

Lessons on Teaching Undergraduate General Relativity and Differential Geometry Courses

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Abstract

We describe the course content and lessons learned teaching simultaneously offered courses to undergraduate physics and mathematics majors. A subset of students took both courses. The general relativity course was offered in the physics curriculum and focused more on the physics with standard mathematics prerequisites. The differential geometry course was aimed at the geometry of curves and surfaces ending with a study Cartan's equations and applications to computing curvatures in general relativity.

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General Relativity

Geometry on a Sphere

Special Relativity

Four Vectors

Dynamics

Principle of Equivalence

Newtonian Gravity

Metrics

Light Cones

Local Inertial Frames

Curved Spacetime

Geodesic Equation

Symmetries and Conservation Laws

Schwarzschild Solution

Gravitational Redshift

Perihelion Shift

Black Holes

Cosmology

Einsteins Equation

Prerequisites: Multivariate Calculus, Classical Mechanics, Modern Physics, Jr-Sr Standing.

Text: J. B. Hartle, *Gravity: An Introduction to Einstein's General Relativity*, Addison-Wesley, 2003.

Differential Geometry

Linear Algebra	Exterior Derivatives
Tangent Vectors	Hodge * Operator
Curves	Frames
Fundamental Theorem of Curves	Curvilinear Coordinates
Surfaces	Covariant Derivatives
Curvature of Curves and Surfaces	Cartan Equations
1-Forms	Manifolds
Tensors	Fundamental Forms
Higher Rank Forms	Curvature and Einsteins Equation

Prerequisites: Linear Algebra, Multivariate Calculus, Jr-Sr Standing.

Text: G. Lugo, *Differential Geometry and Physics*, 1995, 1998, 2004; M. Lipschutz , *Schaum's Outline of Differential Geometry*, 1969.

Class Members

General Relativity 7 physics majors at junior and senior level.

Differential Geometry 5 physics majors, 3 mathematics majors. (Several double majors)

Overlap 5 students took both classes.

Both instructors attended/participated in both courses.

Class Organization

Physics

Lecture Room

Large Blackboard

Computer Projection/Internet

Use of Web Sites

Maple 10 Worksheet Demos

HW selected from text - Physics based

2 In-class Exams/In-class Final

Two Projects

Mathematics

Small Computer Lab

Sliding White Boards

Computer Projection/Internet

Lectures Handwritten and Projected

Maple 10 Worksheet Demos

HW handouts - 'simple' computations

2 In-class Exams/Take Home Final

One Optional Project

GR Survey - Halfway Into the Course

1. Future Topics

Rank the following topics as to which you would hope to see most (9) to least (1).

- (a) Solar System Tests of General Relativity
- (b) Gravitational Lensing, Accretion Disks, and Binary Pulsars
- (c) Collapse to a Black Hole
- (d) Astrophysical Black Holes
- (e) Gravitational Waves
- (f) Cosmological Models
- (g) Cosmological Parameters and Surveys of the Universe
- (h) Curvature and the Einstein Equation (Requires more mathematics)

2. Study Habits

- (a) I read the lecture material in the book
 - a. Well before the lecture b. The night before the lecture c. After the lecture d. In pieces as I work through the problems e. I do not read the book
- (b) I usually start the homework
 - a. As soon as it is assigned b. Only within two days its is due c. After it is due
- (c) I typically seek help with the homework
 - a. Never b. Rarely c. Once each homework c. Twice each homework d. More than twice for each homework
- (d) When doing homework I
 - a. Work alone b. Sometimes consult with classmates c. Sometimes work in groups d. Always work with at least one other classmate

3. I have problems with
 - (a) Trigonometry
 - (b) Hyperbolic Functions
 - (c) Physics 201 Material
 - (d) Classical Dynamics Material
 - (e) Recalling Spherical Coordinates
 - (f) Indices
 - (g) Approximations Involving Small Quantities
 - (h) Other?

