Physics Modeling For Pre-Med Undergraduates

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ABSTRACT

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Undergraduate students on track for medical school are often required to take general physics lab courses. Many of these students carry an attitude of obligation into their physics courses which can make it challenging for physics teachers to engage students in the course material. We have addressed the question: How does participating in medically based models in physics labs affect pre-med undergraduate perceptions of and performance in the scientific process? We redesigned the electricity and magnetism lab for an introductory physics lab course, where about 70 percent of the students enrolled reported plans to attend medical school. We patterned the lab after the magnetic resonance of an MRI machine to situate learning and encourage scientific modeling. We produced a survey to collect student perceptions of scientific modeling before and after participating in this lab. In addition to the surveys, we coded student work with rubrics based on the American Association of Physics Teachers and Next Generation Science Standards for scientific modeling to measure their performance before, during, and after the lab. Most notably, the student definitions and applications of scientific modeling increased without receiving direct instruction on the subject. Additionally, student engagement in scientific modeling improved from general high school levels to introductory and intermediate college levels.

Keywords: Scientific modeling, Pre-medical, Undergraduates, Situated Learning, Physics lab course, Magnetic resonance

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Contents

List of Figures

List of Tables

Chapter 1

Introduction

For pre-medical undergraduate students enrolled in general physics courses, scientific modeling can be the bridge that connects the physical sciences to the life sciences. The difference between the physical and life sciences can be difficult to reconcile for students and teachers alike. The approaches to these sciences can be dissimilar, and when people are used to one approach, it can be challenging to see the value or application of any other. Because this disconnect has been apparent in introductory physics courses for non-majors in many colleges [1], including our own, we sought to address the stumbling block. At the heart of any scientific practice—no matter the approach—there is a foundation of scientific modeling; biologists use models just as often as physicists do to test hypotheses. Knowing that scientific modeling skills can be beneficial in any field, including the medical field, we chose to adjust our approach to part of an introductory physics lab course to emphasize scientific modeling practices for the high concentration of pre-med students enrolled. More specifically, we applied models for physics in a medical context and looked for answers to the following research questions:

How does participation in medically based models in introductory physics labs affect pre-med undergraduate perceptions of the scientific process?

How does participation in medically based models in introductory physics labs affect the performance of pre-med undergraduates in the scientific process?

1.1 Physics and Pre-Med Students

In our introductory physics lab courses for non-physics majors, about 70 percent of the students are on track for medical school or other professional schools such as dental school (E-CLASS for Experimental Physics, 2022). Often, the attitude that pre-med students carry into a required physics course is an obligation to fulfill the requirements for their medical school applications but little interest in the actual subject matter [1]. Because a physicist's approach to science may be different from a medical student's approach, there are often situations where pre-med students doubt the relevance of physics to their future careers while enrolled in physics courses [1]. This lack of connection is concerning because there is a significant amount of overlap between physics and the life sciences. The scientific practices that are developed in lab courses are applicable to every type of science. For example, the ability to make conclusions (or diagnoses) based on data collected during an experiment is a skill frequently implemented by physicians and physicists alike. The physics courses that pre-med students participate in should therefore be focused on not only helping students gain a better understanding of basic physics principles, but also teaching them higher levels of problem solving and scientific modeling skills [2]. According to the American Association of Physics Teachers (AAPT), the target learning outcome in these entry level physics lab classes for non-physics majors should be to expand the students' understanding and ability to participate in experimental investigations because science is interdisciplinary in nature [3]. We used this target learning outcome as the foundation of our course goals.

