AC 2008-568: DESIGNING MAGNETIC RESONANCE IMAGING CURRICULUM FOR UNDERGRADUATES: SAFE, HANDS-ON AND INEXPENSIVE INSTRUCTION

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Designing Magnetic Resonance Imaging Curriculum for Undergraduates: Safe, Hands-On and Inexpensive Instruction

A new hands-on curriculum developed at Vanderbilt University focuses on teaching medical imaging, specifically magnetic resonance imaging (MRI). This material was designed to engage students in real world applications of biomedical engineering through challenge based activities. These activities include homework, quizzes, and hands-on experiments. The materials for each activity are easy to find and can be purchased for under $25. The curriculum begins with a Grand Challenge that presents a medical case in order to interest the students. The challenge questions allow the students to play the role of the patient, technician, and physician. The material was organized in five modules: Electromagnetic Fields and Magnetic Moments, Spin Behavior: Excitation and Relaxation, Spatial Encoding and Detecting Signals, Image Reconstruction, and Image Characteristics. In addition, there are expert interviews that provide the students with multiple perspectives on the information. The material was tested in the summer of 2007 on five students in order to gain feedback, correct errors, and gauge student understanding. Testing showed that the curriculum had a positive impact on student interest in biomedical imaging and resulted in several improvements and additions to the curriculum. During the academic year, the materials will be field-tested at the undergraduate and high school level. Additionally, the materials are being adapted for high school level implementation.

Curriculum

Our goal is to develop a curriculum that engages students, introducing them to the exciting field of biomedical imaging, while teaching required math, science, and engineering concepts. The Magnetic Resonance unit of the imaging curriculum was written and field tested during the summer of 2007. All curriculum development was based on research for human learning presented in the National Academy of Science report How People Learn[1]. Specifically, the instruction is designed around "anchored inquiry" of interesting challenges[2,3]. Students' inquiry processes are guided by an instructional sequence built around a learning cycle called the 'Legacy cycle'[3].Each of the five legacy cycle modules in this unit includes a new challenge question, interviews with experts in the imaging field to guide their inquiry, and lectures and hands-on activities to equip students in answering each challenge. Each of the hands-on activities was designed to use materials under $25, enabling the curriculum to be integrated in various classroom environments. By maintaining a challenge-focused structure, the relevance of each lesson is more apparent to learners.

The curriculum unit begins with a grand challenge that is then divided into five challenges, starting students with the basics of magnets and magnetic fields, covering how MR images are created, and examining general image properties. By completing the five modules, students are equipped to answer the following grand challenge question:

Claire, a lawyer in her early 30's, has been experiencing dizziness and numbness in her legs. She has also had trouble seeing clearly while driving and can't seem to remember the details of her cases. She schedules an appointment with her regular physician and explains what has been happening. After a routine examination and tests to rule out other causes, the physician suspects Claire has multiple sclerosis and orders a magnetic resonance imaging (MRI) study of her brain.

- *For what physiological systems is MRI most often used?*
- *What might the physician expect to see in the images?*
- *What properties of the different types of brain tissues might distinguish them from one another in MR images?*
- *Why does the physician order an MRI instead of x-ray, CT, or ultrasound?*

The five modules were developed to take students through Claire's experience when she arrives for her MRI scan and include the technologist's and radiologist's responsibilities of taking and analyzing the images. In answering each challenge question, the student assumes the role of an MRI technician or radiologist, keeping them engaged throughout the learning process.

Included in the curriculum unit are a teacher manual, electronic slides, and a student manual. The instructor manual includes a suggested timeline based on a 50 minute class, pages for notes during each lecture, and suggestions on where to obtain the necessary materials for each hands-on activity. The electronic slides are organized into the five modules and include suggested stopping points for each hands-on activity. The student manual contains pages for note taking during lectures and the instructions to the hands-on experiments. It also includes an interest survey to be taken before and after using the materials to evaluate students' initial knowledge and learning styles, as well as their interest in science and engineering. The hands-on experiments included in this curriculum are given in Table 1.

