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# ECE 518 - Biophotonics

## Course Details

Instructor: Randy A. Bartels

Office: B316 Scott Bioengineering

Office Hours: By appointment

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Phone: (970) 491-8971

### Classroom information:

Lecture: 11:00 am - 11:50 am , M/W/F Engineering B2

Dates: Aug. 23 - Dec. 14

### Class Zoom Information:

Join Zoom Meeting

<https://zoom.us/j/97109727630?pwd=bmk4Z0txZFpCeHd3QUxsZHpwOUJJZz09>

(<https://zoom.us/j/97109727630?pwd=bmk4Z0txZFpCeHd3QUxsZHpwOUJJZz09>)

Meeting ID: 971 0972 7630

Passcode: ECE518!@

Online lecture posted by 5:00 pm

## Course Description

The objective of this course is to provide students with a fundamental background in optical interactions in biological systems and tissues and to provide the students with an understanding of the capabilities and limitations of the use of optics and lasers in medicine and biology. Fundamental concepts of optics and laser-tissue interaction will be discussed in order to provide a basis for the

understanding of the current technology. Successful students will be able to evaluate the capabilities of optical spectroscopic and imaging tools for evaluating physiological condition, health, and behavior of biological systems. They will be able to evaluate and interpret data from biomedical optical measurements, and design optical instrumentation for medical applications.

## Textbook

Quantitative Biomedical Optics: Theory, Methods, and Applications

by Irving J. Bigio and Sergio Fantini,

Cambridge University Press

January 2016

**ISBN:** 9781139029797

DOI: <https://doi.org/10.1017/CBO9781139029797> (<https://doi.org/10.1017/CBO9781139029797>)

<https://www.cambridge.org/highereducation/books/quantitative-biomedical-optics/5CAD764FCF30B1BB9EEA3DA7B60B7A4F#overview>

(<https://www.cambridge.org/highereducation/books/quantitative-biomedical-optics/5CAD764FCF30B1BB9EEA3DA7B60B7A4F#overview>)

&

Principles of Scattering and Transport of Light

by Rémi Carminati, ESPCI, Paris, John C. Schotland, Yale University, Connecticut

Cambridge University Press

July 2021

**ISBN:** 9781316544693

DOI: <https://doi.org/10.1017/CBO9781139029797> <https://doi.org/10.1017/9781316544693>  
(<https://doi.org/10.1017/9781316544693>)

<https://www.cambridge.org/highereducation/books/quantitative-biomedical->

<https://www.cambridge.org/core/books/principles-of-scattering-and-transport-of-light/72B09D4FBD26689DC3D49BDB4436E7FA>

(<https://www.cambridge.org/highereducation/books/quantitative-biomedical->

[optics/5CAD764FCF30B1BB9EEA3DA7B60B7A4F#overview](#))

## Course Schedule

Week	Topic	Preparation for Class	Assignments Due
Week 1	Introduction to Biophotonics (A&B)  Wave propagation	Read Syllabus  Read Chapter 1  Lecture Slides	Quiz01
Week 2	Examples: Wave propagation  Optical Absorption and Fluorescence in Biological Systems  Vibrational Spectroscopy	Read Chapters 2, 5, & 6  Lecture Slides	Quiz02 and HW01
Week 3	<b>Labor Day</b>  Examples: Hyperspectral simulations  Transmission Matrices	Lecture Slides  Paper: "Spectral Unmixing" IEEE SIGNAL PROCESSING MAGAZINE (2002).  <a href="https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.653.8400&amp;rep=rep1&amp;type=pdf">https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.653.8400&amp;rep=rep1&amp;type=pdf</a>  <a href="https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.653.8400&amp;rep=rep1&amp;type=pdf">https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.653.8400&amp;rep=rep1&amp;type=pdf</a>	Quiz03 and HW02

		<a href="#">DOI=10.1117/1.5000046&amp;rep=rep1&amp;type=pdf</a>	
Week 4	A gentle introduction to Optical Scattering (I, II)  Propagation in Random Media	Lecture Slides	Quiz04 and HW03
Week 5	Tissue Properties  Speckle and Optical Coherence  Homework & Quiz Review	Lecture Slides	Quiz05 and HW04
Week 6	Exam Review  Midter Exam #1  Diffuse Reflectance Spectroscopy with small source-detector separations	Read Chapter 8  Lecture slides	No Quiz, NHM01
Week 7	The radiative transport equation (RTE)  Optical Diffusion	Read Chapters 9	Quiz06 and HW05

