Term Information

Effective Term	Spring 2024
Previous Value	*Spring 2014*

Course Change Information

What change is being proposed? (If more than one, what changes are being proposed?)

We propose a re-numbering of Astronomy 1142 to 2142. The revised course, Astronomy 2142, is proposed for inclusion in the Number, Nature and Mind Theme. It will also continue to satisfy the legacy Foundations course requirement, although it is not eligible for the new Foundations (which require 4 credits and a lab).

What is the rationale for the proposed change(s)?

Astronomy 2142 was one of the 10 initial courses submitted in the approved proposal for the Number, Nature and Mind Theme. To create Astronomy 2142, we extensively revised the prior Foundations 1142 course, and we view 2142 as a logical replacement for 1142. The proposed changes include a number of elements that require a 2000-level designation rather than a 1000-level designation. These include the requirement that the natural sciences Foundation be satisfied, readings, more in-depth problem sets, in-class discussions, a summary written essay, a variety of assessment tools, and a greater emphasis on interdisciplinary questions.

What are the programmatic implications of the proposed change(s)?

(e.g. program requirements to be added or removed, changes to be made in available resources, effect on other programs that use the course)?

The new course will satisfy the GE Themes, but not the foundations. The precursor course was not a prerequisite for other courses, and neither is the proposed 2142 course. We therefore expect no net impact on other programs. Neither course requires a laboratory, so there is no change in required laboratory facility needs.

Is approval of the requrest contingent upon the approval of other course or curricular program request? No

Is this a request to withdraw the course? No

General Information

Course Bulletin Listing/Subject Area	Astronomy
Fiscal Unit/Academic Org	Astronomy - D0614
College/Academic Group	Arts and Sciences
Level/Career	Undergraduate
Course Number/Catalog	2142
Previous Value	*1142*
Course Title	Black Holes
Transcript Abbreviation	Black Holes
Course Description	This course will tell the story of black holes: how they were conceived as theoretical ideas, how they might form from dying stars, how they were discovered, what roles they play in cosmic history, how they distort space and time, how they produce tiny but detectable gravitational wave signals, and some of the remaining mysteries they present to contemporary physics.
Previous Value	*The nature, formation, and discovery of black holes in the universe.*
Semester Credit Hours/Units	Fixed: 3

Offering Information

Length Of Course	14 Week, 12 Week
Flexibly Scheduled Course	Never
Does any section of this course have a distance education component?	No
Grading Basis	Letter Grade
Repeatable	No
Course Components	Lecture
Grade Roster Component	Lecture
Credit Available by Exam	No
Previous Value	**Yes**
Previous Exam Types	*Departmental Exams*
Admission Condition Course	Yes
Admission Condition	Natural Science
Off Campus	Never
Campus of Offering	Columbus, Lima, Mansfield, Marion, Newark, Wooster
Previous Value	*Columbus, Lima*

Prerequisites and Exclusions

Prerequisites/Corequisites	Prereq: Completion of the Natural Science GE Foundation and Math at the level of 1050 or higher, or permission of instructor. If taken for the GEL, Math at the level of 1050 or higher, or permission of instructor. For the GEL, students should consult with the course instructor or advisor to ensure adequate preparation for the course.
Previous Value	*Prereq: ACT Math Subscore of 22 or higher, or Math Placement Level R or better, or Math 1050 (075), or permission of instructor.*
Exclusions	Not open to students with credit for 1142.
Previous Value	Not open to students with credit for 142.
Electronically Enforced	No

Cross-Listings

Cross-Listings

Subject/CIP Code

Subject/CIP Code	40.0201
Subsidy Level	General Studies Course
Intended Rank	Freshman, Sophomore, Junior, Senior

Requirement/Elective Designation

General Education course:

Physical Science; Number, Nature, Mind

Previous Value

General Education course:

Physical Science

Course Details

Course goals or learning objectives/outcomes

- The course goals and learning objectives are taken from those required for all new GE courses, as well as those specific to the Origins and Evolution Theme. Learning objectives are in the attached ELO questionnaire.Successful students will:
- General GE Goal 1: Analyze an important topic or idea at a more advanced and in-depth level than in the Foundations component.
- General GE Goal 2: Integrate approaches to the theme by making connections to out-of-classroom experiences with academic knowledge or across disciplines and/or to work they have done in previous classes and that they anticipate doing in future.
- Number, Nature and Mind GOAL 1: Analyze the nature of mathematics and/or mathematical reasoning at a more advanced and in-depth level than in the Foundations component.
- Number, Nature and Mind GOAL 2: integrate approaches to number, nature, and mind by making connections to their own experience of mathematical thinking and its application in the world, and by making connections to prior work (abridged)
- Number, Nature and Mind GOAL 3: Successful students will experience and examine mathematics as an abstract formal system accessible to mental manipulation and/or mathematics as a tool for describing and understanding the natural world.

Previous Value

- *Understanding the basic principles and central facts of astrophysics, and their relation to other ideas in the physical and biological sciences.*
- *Understanding how we discovered the important principles and facts of astrophysics, thus understanding key events in the history of science both as events in human history and as case studies in the methods of science.*
- *Investigating the relationship between science and technology.*
- *Understanding the social and philosophical implications of major scientific discoveries.*

Content Topic List

- Black holes in theory and reality
- Gravitation: Newton and Einstein
- Black holes and time warps
- Life cycle of stars and formation of black holes
- Quasars and supermassive black holes
- Gravitational waves and the Event Horizon Telescope
- Black hole exotica

Previous Value

- *Black holes in theory and reality*
- *Gravitation: Newton and Einstein*
- *Black holes and time warps*
- *Life cycle of stars and formation of black holes*
- *Quasars and supermassive black holes*
- *Black hole exotica*

Sought Concurrence

No

Attachments

- syllabus_a1142.pdf: Sample prior syllabus

  (Syllabus. Owner: Pinsonneault,Marc Howard)
- Astro2142_Syllabus_Draft_mar232023.pdf: Revised new syllabus

  (Syllabus. Owner: Pinsonneault,Marc Howard)
- Astron2142_elo_questionnare_mar212023.docx: elo questionnare

  (GEC Model Curriculum Compliance Stmt. Owner: Pinsonneault,Marc Howard)
- 2142_revision_cover_mar232023.docx: cover letter detailing changes

  (Cover Letter. Owner: Pinsonneault,Marc Howard)

Comments

- Per conversation with the department, it was determined that old materials were submitted to ASCCAS on 1/20/23. Returning the course to the department to upload the correct revised materials. RLS *(by Steele,Rachel Lea on 01/27/2023 12:47 PM)*
- Please see Panel feedback e-mail sent 10/20/22. *(by Cody,Emily Kathryn on 10/20/2022 04:04 PM)*
- This is one of four astronomy courses being transitioned from the 1000 level to the 2000 level. *(by Pinsonneault,Marc Howard on 08/30/2022 03:13 PM)*