1.2 Scientific Modeling and its Role in the Classroom

Within introductory lab courses across the world, it is common to find assignments and experiments that are set up in a traditional “recipe” style [4]. In such an approach, a teacher presents students with a set of lab instructions for them to follow step-by-step while aiming for a specific result (such as confirming the acceleration of gravity or verifying some other constant). While this method of teaching is convenient and informative for both teachers and students, it is not the most effective way to equip students with the skills necessary to excel in the world of scientific research [5]. One flaw of this recipe style is the lack of authentic investigative experience; the labs are hands-on but not heads-on [6]. In fact, instruction settings with this verification structure have been found to provide no statistically significant benefit to students in regard to their performance or course content comprehension [7]. Rather than simply confirming what was already taught in a lecture or previous lesson, classroom experiments should be used to provide practice and experience with scientific modeling [8]. To better address course goals, as recommended by AAPT, many educators have begun implementing a model-based method of teaching instead. Figure 1.1, from an AAPT report of recommendations for undergraduate physics laboratories, depicts the overlap between many important scientific practices all closely related to scientific modeling [3].

Scientific modeling is a method in which students are challenged to describe a specific scientific phenomenon in simple ways that are both familiar to them and provide grounds for them to predict further outcomes [9] [10]. This method of scientific exploration should not be limited to advanced scientific researchers who have years of experience; the scientific modeling approach should be integrated into science classrooms at every stage of education [11]. Students who engage in actual scientific practices develop a better understanding of—and proficiency in—the decision-making process involved [12].

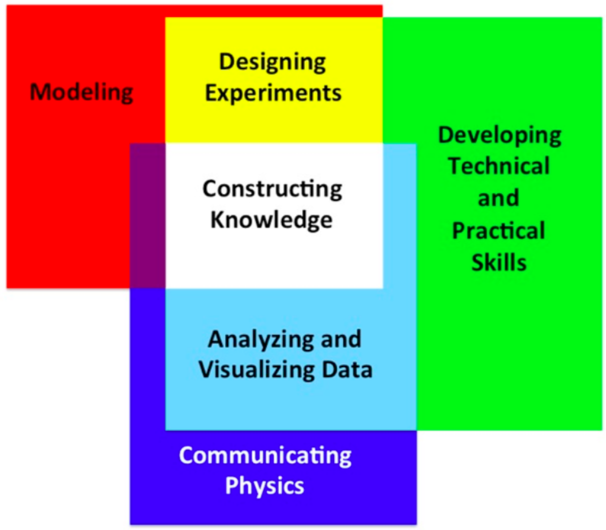


Figure 1.1 Visual model of the overlapping scientific skills associated with modeling [3].

1.3 Theoretical Framework: Situated Learning and Scaffolding

This work is built within the framework of Situated Learning Theory. Situated learning, as visualized in Fig. 1.2, takes place when students can explore and practice the applications of class material in authentic contexts alongside other students to better foster constructivist learning [13]. Such authentic and applicable contexts are beneficial to students because they have the opportunity to develop the skills needed to apply what they learn, rather than simply gaining knowledge of seemingly abstract principles [14]. Billett [15] proposed that learning is closely linked to the circumstances and context of the learning environment and that students may have difficulty transferring their experiences and knowledge to spaces different from that original context. In other words, experiments centered around affirming constants or other inauthentic projects can undermine the goals of the course because it is not a transferable experience. Conversely, social interactions between students help foster learning because interacting with other people is a significant source of developing knowledge [16]. This interactive development of knowledge is supported by the constructivist learning approach where students are given the opportunity to express their thought

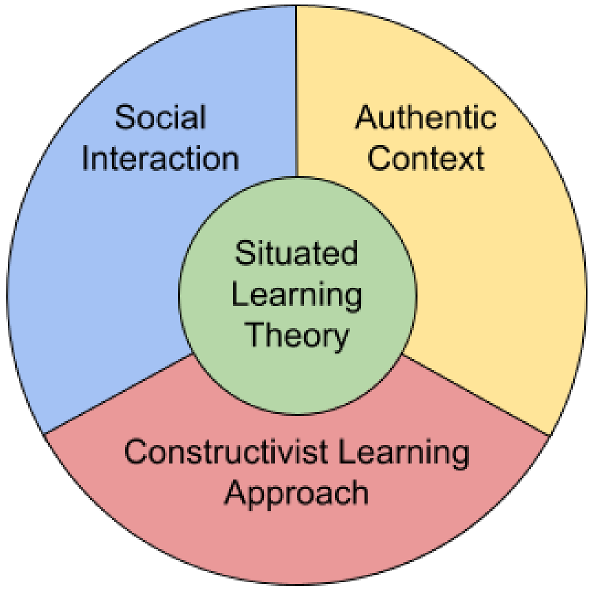


Figure 1.2 The main tenets of Situated Learning Theory (adapted from Green et al. (2018)) [13].

processes, learn by inquiry or problem solving, and add new knowledge to the foundational understandings they already had [17].