Week 7	<p>solutions of the RTE</p> <p>Monte Carlo Solution of the RTE</p>	Lecture slides	Quiz06 and HW05
Week 8	<p>Continuous Wave Methods for Tissue Spectroscopy</p> <p>Time-Domain Methods for Tissue Spectroscopy</p> <p>Frequency-Domain Methods for Tissue Spectroscopy</p>	<p>Read Chapters 10, 11, &amp; 12</p> <p>Lecture slides</p>	Quiz07 and NHW02
Week 9	<p>Experimental Methods for Tissue Spectroscopy</p> <p>Diffuse optical imaging and tomography</p> <p>In vivo applications of diffuse optical spectroscopy and imaging</p>	<p>Read Chapters 13, 14, &amp; 15</p> <p>Lecture slides</p>	Quiz08 and HW06

Week 10	<p>Combining light and sound for imaging</p> <p>Optical Biomedical Imaging</p> <p>Optical Coherence Tomography</p>	<p>Read Chapters 16, 17, &amp; 18</p> <p>Lecture slides</p>	Quiz09 and HW07
Week 11	<p>Properties of Transmission Matrices in random media</p> <p>Imaging by controlling multiple scattering</p> <p>Homework Review</p>	Lecture slides	Quiz10 and HW08
Week 12	<p>Exam Review</p> <p>Midterm Exam #2</p> <p>Properties of Reflection Matrices in random media</p>	Lecture slides	No quiz, NHW03
	Coherent imaging with reflection		

Week 13	Reflection matrices Small angle RTE solutions Correlations in transmission and reflections matrices	Lecture slides	Quiz11 and HW09
Week 14	<b>Fall Break</b>	<b>Fall Break</b>	<b>Fall Break</b>
Week 15	Distortion matrix imaging Coherent acoustic-optical imaging Controlling energy delivery	Lecture slides	Quiz12 and HW10
Week 16	Optimization of imaging deep in tissue Imaging with customized speckle Review for the final	Lecture slides	Quiz13 and HW11

## Exam Dates

Midterm 1: September 29, 2021

Midterm 2: November 10, 2021

Final Exam: December 14, 2021

## Online Resources

# Biology and Biological Optics Resources

Lectures on biology and techniques: <https://www.ibiology.org/biology-online/>  
(<https://www.ibiology.org/biology-online/>)

Quantitative Biological Imaging (good lectures): <https://www.quantitativebioimaging.com/>  
(<https://www.quantitativebioimaging.com/>)

Biology numbers: <https://bionumbers.hms.harvard.edu/search.aspx>  
(<https://bionumbers.hms.harvard.edu/search.aspx>)

Biology numbers: <http://book.bionumbers.org> (<http://book.bionumbers.org>)

# Optics and Physics Resources

Online optics textbook: <https://optics.byu.edu/home> (<https://optics.byu.edu/home>)

Online physics textbook: <https://opentextbc.ca/universityphysicsv3openstax/>  
(<https://opentextbc.ca/universityphysicsv3openstax/>)

Hyperphysics: <http://hyperphysics.phy-astr.gsu.edu/hbase/index.html> (<http://hyperphysics.phy-astr.gsu.edu/hbase/index.html>)

Introduction to Scattering:

<https://www.youtube.com/watch?v=IU-QEm-2hFs> (<https://www.youtube.com/watch?v=IU-QEm-2hFs>)

<https://www.youtube.com/watch?v=f6sHn3pyAro> (<https://www.youtube.com/watch?v=f6sHn3pyAro>)

Virtual photonics: <https://virtualphotonics.org/> (<https://virtualphotonics.org/>)

Scattering and absorption spectroscopy: <https://omlc.org/~prahl/> (<https://omlc.org/~prahl/>)

NIST chemistry and spectroscopy database: <https://webbook.nist.gov/chemistry/>  
(<https://webbook.nist.gov/chemistry/>)



Thorlabs technical guides: [https://www.thorlabs.com/navigation.cfm?guide\\_id=2474](https://www.thorlabs.com/navigation.cfm?guide_id=2474)  
([https://www.thorlabs.com/navigation.cfm?guide\\_id=2474](https://www.thorlabs.com/navigation.cfm?guide_id=2474))