Workflow Information

Status	User(s)	Date/Time	Step
Submitted	Pinsonneault,Marc Howard	08/30/2022 03:14 PM	Submitted for Approval
Approved	Weinberg,David Hal	08/30/2022 05:27 PM	Unit Approval
Approved	Vankeerbergen,Bernadette Chantal	09/27/2022 01:46 PM	College Approval
Revision Requested	Cody,Emily Kathryn	10/20/2022 04:04 PM	ASCCAO Approval
Submitted	Weinberg,David Hal	10/21/2022 04:36 PM	Submitted for Approval
Approved	Weinberg,David Hal	01/20/2023 08:26 AM	Unit Approval
Approved	Vankeerbergen,Bernadette Chantal	01/20/2023 12:57 PM	College Approval
Revision Requested	Steele,Rachel Lea	01/27/2023 12:47 PM	ASCCAO Approval
Submitted	Pinsonneault,Marc Howard	03/23/2023 01:43 PM	Submitted for Approval
Approved	Weinberg,David Hal	08/23/2023 11:58 AM	Unit Approval
Approved	Vankeerbergen,Bernadette Chantal	08/23/2023 12:44 PM	College Approval
Pending Approval	Jenkins,Mary Ellen Bigler Hanlin,Deborah Kay Hilty,Michael Vankeerbergen,Bernadette Chantal Steele,Rachel Lea	08/23/2023 12:44 PM	ASCCAO Approval

THE OHIO STATE UNIVERSITY

College of Arts and Sciences

Department of Astronomy

4055 McPherson Laboratory
140 West 18th Avenue
Columbus, OH 43210-1173

614-292-1773 Phone
614-292-2928 Fax

astronomy.osu.edu

March 23, 2023

To whom it may concern,

We are resubmitting Astronomy 2142 for inclusion in the Origins and Evolution GEN Theme. The panel had three contingencies and six recommendations, list below:

- **CONTINGENCY: The reviewing faculty ask that the most up-to-date, full and complete GEL Goals and ELOs — as well as an explanatory paragraph outlining how the class intends to meet these Goals/ELOs for GEL Natural Science-Physical Science — appear in the course syllabus, per a requirement of General Education courses. The committee notes that the syllabus does contain GEL Goals and ELOs for Natural Science-Physical Science, however this does not reflect the most recent language available. The current GEL Goals and ELOs can be found here on the ASC Curriculum and Assessment Services website: https://asccas.osu.edu/legacy-general-education-gel-goals-and-elos**
- **CONTINGENCY: In the syllabus, please include a course schedule that approximates what topics the instructor anticipates covering weekly (if not daily, as applicable) so students have a stronger sense of the pacing of the class material for the term. This course schedule should also feature titles, author names, and/or links to downloads for readings and/or videos; homework assignments; as well as any important benchmarks.**
- *RECOMMENDATION: The Panel kindly notes that the GE submission form the department provided contains the content/responses for a Psychology 4845 course — and thus strongly recommends revising this material for the course at hand before the proposal goes under review by the Themes Panel.*
- *RECOMMENDATION: The Panel recommends the unit clarify how prerequisites will work for students looking to take this course under the GEL; at present, a Natural Science GEN course is listed as a prerequisite for enrollment.*
- *RECOMMENDATION: The reviewing faculty kindly note that the syllabus contains references to the GEC, which is an old curriculum model; they suggest amending any mentions of this outdated model to instead read New General Education or abbreviated as GEN as appropriate.*
- *RECOMMENDATION: The Panel recommends also providing course-specific learning outcomes in the syllabus, so it is clear to students how this particular class will provide a different experience from other courses within the same GEN theme category.*
- *RECOMMENDATION: Are there any in-class materials or requirements students need to be aware of for the in-class essays? Any special technology they should have on hand? The Panel suggests including this information in the syllabus if applicable.*

- *RECOMMENDATION: The Panel recommends including a grading scale in the syllabus for student reference — as well as more clearly separating out the values of assignments in a section specifically dedicated to assessment/grading in the course.*
- *RECOMMENDATION: The Panel recommends that the syllabus feature the most current Student Life Disability Services (SLDS) statement, available here: https://asccas.osu.edu/curriculum/syllabus-elements*

Attached is a revised syllabus for Astronomy 2142, which we believe is responsive to these requests. We have updated the GEN Goals and Learning Outcomes (1), added the GEL ones (1) and outlined how the class meets both. We include a week by week syllabus (2) that includes the timing of textbook readings, in class quizzes, and homework assignments. We do not specify precise chapter assignments for readings and detailed problem sets because these are topics where different instructors make different choices. We append a corrected GE submission form (3). We have clarified the pre-requisites and expectations for GEL students (4) and adjusted the language around the GEC (5). We provide course-specific learning objectives (6). We have clarified the in-class formats and materials (6). A grading scale is included (7) and the SLDS statement has been updated (8). If you have any questions, please feel free to contact me at 614-292-5346 or via email at pinsonneault.1@osu.edu.

Sincerely yours,

Marc Pinsonneault

Professor of Astronomy, The Ohio State University

Astronomy 2142 – Black Holes
Template Syllabus

Format: 3 contact hours per week, lecture format with in-class participation and questions.
GE Theme: Number, Nature, and Mind
Class Times & Location:
Final Exam:
Homework & Quizzes: Specific dates. See below.
Web Page: http://carmen.osu.edu

Instructor:
Contact:
Office Hours:
Teaching Assistant:
Office Hours:
Instructional Assistant:
Office Hours:
Astronomy Help Sessions:
The Astronomy Department runs help sessions 4 days per week, 4:00-6:00pm. See this link.

Course Description

Black holes are among the strangest objects ever conceived by science, with gravity so strong that it traps light and warps space and time almost beyond recognition. But black holes are more than theoretical oddities – astronomical observations provide strong evidence that they exist, and that they exist in at least two varieties. Stellar mass black holes are created in the explosive deaths of massive stars, and they can "light up" and become detectable by ingesting the outer layers of orbiting companions. Supermassive black holes, millions or even billions of times more massive than the sun, reside at the centers of galaxies and power quasars, the most luminous objects in the universe.

This course will tell the story of black holes: how they were conceived as theoretical ideas, how they might form from dying stars, how they were discovered, what roles they play in cosmic history, how they distort space and time, and some of the remaining mysteries they present to contemporary physics. Along the way we will learn about Newton's theory of gravity, Einstein's theory of space and time, the life cycle of stars, and the nature of quasars. We will also see how astronomers use observations from telescopes and satellites together with basic physical principles to demonstrate the reality of black holes.

Prerequisites

If taken to satisfy the GEL, the only prerequisite is math at the level of Math 1050. The math in this course will not go beyond simple algebra, but there will be equations and geometrical or mathematical reasoning. The math itself will not be difficult, but the concepts will be challenging, and understanding the connection between mathematical equations and physical concepts will be one of the major things you will learn in this course. If taken to satisfy the Number, Nature and Mind Theme, a Natural Science GEN course is a prerequisite for enrollment, or permission from the instructor. Students taking the course to satisfy the GEL should consult with their advisor and/or the course instructor to ensure that they have adequate preparation for the course materials.