As is the case with any area of growth, there is a Zone of Proximal Development (ZPD) between a student's independent abilities to engage in the scientific modeling and a higher level of ability that requires guidance [18]. Instructors who foster learning within this ZPD enable their students to more confidently progress from one level of performance to the next [19]. Distributed scaffolding is one way to engage students in the ZPD and includes access to multiple tools, resources, and—much like Situated Learning Theory—social interactions [20].

In one of our introductory lab courses for non-physics majors, we explored the impact of situated learning on pre-med students and their scientific modeling practices. We redesigned an electricity and magnetism lab to include an investigation of a simplified analog of a magnetic resonance imaging (MRI) machine. By using the context of an MRI machine, our students were able to engage with the scientific phenomena of solenoids, gradient magnetic fields, and magnetic resonance within a context that is meaningful to them. We tracked their engagement and understanding of scientific modeling before, during, and after the MRI lab to better understand how situating their learning in this way impacted how sophisticatedly they engaged in scientific modeling.

Chapter 2

Methods

We used a structured approach [21] to address our research questions because we wanted to compare the student perspectives and performance from before and after our adjustments to the lab. We redesigned the electricity and magnetism lab in an introductory physics lab course for non-majors from a traditional recipe approach to exploration of the situated model of an MRI machine. By maintaining several other traditional labs in the course (such as labs that we will refer to as labs 3 and 8), we were able to carry out a cross-case analysis of student progress. The following sections describe the context of the study, a description of the MRI lab rebuild, and a description of our analytical methods.

2.1 Context and Participants

The introductory physics lab course for non-majors (PHSCS 108) in our study covers electricity, magnetism, waves, and optics. While students are highly encouraged to take the lab concurrently with the companion lecture course that teaches electricity and magnetism, it is a separate course. The content taught through the labs and lectures are not lined up perfectly so while students are often able to apply principles from their lectures to the labs, there are other times when they are using the