## Computational Imaging

Computational Imaging Lecture Series: <https://sites.google.com/view/sps-space>  
(<https://sites.google.com/view/sps-space>)

Diffuse Optical Spectroscopic Imaging (DOSI): <https://vimeo.com/88174807>  
(<https://vimeo.com/88174807>)

Diffuse Imaging: <https://www.youtube.com/watch?v=fKMghVWOoA0>  
(<https://www.youtube.com/watch?v=fKMghVWOoA0>)

Spatial Frequency Domain Imaging: <https://www.youtube.com/watch?v=l3l9-pfLl4o>  
(<https://www.youtube.com/watch?v=l3l9-pfLl4o>)

## Microscope (and optics) Resources

Olympus Microscope Resource Center: <https://www.olympus-lifescience.com/en/microscope-resource/> (<https://www.olympus-lifescience.com/en/microscope-resource/>)

Nikon MicroscopyU: <https://www.microscopyu.com/> (<https://www.microscopyu.com/>)

UofA Microscopy Resources: <https://microscopy.arizona.edu/learn/microscopy-imaging-resources-www> (<https://microscopy.arizona.edu/learn/microscopy-imaging-resources-www>)

ImageJ: <https://imagej.nih.gov/ij/> (<https://imagej.nih.gov/ij/>)

Molecular Expressions Primer: <https://micro.magnet.fsu.edu/primer/>  
(<https://micro.magnet.fsu.edu/primer/>)

Royal Microscopical Society: <https://www.rms.org.uk/study-read/news-listing-page/online-microscopy-talks-list.html> (<https://www.rms.org.uk/study-read/news-listing-page/online-microscopy-talks-list.html>)

Fluorescence tutorials: <https://www.thermofisher.com/us/en/home/support/tutorials.html>

<https://www.thermofisher.com/us/en/home/support/tutorials.html>

## Weekly Canvas Quizzes

There will be a weekly quiz on Canvas. For this quiz, you will answer several questions that require either a numerical answer or a formula answer. You will have infinite attempts at providing the answer so that, hopefully, everyone is successful with these quizzes. In addition to the answer, you will need to upload a written out answer that explains how you computed your result(s) for the quiz solution as part of the homework assignments. Details of the formatting requirements for homework are provided below.

## Software

Mathematica is highly recommended for this course.

## Assignments and Canvas

I will post all assignments on Canvas, and all assignments must be submitted through Canvas.

All assignments will be submitted as a pdf file and will be prepared either in Mathematica, LaTeX, or a similar program so that all responses are typeset. All code used for calculation must be submitted in the pdf.

It is expected that you will use the following format for submitting all assignments:

LAST.FIRST.ASSIGNMENT.pdf

For example: Bartels.Randy.HW01.pdf

## Homework Policy

The homework is an essential part of the course. You should attempt all problems yourself, but feel free to argue with your colleagues about them. (Simply copying each other's solutions is, however, counterproductive for all parties and is not acceptable.)

A few of the problems will be numerical, not involving heavy computation, but more in the way of modeling pulse propagation through various dispersive elements, so you will need to use your favorite math package (e.g., Mathcad, Maple, Matlab, Mathematica, IDL, etc.).

To clarify, a homework solution MUST include a full explanation of how the problem is set up, the

motivation of steps in the analysis, and an interpretation of the results. The entire point of homework is to explore and think about the material presented in the class AND to be able to communicate your findings. The ability to communicate scientific ideas is of critical importance. Moreover, the emphasis of homework is to analyze each physical situation, interpret that analysis, and communicate the meaning. As a result, the emphasis is NOT on algebraic manipulations.

You are encouraged to use Mathematica (and to a MUCH lesser extent other mathematical tools) to write up your solution. All solutions MUST be in a highly simplified form that YOU interpret correctly. Remember: each homework solution should be a short story that includes a reproduction of appropriate diagrams and may require plots of the final solutions you find to explain behaviors.

