Syllabus
Principles of Magnetic Resonance Imaging (BMEN 4430)
Spring 2024

Date/Time:	Thursdays, 4:10-6:40 PM
Location:	1) Lectures: 233 Seeley W. Mudd Building 2) Live Sessions: 3T MRI scanner (TBD)
Instructor:	Christoph Juchem, Ph.D. cwj2112@columbia.edu (please use subject "BMEN E4430") Office hours: Thursday, 2:30 P.M. – 3:30 P.M., room TBD
Teaching Assistant:	Iabelle Zinghini, M.Sc. iaz2112@columbia.edu (please use subject "BMEN E4430") Office hours: Tuesday, 4 P.M. – 5 P.M., room TBD
Prerequisites:	PHYS UN1403 and APAM E2101 *or* PHYS C1403 and APAM E2101 *or* instructors' permission
Credits:	3 points

Course Description

Topics include the fundamental principles of Magnetic Resonance Imaging (MRI) and the physics and mathematics of image formation, emphasizing the application of MRI to scientific research and clinical diagnostics. The course will examine both theory and experimental design techniques. The course will be complemented, circumstances permitting, by experiments run in real-time at the MRI scanner.

Course Objectives

At the end of the course, attendees should

- be familiar with the concepts of MRI
- understand the basic magnetic resonance scanner and hardware architecture
- have an overview of the various MRI techniques
- recognize the spectrum of research and clinical MRI applications
- be able to describe the potential, limitations, and pitfalls of MRI
- be able to discuss MRI aspects before an audience of peers
- be able to provide some critique of MRI projects and manuscripts

Suggested Textbooks

1. *Magnetic Resonance Imaging : Physical Principles and Sequence Design*, Robert W. Brown, Yu-Chung N. Cheng, E. Mark Haacke, Michael R. Thompson, Ramesh Venkatesan, ISBN 9780471720850, https://clio.columbia.edu/catalog/10873044
2. *Magnetic Resonance Imaging Handbook*, edited by Luca Saba, ISBN 9781482216202, https://clio.columbia.edu/catalog/12583458
3. *Principles of Magnetic Resonance Imaging: A Signal Processing Perspective*, Zhi-Pei Liang, Paul C. Lauterbur, ISBN 0780347234, https://clio.columbia.edu/catalog/12461127

4. *MRI: Basic Principles and Applications*, Brian M. Dale, Mark A. Brown, and Richard C. Semelka, ISBN 9781119013037, https://clio.columbia.edu/catalog/11720594
5. *The Mathematics of Medical Imaging: A Beginner's Guide*, Timothy G. Feeman, ISBN 9783319226651, https://clio.columbia.edu/catalog/11685941
6. *MRI: Essentials for Innovative Technologies*, Giuseppe Placidi, ISBN 9781439840405, https://clio.columbia.edu/catalog/9586884

Note that electronic versions of all books are available through Columbia's online library free of charge

Grading Criteria

11 problem sets at 3% each:	33%
Participation:	7%
Midterm exam:	30%
Final exam:	30%

Policies

The course follows Columbia University policies, including those describing the Rights and Responsibilities of its members. Also, please note the Faculty Statement on Academic Integrity. Academic integrity violations will be referred to the Student Conduct and Community Standards Office and may constitute grounds for course failure.

Homework Assignments

All homework is due at the beginning of the next class and is to be submitted via CourseWorks (courseworks2.columbia.edu).

Course Participation Grade

To receive full points for participation, students will be expected to remain generally engaged and vocal during class lectures and discussions.

Make Up Exams

Only students with legitimate reasons will be allowed to postpone examinations or make up for missed ones. Note that

1) students are expected to present appropriate documentation, e.g. a doctor's note
2) all make-up exams will be oral - no exceptions.

Office of Equal Opportunity and Affirmative Action (EOAA): Course Environment

Names/Pronouns. You deserve to be addressed in a manner that reflects your identity. You are welcome to tell us your pronoun(s) and/or name (if different from University records) at any time, either in person or via email.

Discrimination. We embrace the diversity of gender, gender identity & expression, sex, sexual orientation, race, ethnicity, national origin, age, religion, disability status, family status, socioeconomic background, and other visible and non-visible identities. Columbia University does not tolerate unlawful discrimination, discriminatory harassment, sexual assault, domestic violence, dating violence, stalking, or sexual exploitation, and all such conduct is forbidden by Columbia University Policy.

Accessibility. We want you to succeed in this course. Contact disability@columbia.edu for learning accommodations.

