Syllabus
Principles of Magnetic Resonance Imaging (BMENE4430)
Spring 2021

Date/Time:	Thursdays, 4:10-6:40 PM
Location:	Zoom (virtual), MRI scanner (circumstances permitting)
Instructor:	Christoph Juchem, Ph.D. cwj2112@columbia.edu (please use subject "BMEN E4430") Office hours: Thursday, 2 P.M. - 3 P.M., Zoom (Virtual)
Teaching Assistant:	Nabil Ettehadi, M.Sc. ne2289@columbia.edu (please use subject "BMEN E4430") Office hours: Tuesday, 4 P.M. – 5 P.M., Zoom (Virtual)
Prerequisites:	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 with an emphasis on 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

10 problem sets at 3% each:	30%
Participation:	20%
Midterm exam:	20%
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.

Homework Assignments

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

Course Participation Grade

To receive full points for participation, in addition to remaining generally engaged and vocal during class lectures and discussions, students will be expected to participate in the following activities:

> **PollEverywhere quizzes during lecture:** Every course lecture will involve a variable number of live quiz questions to which students will be expected to submit answers in real time for a participation score. Everyone enrolled in the class via Courseworks is automatically enrolled in PollEverywhere; this can be confirmed on https://www.polleverywhere.com/login by submitting either one's Columbia (UNI) email address or, for non-UNI students, the non-Columbia email address through which one enrolled in Courseworks and clicking "Log In Via Columbia." Students should confirm at the beginning of each lecture that they are logged in to PollEverywhere, and at quiz time students will be directed to a URL that will enable them to participate in live questions.
>
> **Piazza discussion:** Every week students will be expected to post at least one question and at least one answer to another student's question on our Piazza forum, moderated regularly by the course instruction team.

Please let the instruction team know if you have any trouble accessing either PollEverywhere or Piazza. Students who anticipate needing to miss a lecture should contact the instruction team in advance so that alternate assignments can be arranged.

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.

Camera During Online Participation
Course participants attending online are expected to keep their camera on at all times.

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

Detailed Course Schedule
(next page)

Week	Date	Lecture	Topics	Assignments
1	1/14/2021	1	**Basics of Magnetic Resonance** spin, magnetic resonance, Boltzmann distribution, excitation, Larmor condition, sensitivity, FID, basic experiment	HW1 out, due 1/21/2021
2	1/21/2021	2	**MR Scanner Architecture** scanner architecture, field gradients, radio-frequency pulses, signal detection, signal demodulation, laboratory/rotating frame	HW2 out, due 1/28/2021
3	1/28/2021	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 2/4/2021
4	2/4/2021	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 2/11/2021
5	**2/9/2021**	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 2/18/2021
6	2/18/2021	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	
7	2/25/2021	-	**Midterm Exam**	
8	3/4/2021	-	**Spring Recess**	
9	3/11/2021	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	HW6 out, due 3/18/2021
10	3/18/2021	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 3/25/2021
11	3/25/2021	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 4/1/2021
12	4/1/2021	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 4/8/2021
13	4/8/2021	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 4/15/2021
14	4/15/2021	12	**Hot Topics and MRI in Action** 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	
15	4/22/2021	-	**Final Exam**	