Textbook and Lecture Notes

The textbook is *Black Holes and Time Warps: Einstein's Outrageous Legacy*, by Kip Thorne. It is available from the campus bookstore and for online ordering through Amazon or other booksellers. It is also available in the Science and Engineering Library.

This is not your typical science textbook. It was written as a popular book for a broad audience, and it covers both the science of black holes and the history of black hole discoveries. It does not perfectly match to our course material, covering some topics in less detail than we will treat them and other topics in more detail. On the whole, it is a great book, written by one of the world's most creative black hole researchers. The author, Kip Thorne, shared the 2017 Nobel Prize for Physics for his pivotal role in the first detection of gravitational waves.

Required and optional reading assignments will be specified as the course progresses. Roughly 3/4 of the book will be required reading, and the homework assignments and in-class questions will draw on these readings.

The instructor will provide additional course materials through Carmen or a dedicated course web page. At the instructor's discretion these additional materials may include lecture notes and/or copies of slides shown in class, as well as links to images, videos, and other resources that are helpful in learning the course material or exploring further.

Grading

Grades will be based on four take-home assignments (30% total), in-class questions (20% total), a take-home essay (10%), a midterm exam (15%), and a final exam (25%). The take-home assignments will consist of questions from the lectures and reading and multi-part problems for you to work out, and they should typically take 4-8 hours apiece. The essay (3-5 pages) will be assigned near the end of the course and will involve reflection on the course's central themes. The exams will be primarily multiple choice or short answer questions and may include short essays.

There will be in-class questions on most class days. The three lowest scores from the in-class questions will be dropped in computing the average score. While there is no direct attendance grade, if your attendance is poor you will inevitably do poorly on the in-class question grade, and probably on everything else as well.

Grading Scale. Grades will be assigned on the A-E scale, with A scores at 90%+, B 80-89.9%, C 70-79.9%, D 60-69.9%, and E below 60%. For A, B, and C grades, the lowest third will be marked as A-, B-, C-. For B, C and D, the upper third will be marked as B+, C+, D+.

Course Topics & Week-By-Week Breakdown

Week 1: Introduction: Black Holes, the Universe, Time & Space Scales

Reading from textbook: Start Introduction and Prologue.

Week 2: Newtonian Dynamics : Kepler, Galileo, Forces & Acceleration

Week 3: Newtonian Dynamics : Gravity, Orbits, Tides

Take-home Assignment #1 due.

Reading from textbook: Start Chapter 1.

Week 4: Light & Matter: Light, Wavelength, Frequency, Energy, Spectroscopy, Atoms

Week 5: Special Relativity: Reference Frames, Luminiferous Aether, Michelson-Morley Experiment

Reading from textbook: Start Chapter 2.

Week 6: Special Relativity: Spacetime diagrams, Time Dilation, Length Contraction, $E = mc^2$

Take-home Assignment #2 due.

Week 7: General Relativity: Non-Inertial Reference Frames, Equivalence Principle, Geodesics

Midterm.

Reading from textbook: Start Chapter 3.

Week 8: General Relativity: Experimental evidence, Light Bending, Gravitational Time Dilation

Week 9: Origin of Black Holes: Physics of Stars, Low-Mass Stars, Fusion, White Dwarfs

Reading from textbook: Excerpts from Chapters 4, 5, 6.

Week 10: Origin of Black Holes: High-Mass Stars, Neutron Stars, Black Hole Formation, Accretion

Take-home Assignment #3 due.

Week 11: Discovery of Black Holes: Discovery, Black Hole Census, Super-Massive Black Holes

Reading from textbook: Excerpts from Chapters 7, 8, 9.

Week 12: Discovery of Black Holes: Quasars, Galaxies, Correlations

Week 13: Waves to Wormholes: Gravitational Waves: Production, Detection, Discovery

Take-home Assignment #4 due.

Reading from textbook: Excepts from Chapters 10, 11, 12, and 14.

Essay Assigned.

Week 14: Waves to Wormholes: Quantum Mechanics, Hawking Radiation, Thermodynamics

Week 15: Waves to Wormholes: String Theory, Information Paradox, Time Travel

Essay Due.

Final Exam.

Learning Objectives

General Education Learning Goals & Outcomes

This course is approved as a part of the new GE Theme: Origins and Evolution.

GEN Goals

For all themes, the goals are that successful students will:

1. Analyze an important topic or idea at a more advanced and in-depth level than in the Foundations component. [Note: In this context, "advanced" refers to courses

that are e.g., synthetic, reply on research or cutting-edge findings, or deeply engage with the subject matter, among other possibilities.]

2. Integrate approaches to the theme by making connections to out-of-classroom experiences with academic knowledge or across disciplines and/or to work they have done in previous classes and that they anticipate doing in future.

Goals of the GEN *Number, Nature, and Mind* Theme in particular:

1. Successful students will analyze the nature of mathematics and/or mathematical reasoning at a more advanced and in-depth level than in the Foundations component.

2. Successful students will integrate approaches to number, nature, and mind by making connections to their own experience of mathematical thinking and its application in the world, and by making connections to work they have done in previous classes and/or anticipate doing in the future.

3. Successful students will experience and examine mathematics as an abstract formal system accessible to mental manipulation and/or mathematics as a tool for describing and understanding the natural world.

For all GEN Themes, the expected learning outcomes tied to the goals are that successful students will be able to:

1.1. Engage in critical and logical thinking about the topic or idea of the theme.

1.2. Engage in an advanced, in-depth, scholarly exploration of the topic or idea of the theme.

2.1. Identify, describe, and synthesize approaches or experiences as they apply to the theme.

2.2. Demonstrate a developing sense of self as a learner through reflection, self-assessment, and creative work, building on prior experiences to respond to new and challenging contexts.

For **the GEN *Number, Nature, and Mind* Theme, the Expected Learning Outcomes tied to the goals are that** successful students are able to:

1.1 Engage in critical and logical thinking about the ideas embodied within “Number, Nature, Mind”

1.2 Engage in an advanced, in-depth, scholarly exploration of the ideas embodied by “Number, Nature, Mind”.

2.1 Identify, describe, and synthesize approaches or experiences as they apply to “Number, Nature, Mind”.

2.2 Demonstrate a developing sense of self as a learner through reflection, self-assessment, and creative work, building on prior experiences to respond to new and challenging contexts.

3.1 Analyze and describe how mathematics functions as an idealized system that enables logical proof and/or as a tool for describing and understanding the natural world or human cognition.

The specific learning objectives for Astronomy 2142 (Black Holes) are:

1. Students develop a physical understanding of Newton's and Einstein's theories of gravity, space, and time, the similarities and differences between them, and the senses in which Einstein's theory has superseded Newton's.

2. Students understand how Einstein's theory leads to the prediction of black holes and of the properties it predicts black hole to have.

3. Students understand the interplay between gravity, pressure, and nuclear energy generation in governing the life cycle of stars, and of how and why the deaths of massive stars are expected to lead to the formation of black holes.

4. Students understand how astronomers discovered the first empirical evidence for black holes and how they have set out to demonstrate the existence of black holes as conclusively as possible.