## Homework Formatting Requirements

All homework assignments must be submitted in narrative form. Consider each answer a short essay or paper. In all instances, you should provide a quick background and motivation in the context of Optical Microscopy and then develop your answer to the questions while explaining each step. Below are notes on writing and formatting requirements:

These notes are adapted from Stephen Boyd et al.:

[https://web.stanford.edu/class/ee364b/latex\\_templates/template\\_notes.pdf](https://web.stanford.edu/class/ee364b/latex_templates/template_notes.pdf)  
([https://web.stanford.edu/class/ee364b/latex\\_templates/template\\_notes.pdf](https://web.stanford.edu/class/ee364b/latex_templates/template_notes.pdf))

You will likely find that when you write out a detailed explanation on a question, you will find that there are gaps in your understanding and thought process. The process of writing out a full explanation will help you clarify your thought and understanding.

John von Neumann once said, “There’s no sense in being precise when you don’t even know what you’re talking about,” and Niels Bohr wrote, “Never express yourself more clearly than you can think.” Keep these in mind.

**Write in good english:** Always write good English, even when the subject that you are discussion contains mathematics. This includes correct grammar, word choice, punctuation, spelling, phrasing, and common sense. A classic on this topic, only slightly dated, is Strunk and White [1].

**Keep the reader in mind:** Perhaps the most important principle of good writing is to keep the reader in mind: What do they know so far? What do they expect next and why? Do they have sufficient motivation for stated results? As part of this, make sure you know what level of reader you are writing for and stay consistent with that level. If the reader is expected to know microscopy, do not keep defining standard concepts like numerical aperture (you will know this well before the end of the

course if you don't already know about this)!

**Write to allow skipping over formulas:** Many readers will first read through the paper ignoring or skipping all but the simplest formulas. Your sentences and overall report should flow smoothly, and make sense, when all but the simplest formulas are replaced by “blah” or a similar placeholder. As a related point, do not simply display a list of formulas or equations in a row; tie the concepts together with a running commentary.

## Online Course Details

All lectures will be available online and simultaneous participation will be available with Zoom.

## Late Policy

You are expected to manage your schedule and meet all assigned deadlines. Items turned in within 24 hours after a deadline will receive a 25% penalty. Items turned in 24-48 hours late will receive a 50% penalty. Items submitted more than 48 hours late will not be accepted. Any exceptions must be approved in advance. Late submission is not allowed for the final exam.

## Honor Pledge

For all work in this course, it is assumed that the following statement is true: I will not give, receive, or use any unauthorized assistance. The exception is that students may discuss approaches and clarifications regarding homework problems. In fact, this is highly encouraged and you may learn a lot from your peers and from helping your peers.

## Professionalism and Academic integrity

This course will adhere to the CSU Academic Integrity Policy as found on the Student Responsibilities page of the [CSU General Catalog \(http://catalog.colostate.edu/general-catalog/policies/students-responsibilities/#academic-integrity\)](http://catalog.colostate.edu/general-catalog/policies/students-responsibilities/#academic-integrity) and in the [Student Conduct Code. \(https://resolutioncenter.colostate.edu/wp-content/uploads/sites/32/2018/08/Student-Conduct-Code-v2018.pdf\)](https://resolutioncenter.colostate.edu/wp-content/uploads/sites/32/2018/08/Student-Conduct-Code-v2018.pdf)

For more details on academic integrity, please read [Practicing Academic Integrity. \(http://learning.colostate.edu/integrity/index.cfm\)](http://learning.colostate.edu/integrity/index.cfm)

At a minimum, violations will result in a grading penalty in this course and a report to the Office of

Student Resolution Center.

## References

[1] W. Strunk and E. White. The Elements of Style. Macmillan, 1957.

## Matlab and Tutorials

**CSU Matlab install (and tutorials):** <https://www.mathworks.com/academia/tah-portal/colorado-state-university-40638290.html> (<https://www.mathworks.com/academia/tah-portal/colorado-state-university-40638290.html>)

**A list of tutorials:** <http://engineering.nyu.edu/mechatronics/vkapila/matlabtutor.html>  
(<http://engineering.nyu.edu/mechatronics/vkapila/matlabtutor.html>)

**Matlab tutorials for image processing:**

[http://www.audentia-gestion.fr/Matlab/Matlab-Image\\_Processing\\_Tutorial.pdf](http://www.audentia-gestion.fr/Matlab/Matlab-Image_Processing_Tutorial.pdf)  
([http://www.audentia-gestion.fr/Matlab/Matlab-Image\\_Processing\\_Tutorial.pdf](http://www.audentia-gestion.fr/Matlab/Matlab-Image_Processing_Tutorial.pdf))

