# Student Understanding of the Correlation between Hands-on Activities and Computer Visualizations of NMR/MRI

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**Abstract.** This study utilizes the implementation of research-based learning materials designed to teach students about the physics of magnetic resonance imaging (MRI) in a concepts-based introductory-level physics course. A progression of activities using hands-on experiments and computer visualizations leads students through the basics of magnetism and resonance, and finally toward a model of MRI. Here we seek to describe how students understand the basics of resonance and then proceed to make correlations between the hands-on activities and visualizations. Results show that students had fundamental difficulties with the concepts surrounding resonance, and that it appears to have led to a rudimentary understanding of the visualization and how the two tasks were correlated. Based on student responses, we postulate what further scaffolding will be necessary for helping the students make more robust connections and a more comprehensive understanding of the phenomena associated with MRI.

**Keywords:** physics education, resources, visualizations, resonance, MRI
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## INTRODUCTION

The Modern Miracle Medical Machines (MMMM) project at Kansas State University has produced several research-based learning materials designed to teach students the physics of modern medical devices [1]. One such project focuses on Magnetic Resonance Imaging (MRI), and uses the basic concepts of magnetism along with the generally less-familiar topic of resonance in order to help students construct an understanding of nuclear magnetic resonance (NMR) and MRI. This paper serves as the first analysis of a full scale in-class implementation of the learning materials.

During the development of this activity, Murphy *et al.* examined students' understanding of resonance within the context of compasses in a magnetic field [2]. However, the students in that study were significantly more knowledgeable than the target audience of introductory students. This study aims to further that work by using students enrolled in a concepts-based introductory-level course and examining the connections made between the hands-on and computer visualizations used in the activities.

The overarching research question guiding this study is: *To what extent do students understand the concepts of resonance, and how do they correlate the hands-on activities and computer visualizations designed to help them understand magnetic resonance imaging?*

## LITERATURE REVIEW

Magnetic resonance imaging (MRI) proves to be an interesting classroom application because it uses the basic principles of magnetism while also incorporating the less-familiar topic of resonance. A great body of work exists on student understanding of magnetism, for example works by McDermott and Galili on basic electricity and magnetism [3-5] and by Greca and Moriera and Rainson on the field concept [6, 7]. However, less research has been done on the topic of resonance [8, 9].

The learning materials used here contain both hands-on activities and computer visualizations. A significant body of research has been done to compare student learning in each format. Some work has shown that students who interact with visualizations out-perform students who completed hands-on activities [10], while others have shown no statistical difference between the approaches [11-13]. However, there are fewer studies that highlight the interaction/combination of the two media [14, 15].

## METHODS

### The Activity

The MRI activity follows a progression that works from the basics of magnetism, through resonance, and finally to the ideas of NMR and MRI. A combination of hands-on activities and computer visualizations allows the student to move from macroscopic to microscopic phenomena. Excellent visualizations for all necessary concepts had already been developed by the PhET project at the University of Colorado [16] and were used in the activities. The following is a basic overview of the activities; a more thorough description can be found in [2, 17].

The activities begin with a treatment of the basic concepts of magnetism using compasses and bar magnets. The students are also introduced to the idea of the magnetic field from a current-carrying wire, which is fundamental to understanding the magnetic resonance phenomena and apparatus.

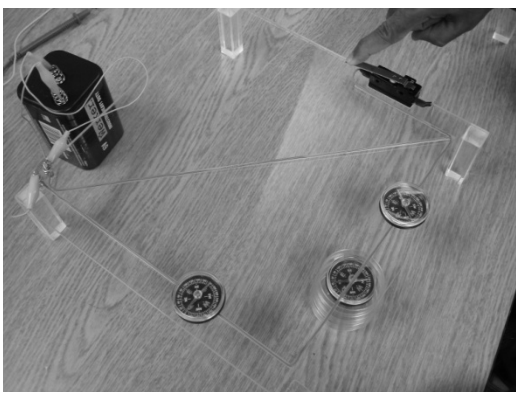

**Figure 1 - Photo of magnetic oscillation activity**

After magnetism is established, the students begin to look at the idea of resonance. First, a simple pendulum is used to discuss the concept of frequency which is then translated to the frequency of the compass needle. Next, resonance is discussed in the context of the traditional pendulum as well as with the compass. A photo of the magnetic oscillator is shown in Figure 1. By tapping a switch to form a closed-circuit, students can create a magnetic field "kick" that will make the compass oscillate and in fact resonate if done at the appropriate frequency. Resonance phenomena are observed for different compasses, external field strengths, and 'kick' strengths (by changing the distance from the compass to the wire). Further, students are exposed to the idea of a Larmor frequency in order to quantify what they have seen [18].

Students then interact with a computer visualization that illustrates the concepts of NMR. In the visualization, atoms are arranged in an external magnetic field and can be perturbed with a magnetic field of variable frequency. A screen shot of the computer visualization is shown in Figure 2. Finally, students are guided through the idea of a gradient field which is necessary to allow for the resonance of selected locations and therefore serves as the 'imaging' component of MRI.