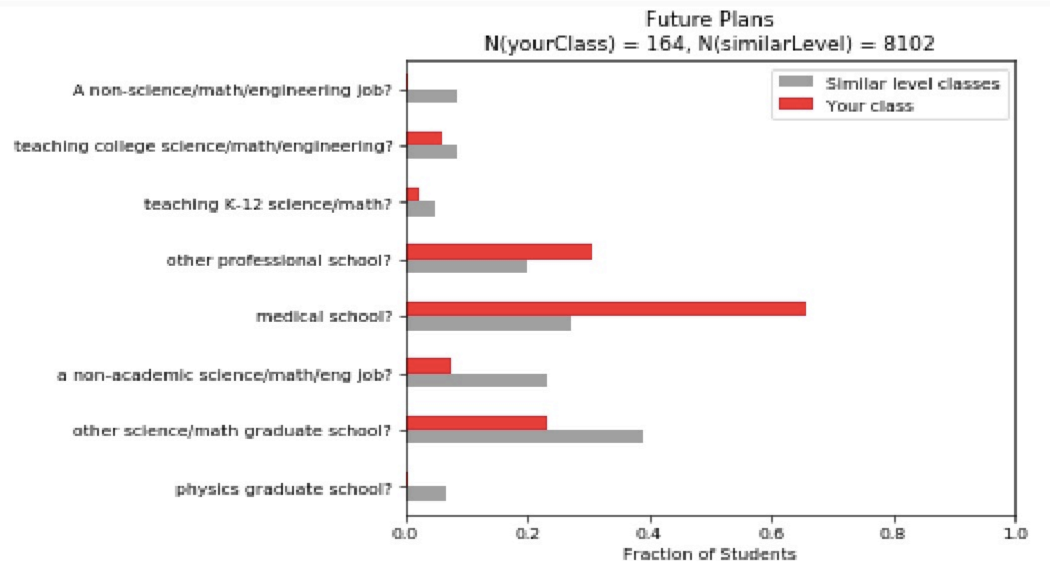


Figure 2.1 The majority of students enrolled in PHSCS 108 are planning on attending medical or other professional schools (such as dental or pharmacy school). For this particular semester, not a single student declared plans for physics graduate school.

labs to explore scientific phenomena for the first time. In alignment with AAPT recommendations for the learning outcomes of non-physics majors [3], the course goals of our PHSCS 108 class are to teach scientific thinking, modeling practices, and experimental design skills.

For an average semester, the course has 12-15 sections with roughly 20-30 students per section. Each section meets once a week for a two-hour period in which the students work through experimental physics labs in groups of three to four. While there is one professor that oversees the progress of all the classes over the course of the semester, there are one or two teaching assistants (TAs)—usually undergraduate students who either are physics majors or have previously taken the PHSCS 108 course themselves—to monitor and instruct each section more closely. The professor and TAs meet once a week to go through the upcoming labs themselves to troubleshoot equipment, solidify their own understanding, and address areas of potential confusion. This arrangement gave us confidence in our restructuring of the lab because we knew the lab would be test-run by the TAs prior to being distributed to the students.

The majority of students who enroll in this course are on track for medical or other professional career schools. According to the Colorado Learning Attitudes about Science Survey for Experimental Physics (E-CLASS) for the undergraduates in our study, just under 70 percent of them had potential plans for medical school, 30 percent for other professional schools (such as dental or physical therapy schools), and no students declared plans for physics graduate school (see Fig. 2.1). This point is important to emphasize because unlike physics undergraduates, these students are most likely unfamiliar with a physicist's approach to experimentation and science learning.

2.2 Description of the MRI Lab

We split the revised MRI Lab into three sections. First, the students are led through a scaffolded exploration of magnetic fields by following instructions to use a hall probe to plot field lines on magnets as well as current-carrying wires. After fostering the foundational principles of magnetism, the emphasis of the lab turns to magnetic resonance. With the importance of student-led scientific modeling in mind, we guided the second part of the lab in a less scaffolded manner using questions like the following:

"Consider a parent pushing their child on a swing. How do you know when someone is pushing a swing in resonance with the natural frequency of the swing? What happens if a swing is pushed too fast or too slow? How does this relate to resonance?"

Following the semi-scaffolded experiments and observations about magnetic resonance, we introduced the context of an MRI machine with two short videos and the following foundation of a model for them to work with:

"It is clear that MRI is a very complicated area of both medicine and physics. . . but you can explore the concepts of magnetic resonance with a simplified model of an MRI machine and a bar magnet that represents a single hydrogen atom in the body."