<http://apps.usd.edu/coglab/schieber/psyc707/pdf/2D-FFT.pdf>  
(<http://apps.usd.edu/coglab/schieber/psyc707/pdf/2D-FFT.pdf>)

[http://mstrzel.eletel.p.lodz.pl/mstrzel/pattern\\_rec/fft\\_ang.pdf](http://mstrzel.eletel.p.lodz.pl/mstrzel/pattern_rec/fft_ang.pdf)  
([http://mstrzel.eletel.p.lodz.pl/mstrzel/pattern\\_rec/fft\\_ang.pdf](http://mstrzel.eletel.p.lodz.pl/mstrzel/pattern_rec/fft_ang.pdf))

[http://users.cs.cf.ac.uk/Dave.Marshall/CM2208/LECTURES/CM2208\\_Fourier\\_Transforms\\_01\\_Th](http://users.cs.cf.ac.uk/Dave.Marshall/CM2208/LECTURES/CM2208_Fourier_Transforms_01_Th)  
([http://users.cs.cf.ac.uk/Dave.Marshall/CM2208/LECTURES/CM2208\\_Fourier\\_Transforms\\_01\\_Theory.pdf](http://users.cs.cf.ac.uk/Dave.Marshall/CM2208/LECTURES/CM2208_Fourier_Transforms_01_Theory.pdf))











## Mathematica Tutorials

**Wolfram site:** <https://www.wolfram.com/language/fast-introduction-for-math-students/en/>  
(<https://www.wolfram.com/language/fast-introduction-for-math-students/en/>)














<https://pages.mtu.edu/~msgocken/pdebook2/mathtut2.pdf>  
(<https://pages.mtu.edu/~msgocken/pdebook2/mathtut2.pdf>)

<http://www2.eng.ox.ac.uk/~labejp/Seminar/Mathematica/MathematicaSeminarNotes.pdf>  
(<http://www2.eng.ox.ac.uk/~labejp/Seminar/Mathematica/MathematicaSeminarNotes.pdf>)

# Course Summary:

Date	Details	Due
Fri Aug 27, 2021	 <b>Quiz 1</b> <a href="https://colostate.instructure.com/courses/126945/assignments/1573883">https://colostate.instructure.com/courses/126945/assignments/1573883</a>	due by 11:59pm
Wed Sep 1, 2021	 <b>Homework 1</b> <a href="https://colostate.instructure.com/courses/126945/assignments/1573891">https://colostate.instructure.com/courses/126945/assignments/1573891</a>	due by 1pm
Fri Sep 3, 2021	 <b>Quiz 2</b> <a href="https://colostate.instructure.com/courses/126945/assignments/1583781">https://colostate.instructure.com/courses/126945/assignments/1583781</a>	due by 11:59pm
Wed Sep 8, 2021	 <b>Homework 2</b> <a href="https://colostate.instructure.com/courses/126945/assignments/1583779">https://colostate.instructure.com/courses/126945/assignments/1583779</a>	due by 1pm
Fri Sep 10, 2021	 <b>Quiz 3</b> <a href="https://colostate.instructure.com/courses/126945/assignments/1583786">https://colostate.instructure.com/courses/126945/assignments/1583786</a>	due by 11:59pm
Wed Sep 15, 2021	 <b>Homework 3</b> <a href="https://colostate.instructure.com/courses/126945/assignments/1583783">https://colostate.instructure.com/courses/126945/assignments/1583783</a>	due by 1pm
Fri Sep 17, 2021	 <b>Quiz 4</b> <a href="https://colostate.instructure.com/courses/126945/assignments/1583787">https://colostate.instructure.com/courses/126945/assignments/1583787</a>	due by 11:59pm
Wed Sep 22, 2021	 <b>Homework 4</b> <a href="https://colostate.instructure.com/courses/126945/assignments/1583784">https://colostate.instructure.com/courses/126945/assignments/1583784</a>	due by 1pm
Fri Sep 24, 2021	 <b>Quiz 5</b> <a href="https://colostate.instructure.com/courses/126945/assignments/1583788">https://colostate.instructure.com/courses/126945/assignments/1583788</a>	due by 11:59pm
Mon Oct 4, 2021	 <b>Numerical Homework 1</b> <a href="https://colostate.instructure.com/courses/126945/assignments/1573897">https://colostate.instructure.com/courses/126945/assignments/1573897</a>	due by 11:59pm