5. Students understand why supermassive black holes are thought to be the central engines of quasars, the most luminous objects in the cosmos, and the observational methods that are used to study quasars and the dormant black holes they have left behind in the centers of galaxies.

6. Students understand the ways that advanced space missions currently under development might lead to deeper understanding of black holes, by measuring X-rays from gas falling towards the event horizon and by measuring gravity waves – propagating ripples in spacetime – produced by colliding black holes at the far edge of the universe.

How this course meets the GEN ELOs:

The topics at the core of Astronomy 2142 – the Newtonian revolution, special and general relativity, black holes and gravitational waves – are among *the most striking examples* of mathematics as a tool for describing and understanding the natural world, making them an ideal subject for addressing these objectives.

You will experience these striking applications of mathematics to physics – Number to Nature – throughout the lectures, readings, and homework assignments. You will learn how mathematics functions as a tool for analyzing the natural world from lectures and readings and, above all, from solving multi-part problems on homework assignments which take you from initial assumptions to sometimes surprising conclusions. The concluding essay will invite you to reflect on the role of mathematical reasoning in the theory of gravity, spacetime, and black holes and on the empirical confirmation of mathematically derived consequences of that theory. This interplay goes to the heart of the Number, Nature, and Mind theme, illustrating that human application of the abstract language of mathematics can lead to startling predictions about the natural world that can then be tested and confirmed by observations and experiments.

This course is also approved as a part of the legacy GE Natural Science-Physical Science category.

Learning Objectives – GE Legacy (GEL) Course

General Education Learning Goals & Outcomes

Students taking the course for the Legacy GE (GEL) will have the following goals and expected learning outcomes.

Goals: Successful students will:

Understand the principles, theories, and methods of modern science, the relationship between science and technology, the implications of scientific discoveries and the potential of science and technology to address problems of the contemporary world.

Expected Learning Outcomes, GEL. The expected learning objective tied to the GEL goals are that students

1. **Understand the basic facts, principles, theories and methods of modern science.**
2. **Understand key events in the development of science and recognize that science is an evolving body of knowledge.**
3. **Describe the inter-dependence of scientific and technological developments.**
4. **Recognize social and philosophical implications of scientific discoveries and understand the potential of science and technology to address problems of the contemporary world.**

How this course meets the GEL ELOs:

We use the study of black holes, and more broadly the Special and General Theories of Relativity, as a worked example for the development of a modern scientific theory. This includes the development of the theory of gravity, from Galileo, Kepler, and Newton through to Einstein. The intellectual evolution of the subject is intimately linked with scientific and technical discoveries, such as the ability to detect gravitational wave signatures, and we tie it to broader philosophical implications.

Academic Misconduct

It is the responsibility of the Committee on Academic Misconduct to investigate or establish procedures for the investigation of all reported cases of student academic misconduct. The term “academic misconduct” includes all forms of student academic misconduct wherever committed; illustrated by, but not limited to, cases of plagiarism and dishonest practices in connection with examinations. Instructors shall report all instances of alleged academic misconduct to the committee (Faculty Rule 3335-5-487). For additional information, see the Code of Student Conduct http://studentlife.osu.edu/csc/.

Students with Disabilities

The University strives to make all learning experiences as accessible as possible. In light of the current pandemic, students seeking to request COVID-related accommodations may do so through the university's request process, managed by Student Life Disability

Services. If you anticipate or experience academic barriers based on your disability (including mental health, chronic or temporary medical conditions), please let me know immediately so that we can privately discuss options. To establish reasonable accommodations, I may request that you register with Student Life Disability Services. After registration, make arrangements with me as soon as possible to discuss your accommodations so that they may be implemented in a timely fashion. SLDS contact information: slds@osu.edu; 614-292-3307; slds.osu.edu; 098 Baker Hall, 113 W. 12th Avenue.

Mental Health Statement

As a student you may experience a range of issues that can cause barriers to learning, such as strained relationships, increased anxiety, alcohol/drug problems, feeling down, difficulty concentrating and/or lack of motivation. These mental health concerns or stressful events may lead to diminished academic performance or reduce a student's ability to participate in daily activities. The Ohio State University offers services to assist you with addressing these and other concerns you may be experiencing. If you or someone you know are suffering from any of the aforementioned conditions, you can learn more about the broad range of confidential mental health services available on campus via the Office of Student Life's Counseling and Consultation Service (CCS) by visiting ccs.osu.edu or calling 614-292-5766. CCS is located on the 4th Floor of the Younkin Success Center and 10th Floor of Lincoln Tower. You can reach an on call counselor when CCS is closed at 614-292-5766 and 24 hour emergency help is also available 24/7 by dialing 988 to reach the Suicide and Crisis Lifeline.

Religious Accommodations

Our inclusive environment allows for religious expression. Students requesting accommodations based on faith, religious or a spiritual belief system in regard to examinations, other academic requirements or absences, are required to provide the instructor with written notice of specific dates for which the student requests alternative accommodations at the earliest possible date. For more information about religious accommodations at Ohio State, visit odi.osu.edu/religious-accommodations.

Weather Or Other Short-Term Closing

Should in-person classes be canceled, we may meet virtually via Zoom during our regularly scheduled time. All updates on course schedule will be communicated via Carmen.

Last Revised: February 2023

Astronomy 1142: Black Holes
Autumn 2021

Meetings: MWF, 3:00 - 3:55, Evans Lab 1008

Web page: http://www.astronomy.ohio-state.edu/∼dhw/A1142

Midterm exam: Wednesday, October 13, in class

Final exam: Friday December 10, noon-1:45 pm, in regular classroom

Instructor: Professor David Weinberg, Dept. of Astronomy, weinberg.21@osu.edu, 292-1773
4055A McPherson Lab (4th floor, enter through main office), mailbox by office

In-person office hours: Thursday, 11:30-12:30, McPherson 4055

Virtual office hours: Friday, 9:15-10:30, Zoom ID 827 776 2849, Passscode 1420

I will usually be available after class 3:55 - 4:20 on Monday and Wednesday

Teaching Assistant: John Bredall, PhD Student, Dept. of Astronomy, bredall.1@osu.edu

Course Material

Black holes are among the strangest objects ever conceived by science, with gravity so strong that it traps light and warps space and time almost beyond recognition. But black holes are more than theoretical oddities — astronomical observations provide strong evidence that they exist, in at least two varieties. Stellar mass black holes are created in the explosive deaths of massive stars, and they can "light up" and become detectable by ingesting the outer layers of orbiting companions. Supermassive black holes, millions or even billions of times more massive than the sun, reside at the centers of galaxies and power quasars, the most luminous objects in the universe. Pairs of black holes can spiral together by emitting gravitational waves, ripples of spacetime that propagate through the cosmos at the speed of light.

This course will tell the story of black holes: how they were conceived as theoretical ideas, how they might form from dying stars, how they were discovered, what roles they play in cosmic history, how they distort space and time, how they produce tiny but detectable gravitational wave signals, and some of the remaining mysteries they present to contemporary physics. Along the way we will learn about Newton's theory of gravity, Einstein's theory of space and time, the life cycle of stars, and the nature of quasars. We will also see how astronomers use observations from telescopes and satellites together with basic physical principles to demonstrate the reality of black holes. The Nobel Prize in Physics from 2017 and the Nobel Prize in Physics from 2020 were both tightly connected to topics of this course, as were earlier Nobel Prizes from 1983, 1993, and 2002.

