TESS light curves. Comparing good vs. bad choices for plotting choices.
3-4	Making models and fitting them to measurements.	Parameterized models, the relation between transit shape and system geometry, merit functions.	Optimizing parameters of a transit model (by eye and by algorithm) to match TESS light curves.
5	Extracting measurements from data.	Technique of aperture photometry, strategies to organize multidimensional data.	Performing aperture photometry on TESS pixel-level data to produce light curves.

		review.	exceptional APO/3.5m proposals for future submission), reviewing proposals in student panels and offering feedback.

MCDB 1161 – Phage Genomics I

In 2009 the University of Colorado at Boulder was selected by the Howard Hughes Medical Institute to participate in the Science Education Alliance SEA, an ambitious higher education program designed to involve freshmen in scientific discovery on a national scale. This phage genomics course is a year-long laboratory research course aimed exclusively at first-year college students to study viruses known as bacteriophages that infect bacteria. Each student isolates and characterizes a novel bacteriophage they isolate from soil samples, using current molecular biology techniques. During the second semester of phage genomics students analyze the genomes of some of phages they isolated using current bioinformatics programs and compare their genome to other phage genomes isolated by students in the SEA from other universities and colleges across the United States. This course has been used as a model for two other introductory MCDB lab courses (the CURE labs) which offer unique research opportunities for first year students at CU-Boulder.

HHMI provided supplies for the phage genomics labs for three years and support for training faculty to teach the two sections of phage genomics. Every year HHMI supports the travel expenses for two students and one faculty member to attend the SEA Symposium. In the past few years, HHMI has provided $5000/year for each section of phage genomics taught at UTeach schools, which includes CU Boulder.

MCDB 1171 & 2171 – Discovery Labs I & II:

CU Boulder's Biological Sciences Initiative's (BSI) support of the MCDB introductory CURE laboratory courses are an excellent example of the University and an external funding source, the Howard Hughes Medical Institute (HHMI), coming together to accomplish common goals. The HHMI, in their 2014 *Sustaining Excellence* Grants Competition, encouraged institutions to introduce greater numbers of students to authentic research at an early stage of their undergraduate career. This aligned well with the BSI's goals of providing research experiences to a greater number and greater diversity of students, as well as the University's strategic goals of student engagement and inclusive excellence. In the 2014 HHMI Competition, CU Boulder's BSI was awarded a $1.5 million, 5-year (5th year funding contingent on progress and sustainability) grant in support of its strategic initiatives to include more undergraduates in authentic, faculty-led research – including the MCDB introductory CUREs. This catalytic impetus has helped nurture collaborations among research faculty, teaching faculty, administrators, program personnel, and assessment experts to accomplish the introductory CUREs in MCDB, which now benefit many undergraduates during their first years at CU Boulder. For additional information, please see: www.colorado.edu/bsi