Table 1: Hands-On Activities Included in Curriculum

Hands-On Activity	**Concepts Taught**
Magnetization Experiment	Shape and Direction of Magnetic Fields
Electromagnetism and Alignment Experiment	Properties of Electromagnets
Energy Levels Experiment	Energy Levels of Nuclei
Nuclear Magnetic Spin Experiment	Precession
Tipping and T1 Processes Experiment	Tipping of Nuclei/Net Magnetization, System recovery and T1 time constant
Spin Echo Experiment	Effect of 'echo' on magnetization/signal in a system
Excitation Homework assignment	Excited and relaxed states of a system
Resonance Experiment	Effect of gradients on nuclear resonance
Frequency/Phase Encoding Gradient Activity	Purpose of gradients during signal acquisition
Fourier Transform Experiment	Properties of Fourier Transform, Image construction in K-Space
Pixel Experiment	Image quality properties

Prior to teaching the curriculum, pre-tests would be administered to the students, evaluating their initial understanding of the material. The instructor would then present the grand challenge question, and allow time for students to generate their own ideas about information they will need to answer it. The electronic slides walk through the lessons and hands-on activities for the module, providing students with the knowledge necessary to answer the challenge question for that module. A "go public" summative assessment activity is also written for each of the five modules to evaluate students' overall understanding of the concepts taught. As each module is completed, students take the relevant post-test for that set of material. When all five of the modules have been completed, the students are then able to go back and complete the grand challenge.

The first challenge on electromagnetic fields and magnetic moments, explains the experiences of the patient when she arrives for her MR scan. Through a series of lectures and hands-on activities, students learn about the basic properties of magnets, what makes an electromagnet, and how magnetic fields are used to generate signals during an MR scan. The challenge description and questions are as follows:

Claire arrives for her scan and is instructed to remove all jewelry and metal from her body and change into a hospital gown. The technician instructs her to lie down on the MRI table, places a rigid cylindrical device over her head, and moves the table into the scanner.

- *Why is she instructed to remove jewelry and metal?*
- *What is happening to Claire once she is in the scanner?*
- *She doesn't feel anything. Why?*
- *What is the cylindrical device around her head?*

As one of the first hands-on activities, students are instructed to build a solenoid using a plastic cup and insulated wire, a project with materials that cost about $5.00. With a compass they are able to observe not only the presence of magnetic field lines, but also determine how the direction of electric current flow contributes to the overall magnetic field. The activity also serves to reinforce the key concept that moving charged particles generate magnetic fields.

The second challenge, "Spin Behavior: Excitation and Relaxation", walks through the process of adding energy to the system, causing the net magnetization to tip, and its return to equilibrium. Through the hands on activity "Tipping and T1 Processes", students use half of a tennis ball, Play-doh®, a wooden pencil and light source such as an overhead projector to visualize how tipping nuclei out of their equilibrium positions moves the net magnetization vector into a new plane. The tennis ball apparatus returns to its initial position after being tipped and released, modeling the return of net magnetization to its equilibrium position following a 90^o pulse. The T1 time constant that describes the rate of magnetization's return to equilibrium is further explored in the activity through a modified set-up. By using three tennis ball halves, each filled with different amounts of Play-doh®, comparisons can be made, simulating tissues with long, medium, and short recovery times. Students are to record observations and determine representative tissue properties based on these relative recovery times. Following this challenge, students should be able to answer the following questions based on the challenge passage:

Claire hears the technician over the intercom. The technician says, "We are beginning with a spin-echo sequence scan." The technician is trying to see if there are any tissues in Claire's brain that look different from normal tissue.