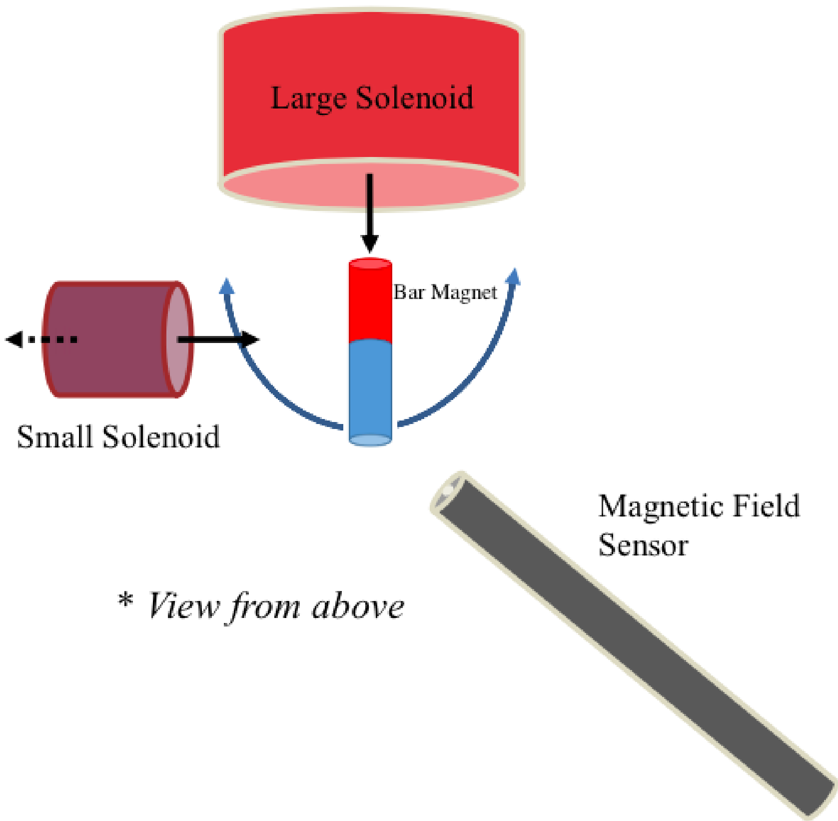


Figure 2.2 Visual provided to students as a potential lab set up to test various hypotheses for the MRI Lab.

With this basic overview of an MRI machine, we turned the third part of the lab over to the students with minimal scaffolding to explore their own hypotheses; we gave them the opportunity to engage in the scientific process on their own. The limited scaffolding we provide includes the simple model just described, recommended settings for measurement tools, and Fig. 2.2 as an example layout of the equipment for experimenting with the gradient magnetic field produced by an MRI machine.

To better illustrate the level of scientific modeling the undergraduates engaged in as a result of the limited scaffolding in the second half of the MRI Lab, we have provided an example of a student's work from their notebook (see Fig. 2.3). In this example, the student shows evidence of scientific modeling when they use the relationships between mass, friction, and damping—which are principles they would have learned in a previous physics lab class on Newtonian kinematics—to predict the relationships between a magnet's mass and its resonance. Following the definition of scientific modeling established in the introduction, this student describes magnetic resonance in a simple way that is both familiar to them and that provides grounds to predict the system's outcomes.