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Fri Oct 8, 2021	 <a href="https://colostate.instructure.com/courses/126945/assignments/1583859">Quiz 6</a>	due by 11:59pm ( <a href="https://colostate.instructure.com/courses/126945/assignments/1583859">https://colostate.instructure.com/courses/126945/assignments/1583859</a> )
Wed Oct 13, 2021	 <a href="https://colostate.instructure.com/courses/126945/assignments/1583903">Homework 5</a>	due by 1pm ( <a href="https://colostate.instructure.com/courses/126945/assignments/1583903">https://colostate.instructure.com/courses/126945/assignments/1583903</a> )
Fri Oct 15, 2021	 <a href="https://colostate.instructure.com/courses/126945/assignments/1583860">Quiz 7</a>	due by 11:59pm ( <a href="https://colostate.instructure.com/courses/126945/assignments/1583860">https://colostate.instructure.com/courses/126945/assignments/1583860</a> )
Wed Oct 20, 2021	 <a href="https://colostate.instructure.com/courses/126945/assignments/1583958">Numerical Homework 2</a>	due by 11:59pm ( <a href="https://colostate.instructure.com/courses/126945/assignments/1583958">https://colostate.instructure.com/courses/126945/assignments/1583958</a> )
Fri Oct 22, 2021	 <a href="https://colostate.instructure.com/courses/126945/assignments/1583861">Quiz 8</a>	due by 11:59pm ( <a href="https://colostate.instructure.com/courses/126945/assignments/1583861">https://colostate.instructure.com/courses/126945/assignments/1583861</a> )
Wed Oct 27, 2021	 <a href="https://colostate.instructure.com/courses/126945/assignments/1583959">Homework 6</a>	due by 1pm ( <a href="https://colostate.instructure.com/courses/126945/assignments/1583959">https://colostate.instructure.com/courses/126945/assignments/1583959</a> )
Fri Oct 29, 2021	 <a href="https://colostate.instructure.com/courses/126945/assignments/1583862">Quiz 9</a>	due by 11:59pm ( <a href="https://colostate.instructure.com/courses/126945/assignments/1583862">https://colostate.instructure.com/courses/126945/assignments/1583862</a> )
Wed Nov 3, 2021	 <a href="https://colostate.instructure.com/courses/126945/assignments/1583960">Homework 7</a>	due by 1pm ( <a href="https://colostate.instructure.com/courses/126945/assignments/1583960">https://colostate.instructure.com/courses/126945/assignments/1583960</a> )
Fri Nov 5, 2021	 <a href="https://colostate.instructure.com/courses/126945/assignments/1583863">Quiz 10</a>	due by 11:59pm ( <a href="https://colostate.instructure.com/courses/126945/assignments/1583863">https://colostate.instructure.com/courses/126945/assignments/1583863</a> )
Wed Nov 17, 2021	 <a href="https://colostate.instructure.com/courses/126945/assignments/1583972">Homework 8</a>	due by 1pm ( <a href="https://colostate.instructure.com/courses/126945/assignments/1583972">https://colostate.instructure.com/courses/126945/assignments/1583972</a> )
Fri Nov 19, 2021	 <a href="https://colostate.instructure.com/courses/126945/assignments/1583872">Quiz 11</a>	due by 11:59pm ( <a href="https://colostate.instructure.com/courses/126945/assignments/1583872">https://colostate.instructure.com/courses/126945/assignments/1583872</a> )
Mon Nov 29, 2021	 <a href="https://colostate.instructure.com/courses/126945/assignments/1583979">Numerical Homework 3</a>	due by 11:59pm ( <a href="https://colostate.instructure.com/courses/126945/assignments/1583979">https://colostate.instructure.com/courses/126945/assignments/1583979</a> )
Fri Dec 3, 2021	 <a href="https://colostate.instructure.com/courses/126945/assignments/1583873">Quiz 12</a>	due by 11:59pm ( <a href="https://colostate.instructure.com/courses/126945/assignments/1583873">https://colostate.instructure.com/courses/126945/assignments/1583873</a> )

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**Quiz 13**

due by 11:59pm

<https://colostate.instructure.com/courses/126945/assignments/1583884>

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Fri Dec 10, 2021



**Numerical Assignment 4**

due by 11:59pm

<https://colostate.instructure.com/courses/126945/assignments/1584012>

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