Course Topics

More specifically, the topics I aim to cover are:

- Newton's theory of gravity
- Special Relativity and spacetime
- General Relativity: Einstein's theory of gravity
- Stellar death and black hole birth
- Stellar mass black holes
- Galaxies, quasars, and supermassive black holes
- The Milky Way's central black hole and the Event Horizon Telescope
- Gravitational waves and black hole mergers
- Black hole evaporation and other exotica

Prerequisites

The only prerequisite is math at the level of Math 1050 (actually, well below this level would be sufficient). The math in this course will not go beyond simple algebra, but there will be equations and geometrical or mathematical reasoning in the lectures and in the assignments. The math itself will not be difficult, but the concepts will be challenging, and *translating concepts into equations and back is one of the major things you will learn during the course.*

Textbook and Lecture Notes

The textbook is *Black Holes and Time Warps: Einstein's Outrageous Legacy*, by Kip Thorne.

This is not your typical science textbook. It was written as a popular book for a broad audience, and it covers both the science of black holes and the history of black hole discoveries. It does not perfectly match to our course material, covering some topics in less detail than we will treat them and other topics in more detail. On the whole, it is a great book, written by one of the world's most creative black hole researchers.

I will specify required and optional reading assignments with each new section of the course.

I will provide lecture notes through the course web page as we get to each new section of the course. You can decide for yourself how best to use them, but you will probably find some hybrid between taking your own class notes and referring to my notes is the most effective.

Assignments, exams, and grading

Grades will be based on four take-home assignments (30% total), in-class questions (20% total), a midterm exam (20%), and a final exam (30%). The take-home assignments will consist of questions from the lectures and reading and problems for you to work out, and they should typically take 4-8 hours apiece. I will accept assignments up to 3 days late but with a substantial penalty (see individual assignments for specifics). There will be in-class questions on most class days. I will drop the three lowest scores from the in-class questions and average the rest. While there is no direct attendance grade, if your attendance is poor you will inevitably do poorly on the in-class question grade, and probably on everything else as well.

Homework assignments must be submitted on paper, not electronically. If you are unable to attend class on the day an assignment is due, turn the assignment in to my mailbox in 4055 McPherson Lab prior to class.

You will be allowed one page (both sides) of handwritten notes for the midterm and two pages (both sides) of handwritten notes for the final.

Makeup exams will be allowed only under exceptional circumstances and by prior arrangement. Makeup exams will be oral and/or essay exams that cover the same general topics as the original exam but in different form.

How To Do Well In This Course

The most important advice is: come to class, start early on the take-home assignments, and get help on those assignments if you need it.

The take-home assignments are intended to be challenging. However, you are welcome to come to my in-person or virtual office hours to get help on them. You may also want to form study groups with others in the class to work on the assignments. You are welcome to do so, though the assignment you turn in at the end must be your own work. If you devote enough time to the assignments and get help on them as needed, you should be able to do well on this portion of the course grade. The work you put into the assignments will also improve your performance on the exams, but that is not the primary purpose of the assignments. They are an integral part of the course in their own right.

For doing well on the exams, my advice is to spend some time each week going over the lecture notes and the in-class questions, identify any things you don't understand, and ask me about them. There will also be question & answer review sessions before the midterm and the final, and attending these will likely improve your performance. I will give other advice in advance of the exams themselves.

Electronics

Calculators are allowed in class and exams. For exams, you may *not* use a cell phone, so you'll need a physical calculator if you want one. For the take-home assignments and some in-class questions, *you will need a calculator with scientific notation, and you will need to know how to use it.*

Except for in-class questions, I ask that you not use cell phones, iPads, or laptops in class. If you regularly use an iPad for taking notes that is OK, but please let me know and please use it in a way that doesn't distract others.

Academic Misconduct

It is the responsibility of the Committee on Academic Misconduct to investigate or establish procedures for the investigation of all reported cases of student academic misconduct. The term academic misconduct includes all forms of student academic misconduct wherever committed; illustrated by, but not limited to, cases of plagiarism and dishonest practices in connection with examinations. Instructors shall report all instances of alleged academic misconduct to the committee (Faculty Rule 3335-5-487). For additional information, see the Code of Student Conduct (studentconduct.osu.edu).

Students with Disabilities

Students with disabilities (including mental health, chronic or temporary medical conditions) that have been certified by the Office of Student Life Disability Services will be appropriately accommodated and should inform me as soon as possible of their needs. The Office of Student Life Disability Services is located in 098 Baker Hall, 113 W. 12th Avenue; telephone 614-292-3307, slds@osu.edu.

Learning objectives

The Curriculum Committee of the College of Arts & Sciences requests that syllabi of all GE courses list the goals and learning objectives for the relevant category of the GEC.

As a Natural Science GE course, the goals are: "Students understand the principles, theories, and methods of modern science, the relationship between science and technology, the implications of scientific discoveries and the potential of science and technology to address problems of the contemporary world."

More specifically, the "Expected Learning Outcomes" for GE Physical Science courses are:

1. Students understand the basic facts, principles, theories and methods of modern science.

2. Students understand key events in the development of science and recognize that science is an evolving body of knowledge.

3. Students describe the inter-dependence of scientific and technological developments.

4. Students recognize social and philosophical implications of scientific discoveries and understand the potential of science and technology to address problems of the contemporary world.

Black holes are an ideal subject for addressing these objectives. In this course we will examine one of the most remarkable scientific stories of the past two centuries, one in which theory, observation, and technology all play crucial and interlocking roles. This story illuminates many facets of the way that scientific inquiry and scientific discovery work to advance human knowledge. Relativity and black holes challenge many of our everyday notions about the nature of reality, sometimes raising questions at the border of science and philosophy.

Some notable dates

Mon Sep 6: Labor Day, no class

Fri Sep 10: Homework assignment 1 handed out

Fri Sep 17: Homework assignment 1 due (at beginning of class)

Fri Sep 24: Homework assignment 2 handed out

Fri Oct 1: Homework assignment 2 due (at beginning of class)

Wed Oct 13: Midterm exam, in class (full period)

Fri Oct 15: Fall break, no class

Fri Oct 29: Homework assignment 3 handed out

Fri Nov 5: Homework 3 due

Mon Nov 22: Homework 4 handed out

Wed Nov 24 and Fri Nov 26: Thanksgiving break, no class

Fri Dec 3: Homework 4 due (at beginning of class)

Fri Dec 10: Final exam, noon - 1:45 pm, in usual classroom

I may adjust the handout/due dates of the homework assignments depending on progress of the class. I won't change the date of the midterm unless we get thrown seriously off schedule by the pandemic.