2.3 Data Collection and Analysis

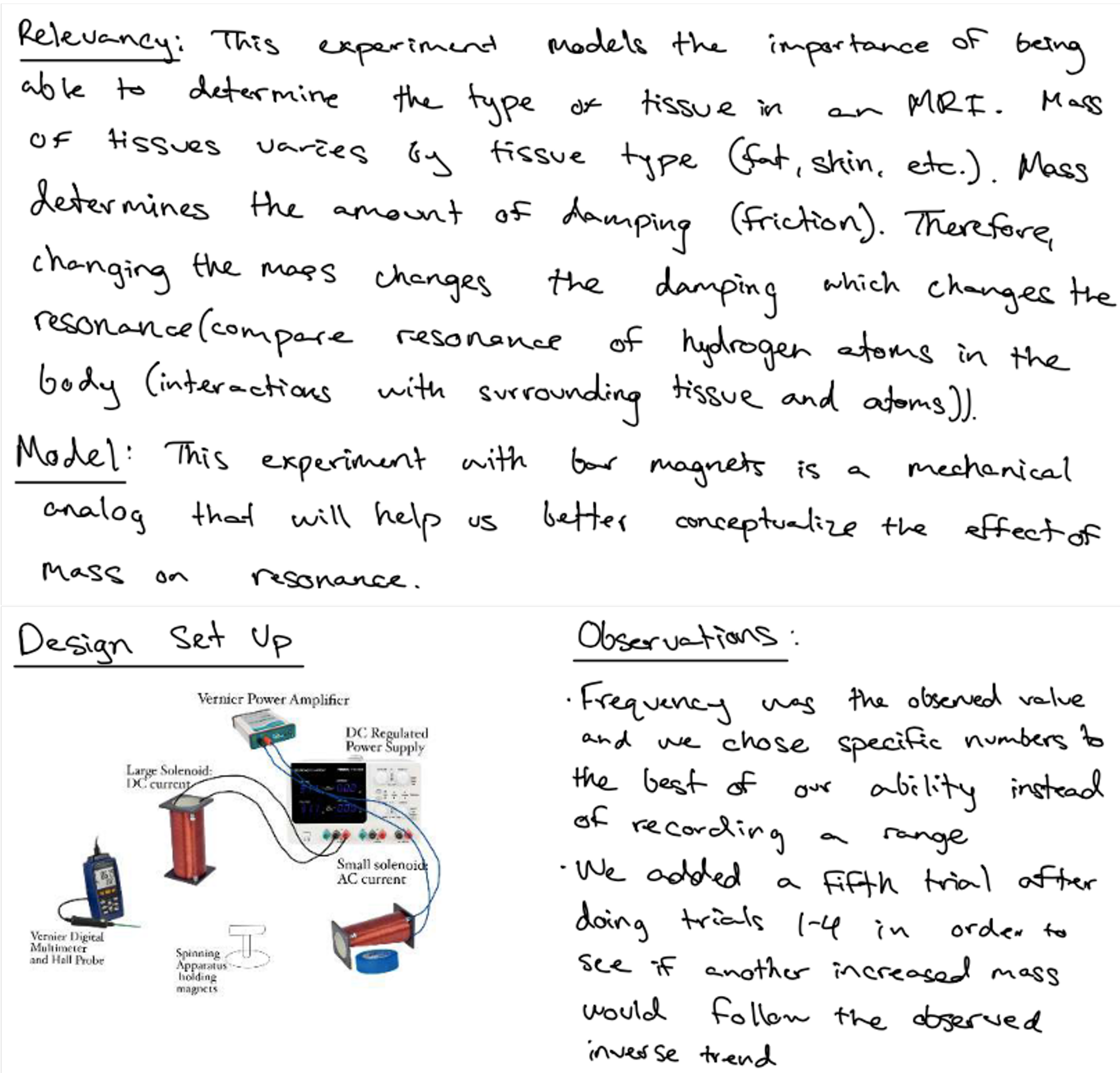
To answer our research questions we collected and anonymized the following data for analyzing: E-CLASS, lab notebooks, lab reports, and in-course surveys (see Table 2.1). With the foundation of the E-CLASS, we wrote two additional survey questions and distributed them to the students before they participated in the MRI lab and again after the lab:

- What is scientific modeling and why is it significant to experimentation?

- How can engaging in physics experimentation prepare you for your future academic and career interests?

Table 2.1 also indicates how many of each data source we had available to us and how many we used in our analysis. The number of available sources usually reflects the total number of students who participated and turned in their work for that source. The MRI lab report is an exception to this because the students submitted these as a group (3-4 students) rather than individually. The samples we used from lab 3 and lab 8 only included students who participated in all three labs (lab 3, MRI lab, and lab 8), giving us a sample size of 75 undergraduates. Copies of each lab is provided in Appendix A.

We used a categorizing analysis approach [21] to track student responses to our survey question, "What is scientific modeling and why is it significant to experimentation?" From those open codes we developed the themes presented in Table 2.2. We then used these themes to track how



Relevancy: This experiment models the importance of being able to determine the type or tissue in an MRI. Mass of tissues varies by tissue type (fat, skin, etc.). Mass determines the amount of damping (friction). Therefore, changing the mass changes the damping which changes the resonance (compare resonance of hydrogen atoms in the body (interactions with surrounding tissue and atoms)).

Model: This experiment with bar magnets is a mechanical analog that will help us better conceptualize the effect of mass on resonance.