Duty to Report. You deserve a University community free from discrimination, harassment, and gender-based misconduct including sexual harassment, sexual assault, domestic and dating violence, stalking, and sexual exploitation. It is therefore University policy to require Columbia faculty and staff to report to EOAA any instance or allegation of prohibited conduct involving any undergraduate or any graduate student that is disclosed to, observed by, or otherwise known to that employee. This requirement to report is in place to help ensure that students are provided appropriate resources and to allow the University to mitigate harm to our community.

There are confidential resources on campus who do not have a Duty to Report, including: Sexual Violence Response & Rape Crisis/Anti-Violence Support Center (SVR), Ombuds Office, Medical Services, University Counseling and Psychological Services, University Pastoral Counseling, Columbia Office of Disability Services. University employees working in a confidential capacity will not report information shared with them.

Additional

All aspects of this syllabus are subject to change.
Suggestions and feedback are welcome.

Course Outline

(next page)

Week	Date	Lecture	Topics	Assignments
1	1/18/2023	1	**Basics of Magnetic Resonance** spin, magnetic resonance, Boltzmann distribution, excitation, Larmor condition, sensitivity, free induction decay, pulse-acquire experiment	HW1 out, due 1/25/2023
2	1/25/2023	2	**MR Scanner Architecture** scanner architecture, field gradients, radio-frequency pulses, signal detection, signal demodulation, laboratory/rotating frame	HW2 out, due 2/1/2023
3	2/1/2023	3	**Basic Sequences and Bloch Equations** relaxation, T1, T2, T2*, Bloch equations, spin echo, Ernst angle, sequence diagram, saturation-recovery, inversion-recovery	HW3 out, due 2/8/2023
4	2/8/2023	4	**Image Formation** spatial selection, spatial encoding, field-of-view, k-space, slice orientation, multi-slice 2D, 3D, gradient-echo, spin-echo, point-spread function, spatial resolution, filtering, signal-to-noise, contrast-to-noise	HW4 out, due 2/15/2023
5	2/15/2023	5	**k-Space Sampling Strategies** Fourier transform, shift theorem, convolution theorem, Nyquist theorem, radial MRI, scan time, echo-planar imaging, spiral imaging, turbo-spin-echo, partial k-space, sparse sampling	HW5 out, due 2/22/2023
6	2/22/2023	6	**Challenges and Solutions** gradient eddy currents and preemphasis, flow artifacts/compensation, respiratory motion, cardiac motion, voluntary movement, water/fat separation, Gibbs ringing, phase aliasing, chemical shift, corrupted data	HW6 out, due 2/29/2023
7	2/29/2023	7	**B0 Hardware, Fields and Safety** scanner B0 field/coil, field strength, gradient fields/coils, PNS, spherical harmonics, region-of-interest, B0 homogeneity, B0 shimming, active/passive, static/dynamic, real-time, multi-coil approach, DYNAMITE	
8	3/7/2023	-	**Midterm Exam**	
9	3/14/2023	-	**Spring Recess**	
10	3/21/2023	8	**MRI Techniques and Applications** T1/T2/T2*/PD-weighting, diffusion weighted imaging, DTI, perfusion, susceptibility weighted imaging, susceptibility mapping, flow imaging, angiography, aterial spin labeling	HW7 out, due 3/28/2023
11	3/28/2023	9	**Radio-Frequency Coils, Pulses and Safety** radio-frequency, sensitivity, RF pulse, selective/non-selective, resonance circuit, detector design, surface/quadrature/phased-array coil, B1 homogeneity/shimming, SAR, power dissipation, tissue heating	HW8 out, due 4/4/2023
12	4/4/2023	10	**Contrast Agents and Functional MRI** hyperpolarized gas, MION, manganese, gadolinium, functional MRI, blood oxygen level dependence, cerebral blood flow, cerebral blood volume, baloon model	HW9 out, due 4/11/2023
13	4/11/2023	11	**Fast and Parallel MRI** scan time, fast spin-echo, fast gradient-echo, TSE, SSFP, partial k-space, sparse sampling, parallel imaging, g-factor, SMASH, SENSE, GRAPPA, GRASP, multislice MRI	HW10 out, due 4/18/2023
14	4/18/2023	12	**Hot Topics in MRI** MR fingerprinting, non-Cartesian encoding, future scanner architecture, low-field MRI, high-temperature magnets, deep learning, scanner setup, experimental procedures, study design, informed consent, in vivo MRI	HW11 out, due 4/25/2023
15	4/25/2023	13	**MRI in Action** MR suite, safety, hardware, informed consent, setup, phantom, participant handling, image geometry, partial volume, sequences, contrast, protocols, scanner operation, image analysis, incidental findings	
16	5/2/2023	-	**Study Days**	
17	5/9/2023	-	**Final Exam**	