New Theme Course Submission Form

Astronomy 2142: Black Holes

Submitted for approval for the new theme Number, Nature, and Mind

Background Statement

Astronomy 1142, Black Holes, has been taught as a Natural Sciences GE course since 2009. Traditionally, Astronomy has numbered all of its GE classes at 1000-level and used 2000-level and above for calculus-based courses designed for astronomy & astrophysics majors. Under the revised GE, we are numbering Foundation courses at 1000-level and renumbering the Theme courses to 2000-level. These courses, including Black Holes, have always required the application of algebra and geometry to understanding the physical universe and solving astrophysics problems. Our renumbering partly acknowledges that students have always regarded these courses as challenging, and it also recognizes the higher level of presentation, discussion, and assignments that are feasible now that students will have completed the Natural Sciences Foundation requirement before taking them.

As described in detail on the syllabus, Astronomy 2142 covers several of the most revolutionary transformations in modern science: the discovery of Newton's laws of motion and gravity, the discovery that space and time and inextricably linked (Einstein's Special Relativity), the modern description of gravity as a phenomenon of curved spacetime (Einstein's General Relativity, GR), the discovery that GR predicts the existence of collapsed objects whose gravity can trap light (black holes), and the extraordinary technological advances in physics and astronomy that have enabled the empirical discovery of stellar mass black holes, supermassive black holes, and gravitational waves. The story of gravity, GR, black holes, and gravitational waves is one of the most stunning examples of the power of mathematics to explain the natural world and predict startling new phenomena, making Astronomy 2142 an ideal course for the *Number, Nature, and Mind* GE Theme.

The 3-credit hour course is comprised of class meetings involving lecture and small-group discussions, in-class questions based on those discussions, readings from the book *Black Holes and Time Warps* by Nobel Prize winning physicist Kip Thorne, homework assignments that include reflection questions based on lectures and reading and multi-part calculational problems that guide students through key topics in gravity and black holes, a concluding essay assignment in which students reflect on course themes, and a midterm and final exam that test mastery of course material. The book is a popular-level but sophisticated account of the history of relativity and black holes written by one of the field's leading scientists, and it is exceptionally good at demonstrating the often circuitous track of major scientific advances. The in-class questions and homework assignments play central roles in achieving the ELOs and assessing that achievement. Examples of the multi-part questions from the homework assignments include: using Newton's theory of gravity to explain Kepler's 3rd law of planetary motion and to infer the mass of Jupiter from the motion of its moons; demonstrating that chemical burning cannot account for the age of the sun but the combination of nuclear fusion and $E=mc^2$ can do so; computing the maximum luminosity and growth rate of a supermassive black hole; and using a detected gravitational wave signal to infer the masses and distance of the merging black holes that produced it. For in-class questions, students first work individually, then discuss their answers with a small group of peers before submitting them. Some of these are reflective, asking students to identify questions they have about black holes or the scientists they found most interesting or surprising in a section of the reading. Some are review, helping students synthesize recently covered material and prepare for exams. Some are advanced, guiding students to deduce $E=mc^2$ from a thought experiment based on momentum conservation, or to compute the measurable impact of a gravitational wave, the angular resolution of the global antenna network that comprises the Event Horizon Telescope, or the time required for a black hole to evaporate through Hawking radiation.

In the remainder of this form, instructions and examples have been set in blue type while the new responses are set in black type.

Overview

Each category of the General Education (GE) has specific learning goals and Expected Learning outcomes that connect to the big picture goals of the program. Expected Learning Outcomes (ELOs) describe the knowledge or skills students should have by the end of the course. Courses in the GE Themes must meet the ELOs common for **all** GE Themes and those specific to the Theme, in addition to any ELOs the instructor has developed specific to that course.

The prompts below provide the goals of the GE Themes and seek information about which activities (discussions, readings, lectures, assignments) provide opportunities for students to achieve the ELO's associated with that goal. The answer should be concise and use language accessible to colleagues outside of the submitting department or discipline. The specifics of the activities matter—listing "readings" without a reference to the topic of those readings will not allow the reviewers to understand how the ELO will be met. However, the panel evaluating the fit of the course to the Theme will review this form in conjunction with the syllabus, so if readings, lecture/discussion topics, or other specifics are provided on the syllabus, it is not necessary to reiterate them within this form.

Goals and ELOs shared by *all* Themes

Goal 1: Successful students will analyze an important topic or idea at a more advanced and in-depth level than the foundations. In this context, "advanced" refers to courses that are e.g., synthetic, rely on research or cutting-edge findings, or deeply engage with the subject matter, among other possibilities.

Goal 2: Successful students will integrate approaches to the theme by making connections to out-of-classroom experiences with academic knowledge or across disciplines and/or to work they have done in previous classes and that they anticipate doing in future.

For each of the ELOs below, please identify and explain course assignments, readings, or other activities within this course that provide opportunity for students to attain the ELO. If the specific information is listed on the syllabus, it is appropriate to point to that document. The ELOs are expected to vary in their "coverage" in terms of number of activities or emphasis within the course. Examples from successful courses are shared on the next page.

Course subject & number

ELO 1.1 Engage in critical and logical thinking.	As described in the syllabus and background statement, students will engage in logical thinking as they derive the consequences of theories of gravity and black holes by applying physical intuition and mathematical reasoning, in lectures and small-group discussions and, especially, in answering in-class questions and homework problems. Students will engage in critical thinking as they reflect on the theoretical and experimental advances that led to new theories of motion, gravity, spacetime, and black holes, addressed in lectures, in small-group discussions and some in-class questions, in readings, and in reflection questions on homework assignments and the concluding essay.
ELO 2.1 Identify, describe, and synthesize approaches or experiences.	Astronomy 2142 begins with the Newtonian revolution and ends with cutting-edge discoveries of the 21st century. In understanding and describing these advances, students will build on the knowledge they have gained from the Natural Sciences foundation courses. The story of gravity and black holes involves an extraordinary, centuries-long interplay between theoretical development and experimental or observational discoveries. Throughout the course students are challenged to identify these approaches, describe the interplay between them, and explain how the synthesis of theory and experiment leads to scientific advances. Students experience this challenge in lectures and reading, in in-class questions, and in homework assignments and exams.
ELO 2.2 Demonstrate a developing sense of self as a learner through reflection, self-assessment, and creative work, building on prior experiences to respond to new and challenging contexts.	At a concrete level, the development and progression of students in Astronomy 2142 is traced most clearly through the increasing sophistication of the multi-part problems in the homework assignments. For example, in the first assignment students use Newton's laws of motion and gravity, soon after they are covered in lecture, to deduce the mass of Jupiter from the orbits of its moons. In a later assignment, students apply the same ideas to calculate orbital periods around white dwarf stars, neutron stars, or black holes. After examining fusion as the energy source of the sun in the second assignment, they compare this energy to the gravitational energy released by supernova explosions and accreting supermassive black holes in subsequent assignments. In the final assignment they apply what they have learned about orbits and gravitational waves to deduce the masses and distances of merging black holes from the observed signal of the first directly detected gravitational wave. At a more abstract level, student reflection and self-assessment occurs through in-class, homework, and exam questions. For example, at several points throughout the course students are asked "what surprised you the most?" about a particular topic, and why. The answers to this question are sometimes startlingly insightful.