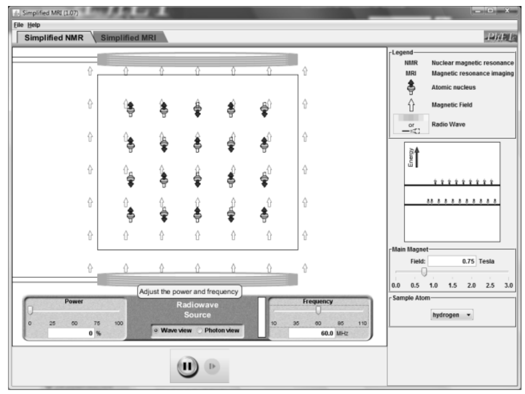


**Figure 2 - Screen shot of the PhET NMR/MRI visualization [16]**

### Data Collection and Analysis

The data analyzed in this paper are from a full implementation of the MRI activity at Mercyhurst College, a small (~3000 students) private college. The activity was implemented in a conceptual-level introductory physics course, primarily taken by non-scientists.

Students worked in groups and completed the activity in worksheet format independently of the teacher/researcher, but could ask for help at any time. In total, 22 students worked in 8 self-selected groups (two groups left before completing the activity).

The data analyzed were taken directly from the student worksheets. An overall phenomenographic approach was utilized to examine the differences in the way students responded to the worksheet questions [19].

## FINDINGS

### Determining Frequency

Unlike the students in the previous study, the introductory students who completed the activities struggled with the idea of resonance and the correlation between the pendulum and the compass. While all groups recognized the length-dependence of the pendulum's frequency, only 3 groups were able to list all of the factors determining the frequency of the pendulum. Further, many groups showed difficulty in actually measuring a frequency, as they were asked to do with the compass in the magnetic field. In fact, only 3 of 8 groups responded with a reasonable number. One group simply wrote a number (that was not close to the expected value) with no explanation. Interestingly, 4 of 8 groups measured the time it took the compass needle to stop oscillating. As one group wrote:

*"7 seconds to completely stop, 7 oscillations, frequency = 1."*

While another group explained:

*"8s to stop. Period = 8s, frequency = 0.8s"*

Each of these examples shows a fundamental misunderstanding of what frequency is and how it is determined. Interestingly, however, as long as they were consistent in the way that they quantified the period, the groups were able to proceed through the activity and establish the same relationships as those who accurately determined frequencies.

### Identifying Correlations

The hands-on activity is set up so that each piece directly correlates with a necessary component of MRI and therefore a component of the visualization. The compass, which is the oscillator, is like the atom. The Earth/bar magnet serves external magnetic field. Tapping the switch at a certain frequency creates the variable-frequency field. And finally, the bar magnets placed different distances from the compass correlates to the magnetic field gradient. Students were directly asked which pieces correlated.

Only one group of students identified the correlation between the compasses and the atoms. Three groups identified the compasses as being related to the frequency. However, the remaining 3 groups answered the question in ways that signified they did not understand what they were being asked.

The Earth/bar magnet was correctly identified by 5 groups as corresponding to the main external magnet in the visualization. Again, the remaining 2 groups answered in such a way as to suggest they did not understand the question.

Finally, only 1 group was able to correctly identify that tapping the switch corresponded to the adjustable frequency in the visualization. (This was not the same group who could accurately identify the compass/atom.) Three groups correlated this to the power, and as one group explained:

*"It causes changes in power, because when the wires are tapped on by the switch it increases the strength of the frequency that is provided."*

This seems to indicate that the students believe the frequency is 'always on' somehow, and that the current in the wire merely strengthens it. Because of the limitations of written response data, however, we have no way of following up with the students to determine their thought process.

### Explaining Magnetic Resonance Imaging

The final question asked of the students was "In your own words, explain how a doctor can determine the location of a tumor within a person's body using magnetic resonance imaging techniques." In general, the groups answered this question far more succinctly than was intended. Instead of providing a brief summary of all of MRI, all of the groups focused on the idea that the tumor is located at the place where you find the most resonance. Only 2 groups discussed the use of the gradient magnets in isolating specific areas of the body.

## CONCLUSIONS AND FUTURE WORK

This research was meant to determine how students interacted with the learning materials to create an understanding of resonance and to what extent they were able to form correlations between the hands-on activities and computer visualizations.

In general, students showed great success in working through the first set of activities on the basics of magnetism. However, these concepts-based introductory-level students began to have difficulty with the concepts surrounding the frequency of a non-traditional oscillator. This difficulty carried over into their understanding of resonance and therefore hindered their ability to form a robust understanding of MRI. It is quite evident that they did not move as quickly through the material as the upper-level students in prior studies. However they did show set-backs in many of the same areas, particularly in terms of the non-traditional oscillator (compass).