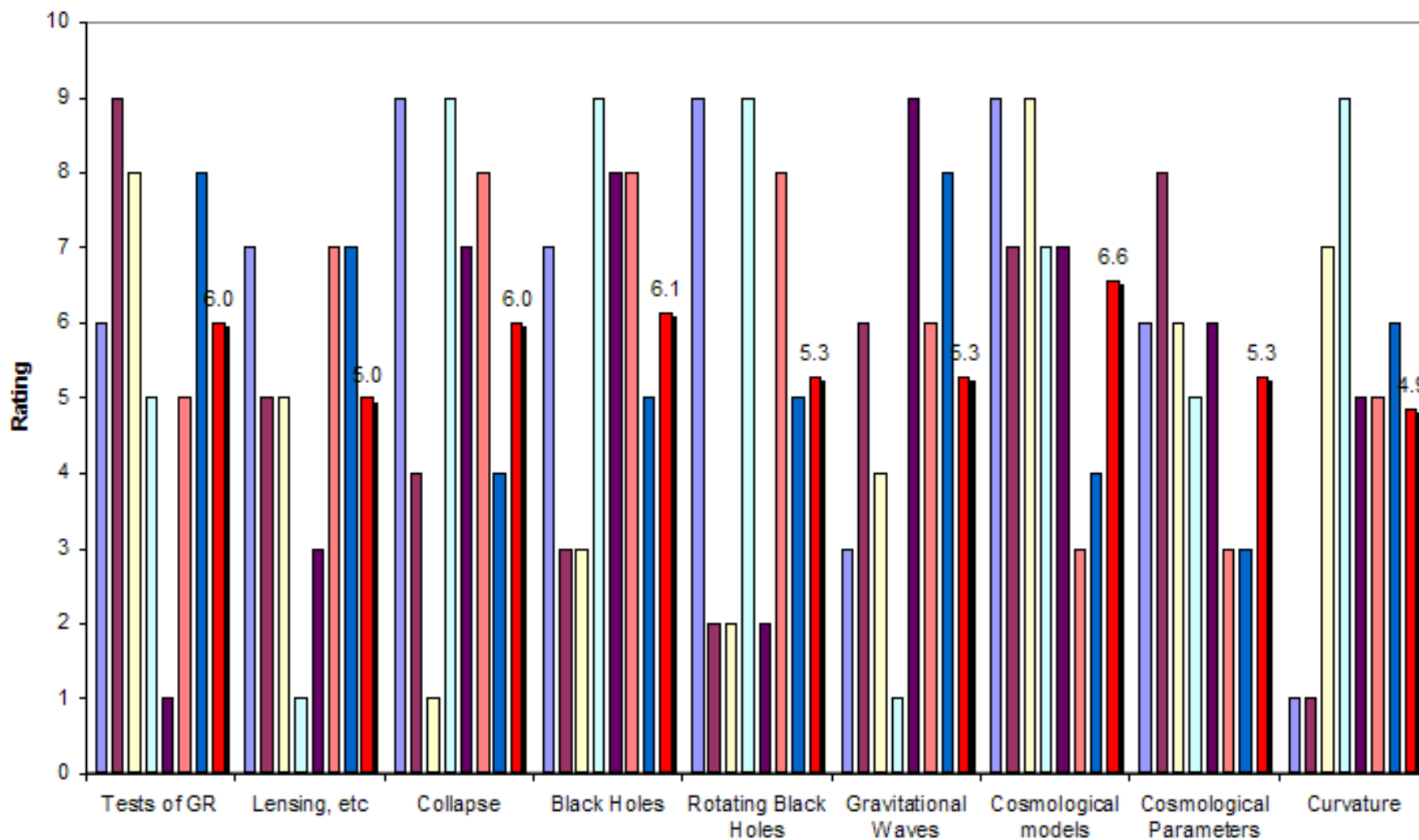
Lessons Learned

Undergraduates need

1. more linear algebra emphasizing linear transformations, the spectral theorem and applications
2. more exposure to using approximations based on binomial expansions
3. more geometric insight
4. more exposure to indexed quantities
5. more practice doing homework in physics classes
6. lessons on how to read physics and mathematics texts
7. to learn how to transfer knowledge between courses

Rank the following topics as to which you would hope to see most (9) to least (1).

Interest in Future Topics
Averages Given with Red Bar



Study Habits I

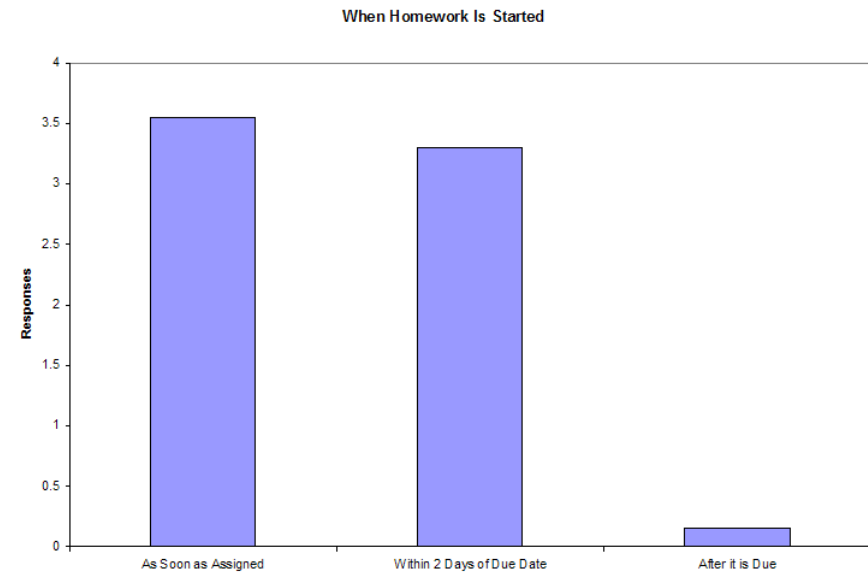
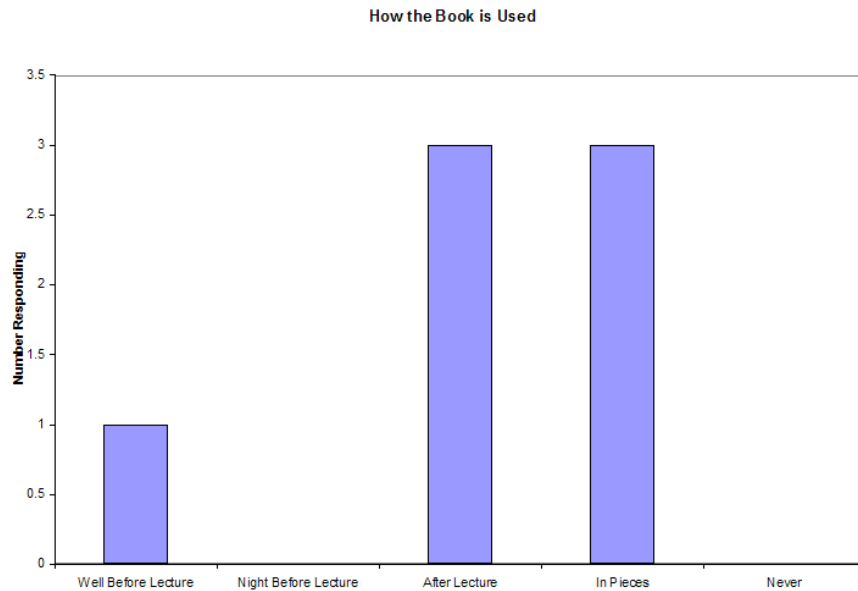