Example responses (from Sociology 3200, Comm 2850, French 2803):

ELO 1.1 Engage in critical and logical thinking.	*This course will build skills needed to engage in critical and logical thinking about immigration and immigration related policy through:* • *Weekly reading response papers which require the students to synthesize and critically evaluate cutting-edge scholarship on immigration;* • *Engagement in class-based discussion and debates on immigration-related topics using evidence-based logical reasoning to evaluate policy positions;* • *Completion of an assignment which build skills in analyzing empirical data on immigration (Assignment #1)* • *Completion 3 assignments which build skills in connecting individual experiences with broader population-based patterns (Assignments #1, #2, #3)* • *Completion of 3 quizzes in which students demonstrate comprehension of the course readings and materials.*
ELO 2.1 Identify, describe, and synthesize approaches or experiences.	*Students engage in advanced exploration of each module topic through a combination of lectures, readings, and discussions.* *<u>Lecture</u>* *Course materials come from a variety of sources to help students engage in the relationship between media and citizenship at an advanced level. Each of the 12 modules has 3-4 lectures that contain information from both peer-reviewed and popular sources. Additionally, each module has at least one guest lecture from an expert in that topic to increase students' access to people with expertise in a variety of areas.* *<u>Reading</u>* *The textbook for this course provides background information on each topic and corresponds to the lectures. Students also take some control over their own learning by choosing at least one peer-reviewed article and at least one newspaper article from outside the class materials to read and include in their weekly discussion posts.* *<u>Discussions</u>* *Students do weekly discussions and are given flexibility in their topic choices in order to allow them to take some control over their education. They are also asked to provide information from sources they've found outside the lecture materials. In this way, they are able to explore areas of particular interest to them and practice the skills they will need to gather information about current events, analyze this information, and communicate it with others.* *Activity Example: Civility impacts citizenship behaviors in many ways. Students are asked to choose a TED talk from a provided list (or choose another speech of their interest) and summarize and evaluate what it says about the relationship between civility and citizenship. Examples of Ted Talks on the list include Steven Petrow on the difference between being polite and being civil,*

	Chimamanda Ngozi Adichie's talk on how a single story can perpetuate stereotypes, and Claire Wardle's talk on how diversity can enhance citizenship.
ELO 2.2 Demonstrate a developing sense of self as a learner through reflection, self-assessment, and creative work, building on prior experiences to respond to new and challenging contexts.	*Students will conduct research on a specific event or site in Paris not already discussed in depth in class. Students will submit a 300-word abstract of their topic and a bibliography of at least five reputable academic and mainstream sources. At the end of the semester they will submit a 5-page research paper and present their findings in a 10-minute oral and visual presentation in a small-group setting in Zoom.* *Some examples of events and sites:* – *The Paris Commune, an 1871 socialist uprising violently squelched by conservative forces* – *Jazz-Age Montmartre, where a small community of African-Americans–including actress and singer Josephine Baker, who was just inducted into the French Pantheon–settled and worked after World War I.* – *The Vélodrome d'hiver Roundup, 16-17 July 1942, when 13,000 Jews were rounded up by Paris police before being sent to concentration camps* – *The Marais, a vibrant Paris neighborhood inhabited over the centuries by aristocrats, then Jews, then the LGBTQ+ community, among other groups.*

Goals and ELOs of the GE Theme: Number, Nature, and Mind

GOAL 1: 1. Successful students will analyze the nature of mathematics and/or mathematical reasoning at a more advanced and in-depth level than in the Foundations component.

GOAL 2: Successful students will integrate approaches to number, nature, and mind by making connections to their own experience of mathematical thinking and its application in the world, and by making connections to work they have done in previous classes and/or anticipate doing in the future.

GOAL 3: Successful students will experience and examine mathematics as an abstract formal system accessible to mental manipulation and/or mathematics as a tool for describing and understanding the natural world.

Enter your ELOs in the Table below, editing and removing rows as needed. There should be at least one ELO for each goal, and they should be numbered to correspond to the goal (e.g., ELO1.1 is the first ELO for Goal 1, ELO 2.2 would be the second ELO for the second goal).

For each ELOs, please identify and explain course assignments, readings, or other activities within this course that provide opportunity for students to attain the ELO. If the specific information is listed on the syllabus, it is appropriate to point to that document. The number of activities or emphasis within the course are expected to vary among ELOs. Examples from successful courses are shared below.

ELO 1.1 Engage in critical and logical thinking about the nature and/or application of mathematical reasoning.	As described in the syllabus and background statement, students will engage in logical thinking about the application of mathematical reasoning as they derive the consequences of theories of gravity and black holes, in lectures and small-group discussions and, especially, in answering in-class questions and homework problems. Students will engage in critical thinking about the application of mathematical reasoning as they reflect on the way that it leads to novel predictions and on the experimental tests of those predictions. These reflections arise in lecture, in small-group discussions and some in-class questions, in readings, and in reflection questions on homework assignments, and in the concluding essay (discussed further under ELO 3.1).
ELO 1.2 Engage in an advanced, in-depth, scholarly exploration of the philosophical and/or cognitive foundations of mathematics and/or the application of mathematics in understanding the natural world.	The topic of black holes engages students in an advanced, in-depth, scholarly exploration of the application of mathematics in understanding the natural world. Through lectures, students encounter this application to understanding first Newtonian gravity, then special and general relativity, then the theory of stars, black holes, and gravitational waves. Through lectures, in-class questions, and, especially, the multi-part problems on homework assignments, they experience the application of mathematical reasoning to derive empirically testable consequences of theories and to interpreting observational or experimental data. They demonstrate their understanding of this process in the assignments themselves and in answers to exam questions.
ELO 2.1 Identify, describe, and synthesize approaches to or experiences of the role of mathematics and mathematical reasoning in different academic and non-academic contexts.	The story of gravity and black holes involves an extraordinary, centuries-long interplay between theoretical development and experimental or observational discoveries. Throughout the course students are challenged to identify these approaches, describe the interplay between them, and explain how the synthesis of theory and experiment leads to scientific advances. Students experience this challenge in lectures and reading, in in-class questions, and in homework assignments and exams. In all aspects of the course, students apply mathematical reasoning in the context of physics and astrophysics, from Newtonian gravity through to cutting-edge discoveries of the 21st century. To build familiarity with and intuitive understanding of physical phenomena and the equations that describe them, lectures refer frequently