It is apparent that more scaffolding is needed to overcome these challenges. In particular, smaller steps must be taken to ascertain that students can successfully measure the frequency of the compass. By accurately measuring the frequency, they will more easily be able to create the resonance condition.

Also, additional support is needed before students are asked to form correlations between the hands-on activities and the visualizations. Students clearly did not understand the question, and therefore we cannot at this time measure the true extent to which they were able to see the connections between the two activities. One possible solution to the issue with student being able to correlate the two media may be to provide students with an example. Another option may be to first inform student of the components of each format, and then ask them to essentially 'match' the components. To more fully explore the underlying issues, learning-teaching interviews should be conducted with the target population.

In general, the introductory-level students had some difficulty with the concept of frequency, the non-traditional oscillator, and resonance. These difficulties hindered their understanding of NMR/MRI. However, we believe that with additional scaffolding, thoughtful re-phrasing of questions, and in general smaller step-sizes through this difficult material, the students will be able to successfully correlate the hands-on activities with the computer visualizations to create a working understanding of NMR/MRI.

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## REFERENCES

1. Kansas State University, P.E.R.G. *Modern Miracle Medical Machines*. 2010; Available from: http://web.phys.ksu.edu/mmmm/.
2. Murphy, S., et al., *Probing Students' Understanding of Resonance*, in *2009 Physics Education Research Conference*, M. Sabella, C. Henderson, and C. Singh, Editors. 2009, AIP Conference Proceedings: Ann Arbor, MI. p. 213-216.
3. Galili, I., *Mechanics background influences students' conceptions in electromagnetism.* International Journal of Science Education, 1995. **17**(3): p. 371-387.
4. McDermott, L.C. and P.S. Shaffer, *Research as a guide for curriculum development: An example from introductory electricity. Part I: Investigation of student understanding.* American Journal of Physics, 1992. **60**(11): p. 994.
5. McDermott, L.C. and P.S. Shaffer, *Research as a guide for curriculum development: An example from introductory electricity. Part II: Design of an Instructional Strategy.* American Journal of Physics, 1992. **60**(11): p. 1003.
6. Greca, I.M. and M.A. Moreira, *The kinds of mental representations - models, propositions and images - used by college physics students regarding the concept of field.* International Journal of Science Education, 1997. **19**(6): p. 771-724.
7. Rainson, S. and L. Viennot. *Superposition of the electric fields and causality: From research to teaching*. in *The Changing Role of Physics Departments in Modern Universities*. 1997. College Park MD: AIP Conference Proceedings.
8. Ambrose, B.S. *Probing Student Reasoning and Intuitions in Intermediate Mechanics: an Example with Linear Oscillators*. in *Physics Education Research Conference*. 2006. Syracuse, NY: AIP Conference Proceedings.
9. Sayre, E.C., M.C. Wittmann, and J.E. Donovan II. *Resource plasticity: Detailing a common chain of reasoning with damped harmonic motion*. in *Physics Education Research Conference*. 2006. Syracuse, New York: AIP Conference Proceedings.
10. Finkelstein, N.D., et al., *When learning about the real world is better done virtually: A study of substituting computer simulations for laboratory equipment.* Physical Review - Special Topics PER, 2005. **1**(1): p. 1-8.
11. Carmichael, A.C., et al. *Comparing the Effects of Physical and Virtual Experimentation Sequence on Students' Understanding of Mechanics*. in *Physics Education Research Conference*. 2009. Ann Arbor, MI: AIP Conference Proceedings.
12. Khlar, D., L.M. Triona, and C. Williams, *Hands on What? The Relative Effectiveness of Physical Versus Virtual Materials in an Engineering Design Project by Middle School Children.* Journal of Research in Science Teaching, 2007. **44**: p. 183-203.
13. Zacharia, Z.C. and G. Olympioua, *Physical versus virtual manipulative experimentation in physics learning*. Learning and Instruction, 2010(in press).
14. Carmichael, A.C., et al., *Comparing the Effects of Physical and Virtual Experimentation Sequence on Students' Understanding of Mechanics*, in *American Educational Research Association*. 2010: Denver, CO.
15. Zacharia, Z., *Comparing and combining real and virtual experimentation: an effort to enhance students' conceptual understanding of electric circuits.* Journal of Computer Assisted Learning, 2007. **23**(2): p. 120-132.
16. Colorado, U.o. *PhET Simulations*. 2009.
17. Zollman, D.A., et al. *Teaching about the Physics of Medical Imaging*. in *2009 International Conference on Physics Education*. 2010. Bangkok, Thailand.
18. Hornak, J.P., *The Basics of MRI*. 1996, http://www.cis.rit.edu/htbooks/mri/index.html.
19. Marton, F., *Phenomenography—a research approach to investigating different understandings of reality.* Journal of Thought, 1986. **21**: p. 28-49.