- *How will distinctions be made between tissues?*

- *Will Claire hear an echo?*
- *Does Claire feel anything now?*

During the third challenge "Spatial Encoding and Detecting Signals", the concept of slice selection is introduced. The resonance hands-on activity uses string, a ruler, some masking tape and six washers, about $3.00 worth of materials, to demonstrate what it means for something to have a resonant frequency, as described below in the student instructions for this activity:

Cut the string into three pieces 25 cm, 50 cm, and 80 cm in length. Tie two of the washers on one end of each piece of string. (Two washers are used at each length for additional weight.) Starting with the 25 cm string, tie the other end to one side of the ruler. Wrap the string around several times until the washer hangs 8 cm below the edge of the ruler. Secure the string with a piece of tape. Next, tie the end of the 50 cm length string to the middle of the ruler and wind the excess until the washer hangs 30 cm below the edge of the ruler. Tape it in place. The 80 cm long string should be tied to the remaining edge of the ruler, and wound to hang 60 cm below the ruler. When you have finished, your final product should look like ***Figure 1****.*

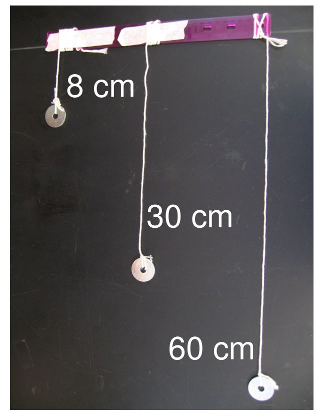


Figure 1: The apparatus used for the resonance experiment is made up of a ruler, washers and string.

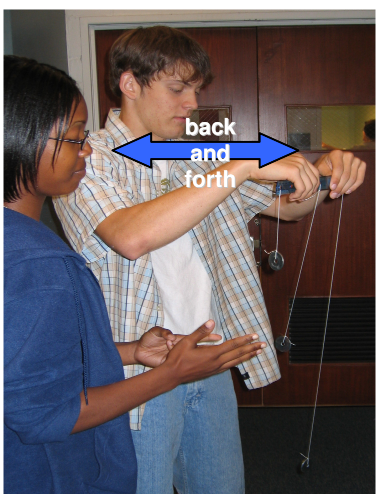


Figure 2: While one student moves the apparatus back and forth, another can count swings to determine the resonance frequency.

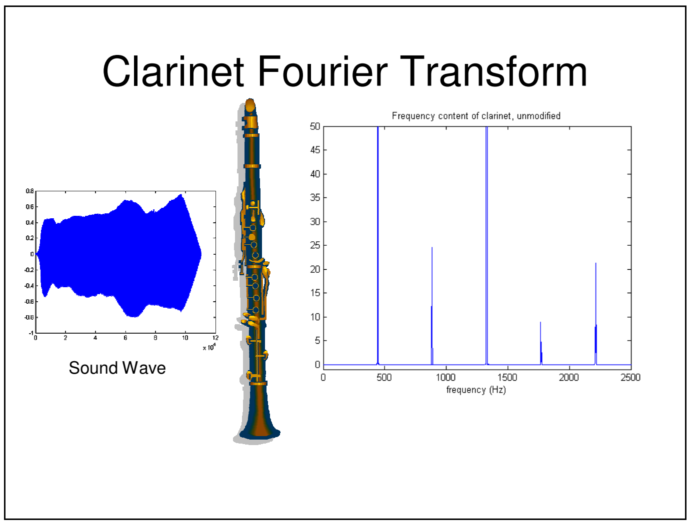
Holding the ruler with two hands, gently move your arms away from your body and then towards in a back and forth motion so the pendulums swing (see ***Figure 2****). There is a particular frequency of arm movement that allows each individual pendulum to swing while the other two remain still. Find the frequency needed to move the smallest pendulum while the middle and long pendulums remain still. While one partner moves the device, the second will time a 10 second interval. The person moving the pendulum should count the number of swings during the 10 seconds.*