	to everyday experience, such as cars, playgrounds, and sports to illustrate acceleration and forces, or balloons and cooking to illustrate pressure, temperature, and thermodynamics. In homework assignments students apply mathematical reasoning to gravity and black holes; for some students, this means relearning algebraic or geometrical techniques that have become unfamiliar through disuse. Students emerge from the course with a refreshed understanding of how to apply quantitative reasoning to the everyday world, a strength that will serve them in context beyond academia.
ELO 2.2 Demonstrate a developing sense of self as a learner through reflection, self-assessment, and creative work, building on prior experiences to respond to new and challenging contexts.	At a concrete level, the development and progression of students in Astronomy 2142 is traced most clearly through the increasing sophistication of the multi-part problems in the homework assignments. For example, in the first assignment students use Newton's laws of motion and gravity, soon after they are covered in lecture, to deduce the mass of Jupiter from the orbits of its moons. In a later assignment, students apply the same ideas to calculate orbital periods around white dwarf stars, neutron stars, or black holes. After examining fusion as the energy source of the sun in the second assignment, they compare this energy to the gravitational energy released by supernova explosions and accreting supermassive black holes in subsequent assignments. In the final assignment they apply what they have learned about orbits and gravitational waves to deduce the masses and distances of merging black holes from the observed signal of the first directly detected gravitational wave. At a more abstract level, student reflection and self-assessment occurs through in-class, homework, and exam questions. For example, at several points throughout the course students are asked "what surprised you the most?" about a particular topic, and why. The answers to this question are sometimes startlingly insightful.
ELO 3.1 Analyze and describe how mathematics functions as an idealized system that enables logical proof and/or as a tool for describing and understanding the natural world.	The topics at the core of Astronomy 2142 – the Newtonian revolution, special and general relativity, black holes and gravitational waves – are among *the most striking examples* of mathematics as a tool for describing and understanding the natural world. (The other is the development of quantum mechanics and its application to atomic and sub-atomic phenomena.) Students experience these striking applications of mathematics to physics – Number to Nature – throughout the lectures, small-group discussions, readings, and homework assignments. They learn how mathematics functions as a tool for analyzing the natural world from lectures and readings and most viscerally from the

	experience of solving multi-part problems on homework assignments, which take them from initial assumptions to sometimes surprising conclusions. The concluding essay invites students to reflect on the role of mathematical reasoning in the theory of gravity, spacetime, and black holes and on the empirical confirmation of mathematically derived consequences of that theory. This interplay goes to the heart of the Nature, Number, and Mind theme, illustrating that human application of the abstract language of mathematics can lead to startling predictions about the natural world that can then be tested and confirmed by observations and experiments.

Example responses (from History/Religious Studies 3680, Music 3364; Sociology 3200) for the "Citizenship" Theme:

ELO 1.1 Describe and analyze a range of perspectives on what constitutes citizenship <u>and</u> how it differs across political, cultural, national, global, and/or historical communities.	*Citizenship could not be more central to a topic such as immigration/migration. As such, the course content, goals, and expected learning outcomes are all, almost by definition, engaged with a range of perspectives on local, national, and global citizenship. Throughout the class students will be required to engage with questions about what constitutes citizenship and how it differs across contexts.* *The course content addresses citizenship questions at the global (see weeks #3 and #15 on refugees and open border debates), national (see weeks #5, 7-#14 on the U.S. case), and the local level (see week #6 on Columbus). Specific activities addressing different perspectives on citizenship include Assignment #1, where students produce a demographic profile of a U.S-based immigrant group, including a profile of their citizenship statuses using U.S.-based regulatory definitions. In addition, Assignment #3, which has students connect their family origins to broader population-level immigration patterns, necessitates a discussion of citizenship. Finally, the critical reading responses have the students engage the literature on different perspectives of citizenship and reflect on what constitutes citizenship and how it varies across communities.*
ELO 1.2 Identify, reflect on, and apply the knowledge, skills and dispositions required for intercultural competence as a global citizen.	*This course supports the cultivation of "intercultural competence as a global citizen" through rigorous and sustained study of multiple forms of musical-political agency worldwide, from the grass-roots to the state-sponsored. Students identify varied cultural expressions of "musical citizenship" each week, through their reading and listening assignments, and reflect on them via online and in-class discussion. It is common for us to ask probing and programmatic questions about the musical-political subjects and cultures we study. What are the possibilities and constraints of this particular version of musical citizenship? What might we carry forward in our own lives and labors as musical citizens Further, students are encouraged to apply their emergent intercultural competencies as global, musical citizens in their midterm report and final project, in which weekly course topics inform student-led research and creative projects.*

Course subject & number

ELO 2.1 Examine, critique, and evaluate various expressions and implications of diversity, equity, inclusion, and explore a variety of lived experiences.	*Through the historical and contemporary case studies students examine in HIST/RS 3680, they have numerous opportunities to examine, critique, and evaluate various expressions and implications of diversity, equity, and inclusion, as well as a variety of lived experiences. The cases highlight the challenges of living in religiously diverse societies, examining a range of issues and their implications. They also consider the intersections of religious difference with other categories of difference, including race and gender. For example, during the unit on US religious freedom, students consider how incarcerated Black Americans and Native Americans have experienced questions of freedom and equality in dramatically different ways than white Protestants. In a weekly reflection post, they address this question directly. In the unit on marriage and sexuality, they consider different ways that different social groups have experienced the regulation of marriage in Israel and Malaysia in ways that do not correspond simplistically to gender (e.g. different women's groups with very different perspectives on the issues).* *In their weekly reflection posts and other written assignments, students are invited to analyze the implications of different regulatory models for questions of diversity, equity, and inclusion. They do so not in a simplistic sense of assessing which model is "right" or "best" but in considering how different possible outcomes might shape the concrete lived experience of different social groups in different ways. The goal is not to determine which way of doing things is best, but to understand why different societies manage these questions in different ways and how their various expressions might lead to different outcomes in terms of diversity and inclusion. They also consider how the different social and demographic conditions of different societies shape their approaches (e.g. a historic Catholic majority in France committed to laicite confronting a growing Muslim minority, or how pluralism *within* Israeli Judaism led to a fragile and contested status quo arrangement). Again, these goals are met most directly through weekly reflection posts and students' final projects, including one prompt that invites students to consider Israel's status quo arrangement from the perspective of different social groups, including liberal feminists, Orthodox and Reform religious leaders, LGBTQ communities, interfaith couples, and others.*
ELO 2.2 Analyze and critique the intersection of concepts of justice, difference, citizenship, and how these interact with cultural traditions, structures of power and/or advocacy for social change.	*As students analyze specific case studies in HIST/RS 3680, they assess law's role in and capacity for enacting justice, managing difference, and constructing citizenship. This goal is met through lectures, course readings, discussion, and written assignments. For example, the unit on indigenous sovereignty and sacred space invites students to consider why liberal systems of law have rarely accommodated indigenous land claims and what this says about indigenous citizenship and justice. They also study examples of indigenous activism and resistance around these issues. At the conclusion of the unit, the neighborhood exploration assignment specifically asks students to take note of whether and how indigenous land claims are marked or acknowledged in the spaces they explore and what they learn from this about citizenship, difference, belonging, and power. In the unit on legal pluralism, marriage, and the law, students study the personal law systems in Israel and Malaysia. They consider the structures of power that privilege certain kinds of communities and identities and also encounter groups advocating for social change. In their final projects, students apply the insights they've gained to particular case studies. As they analyze their selected case*

	studies, they are required to discuss how the cases reveal the different ways justice, difference, and citizenship intersect and how they are shaped by cultural traditions and structures of power in particular social contexts. They present their conclusions in an oral group presentation and in an individually written final paper. Finally, in their end of semester letter to professor, they reflect on how they issues might shape their own advocacy for social change in the future.