Figure 1: I read the material in the book ...

Figure 2: I usually start the homework ...

Study Habits II

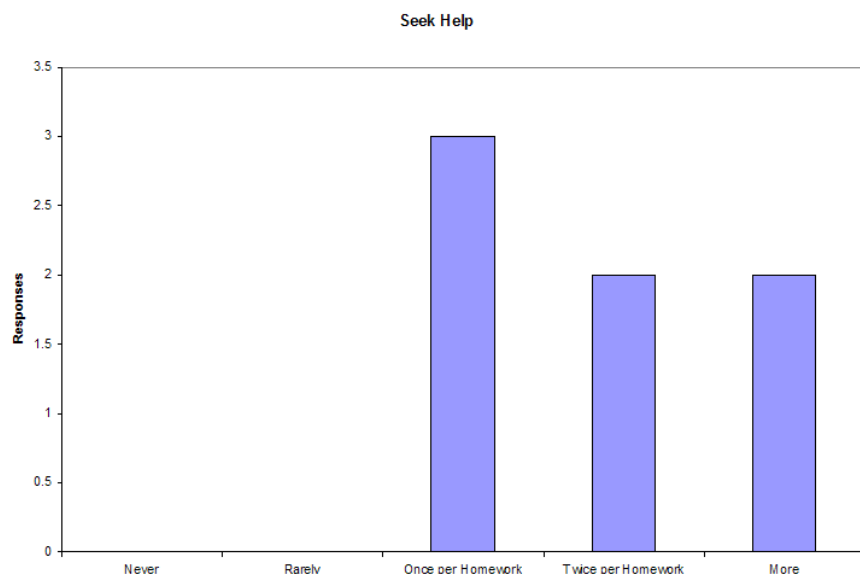


Figure 3: I typically seek help ...

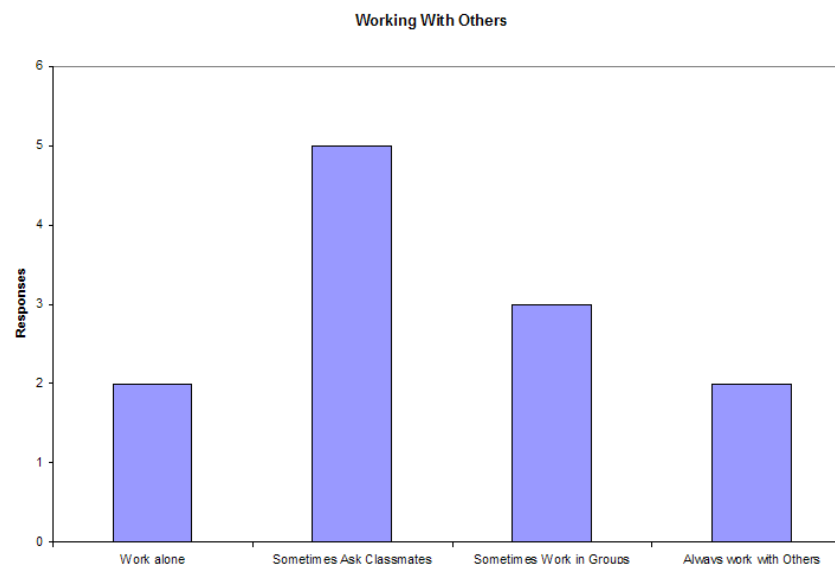


Figure 4: When doing homework I ...

I have problems with ...