This process is repeated and the number of swings for the two remaining lengths is also counted. Based on this data the student can then calculate a resonance frequency in Hz for each string length and draw conclusions about how applying a gradient enables tissues to resonate differently. When the challenge material is completed, the following questions should be answered:

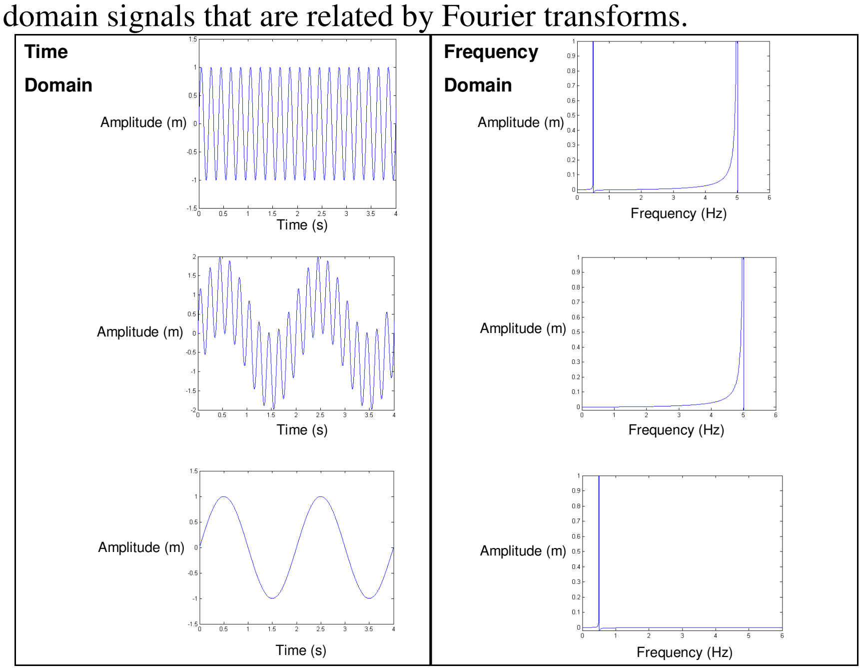
The first scan is complete. However, the radiologist asks the technician to repeat the scan because some important features in the brain cannot be seen, without which a diagnosis cannot be made.

- *How are the signals detected during the scan?*
- *How are tissue locations determined?*
- *What can be changed to improve the finer detail in the image?*

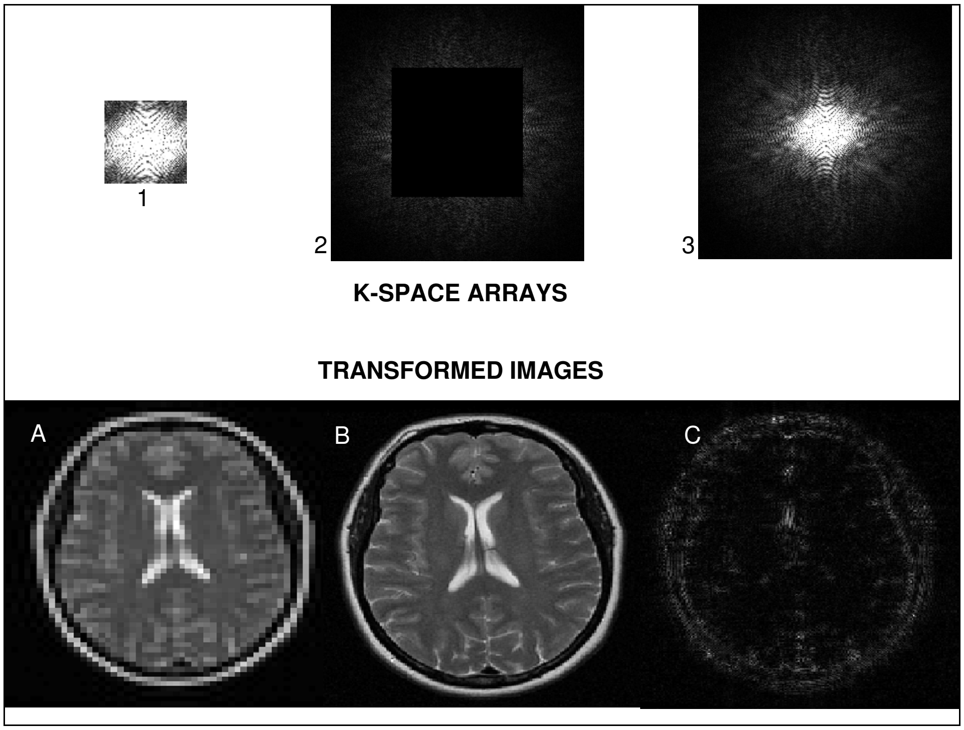
In the fourth challenge on image reconstruction, the Fourier transform is described in detail during explanation of image reconstruction. In the "Fourier Transform Sound Experiment", students are challenged to transform data from the time domain into the frequency domain. This helps reinforce how MR images are created from collecting complex, spatial frequency or "k-space" information which is transformed into spatial information. The sound activity involves playing audio clips of musical instruments playing sound waves for students while they can see the frequency content of the signals. An example visual for a clarinet is shown below:



After listening to several sound bytes, the students are asked to match the following time domain and frequency domain signals that are related by Fourier transforms.



This mathematical operation is later put into the context of MRI in the activity by having students match k-space arrays and their Fourier transform images:



By accurately matching k-space arrays to transformed images students demonstrate their understanding that high spatial frequency information fills the outer edges of a k-space array, and corresponds to the edges in an image, while low spatial frequency information is found in the center of a k-space array and determines the general shapes and contrast of an image. Through these visual challenges, students are able to better understand how this mathematical operation processes MR signal data to form the final image a radiologist studies. With this knowledge, the following challenge questions can be answered:

Claire read a brochure about MRI while she was in the waiting room. She learned that MRI uses radio waves, but does not understand how these waves can be used to make an image.

- *Where do the radio waves come from?*
- *How can you quantify and describe a wave?*
- *How do you describe a radio wave in terms of frequency? In terms of time?*
- *How are the radio waves made into an image?*

The fifth and final challenge on image characteristics addresses image properties, defining terms like pixel, voxel, and spatial resolution. The concepts are reinforced with an activity exploring how pixel size impacts overall image quality. This activity only requires two sheets of graph paper with different sized squares and about 10 minutes to illustrate how drastically images can be affected by the number of pixels. Students are provided a general shape to trace onto the paper but instructed to only shade in squares that are at least 50% covered by the shape. As demonstrated below, a triangle definition results in a rectangle due to the size of the squares on the graph paper. Using two different sizes of graph paper helps students visualize how smaller pixels or voxels improve the quality of the image.

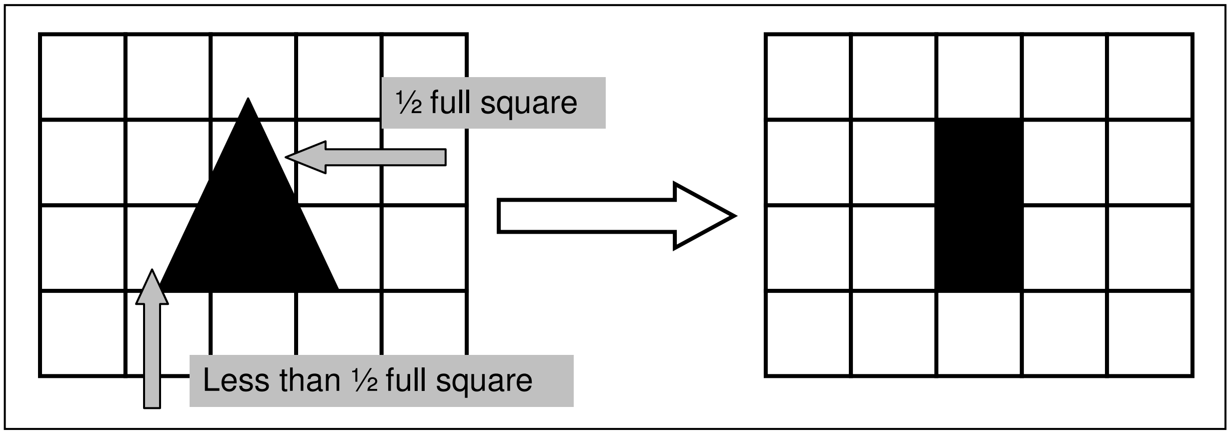


Figure 3: A triangle shape definition positioned as shown would only appear as a rectangle if each pixel were defined based on 50% of the fill, as demonstrated in the hands-on activity "Pixel Experiment".

From the student testing conducted in summer 2007, this was determined one of the easiest concepts taught and this simple activity was a great way to help students commit the concept to memory. The final challenge questions are as follows:

The radiologist examines the two sets of images in order to determine whether or not Claire has multiple sclerosis (MS). One set of images is primarily T1-weighted and the other is primarily T2-weighted. The T1-weighted images have higher spatial resolution and signal-to-noise ratio than the T2-weighted images. The radiologist knows that if there are lesions characteristic of MS, they would show up best on T2-weighted images.

- *What does the radiologist see in the images?*
- *What is spatial resolution?*
- *What does it mean for an image to be T1- or T2-weighted?*
- *What is signal-to-noise ratio and why does it matter?*
- *What makes MS lesions apparent in an MR image?*

Evaluation

Five high school students were invited to work on a paid basis with the project team for thirty hours per week for six days. Prospective participants were informed of the project by their science teachers and were required to fill out an application form that included a brief essay. The five participants were chosen based on applications and recommendations from their science teachers. Information regarding these students' academic performance was not used in the selection process. However, their science background was known as a means to determine their potential level of comprehension of the materials. The group was comprised of three females and two males, one African-American, one Asian-American, and three Caucasians.

The high school students were asked to take pre- and post-workshop surveys to evaluate changes in interest level and attitude towards biomedical engineering, more specifically biomedical imaging. The students tested the new MRI materials providing valuable information on each portion of the curriculum, including the hands-on activities, quizzes, homework assignments, and PowerPoint presentations. The students worked in two groups, with groups changing throughout the day.

These five students provided extensive feedback on paper and through in-depth conversations. They were also able to offer new ideas and angles for teaching different portions of the more challenging concepts. This shortened weeklong course along with student feedback provided an excellent means of evaluation prior to field-testing at the undergraduate and high school levels.

Comparison via paired t-tests for means of pre- and post- survey results indicated an increase in student interest and understanding of what biomedical engineers do ($p<0.05$). It is noted that statistical tests on a sample size of only five are not highly robust. We can expect more significant increases in other survey categories, such as understanding of math and physics concepts, with larger and more uniform sample population. Nonetheless, survey results demonstrated that the one week experience dramatically increased the verbal fluency and intellectual richness of the students' textual responses to questions about these domains.

Future Plans

The curriculum described is being tested during the 2007-2008 academic year. The original curriculum was written for an undergraduate level and has been adapted for additional use in high school classrooms. Testing will be conducted at both undergraduate and high school levels the spring 2008 semester. Feedback from these first users will be gathered and analyzed to direct future improvements. Additional testing schools are also currently being recruited.

Conclusion

A safe, hands-on and inexpensive curriculum for teaching the principles of magnetic resonance imaging developed for high school and undergraduate students was tested by graduated and rising high school seniors. The curriculum successfully stimulated interest in biomedical imaging and biomedical engineering among the test population. Feedback from the high school learners aided in the further development of lectures and activities for the curriculum.

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