Design Set Up

Observations:

- Frequency was the observed value and we chose specific numbers to the best of our ability instead of recording a range
- We added a fifth trial after doing trials 1-4 in order to see if another increased mass would follow the observed inverse trend

Figure 2.3 This example of student work was submitted as part of the MRI lab notebooks. The student clearly illustrates the goal learning outcomes of the course in practicing scientific modeling to simply describe and make predictions about the scientific phenomenon in question.

Source	Available	Used	Description
E-CLASS responses	164	164	Student learning attitudes about science
Lab 3 student notebooks	295	75	Scaffolded lab notebook on electricity and circuits
MRI lab reports	25	25	Un-scaffolded reports completed by groups of three to four students on their MRI exploration
Lab 8 student notebooks	293	75	Scaffolded lab notebook on lenses and optics
Survey responses	96	96	Student answers to the distributed application questions

Table 2.1 Our sources of data collection: The E-CLASS responses were used to determine the background and attitudes of the students. Labs 3 and 8 were used to measure student performance before and after participating in the MRI lab. Survey responses were used to monitor the changes in student definitions and applications of scientific modeling.

undergraduate perceptions and applications of modeling changed between the first and second set of survey responses.

When it came to coding student work and measuring their actual participation in scientific modeling, we used an organizational categories approach [21]. This allowed us to measure student performance against predetermined criteria. We adjusted a rubric from an earlier project (see Tables 2.3 and 2.4) that categorized different levels of sophistication for scientific modeling (ranging from secondary school uses to college level expectations) to our participants' lab work [22]. The grounding for the Modeling Sophistication Rubric (MSR) comes from the framework for Next Generation Science Standards (NGSS) [23] and the AAPT college level modeling recommendations [3].

Student Uses of Modeling	Description	Example
Tool	Modeling is used as a tool that provides some assistance or benefit to their experiments.	"Models can help us see and understand difficult concepts."
Process	Modeling is used as a process through which new information can be attained. Includes the recognition that revision is an important step.	"It is important that scientists test their models and be willing to improve them as new data comes to light."
Multiple Types	Student acknowledges multiple types of models and/or ways to model.	"Physical or mathematical representation of a phenomenon." "Using data, math, stats, theory, to represent observations."
Misconceptions	Incorrect assumptions or ideas regarding modeling.	"You are trying to create a perfect model for the principle you are studying."
Limitations	Student limits the purpose or function of modeling.	"Models are used when it is either impossible or impractical to create experimental conditions where scientists can directly measure outcomes."

Table 2.2 While organizing student responses to the survey questions, we identified the above trends and categorized them according to the descriptions and examples. By comparing student responses from before participating in the MRI lab with their responses from after, we were able to see the changes in student definitions and applications of scientific modeling.

Origin	Element	Description
NGSS	Scientific Principle	Parts of the model are explicitly linked to scientific principles
NGSS	Relationships	Describes relationships and/or patterns in the data
NGSS	Predicts	Model makes predictions about phenomena
NGSS	Limitations	Identifies limitations of the model
NGSS	Sense-making	Students determine whether their results are reasonable
AAPT	Assumptions	Addresses or acknowledges assumptions made in the model
AAPT	Multiple Models	Uses multiple types of models (mathematical, visual, etc.)
AAPT	Complete Analysis	Multiple types of models are used for analysis
AAPT	Systematic Error	Discusses how systematic error and biases affect the model

Table 2.3 Using an organizational categories approach, we used the Modeling Sophistication Rubric to code student lab notebooks. The scientific modeling standards from NGSS are geared towards high school level courses while AAPT is focused on college level engagement.

Score	Criteria
Level zero modeling	Meets no benchmarks
Level one modeling (introductory secondary modeling)	Meets one to two NGSS benchmarks
Level two modeling (intermediate secondary modeling)	Meets three NGSS benchmarks
Level three modeling (advanced secondary modeling)	Meets three to four NGSS benchmarks and one AAPT benchmark
Level four modeling (introductory college modeling)	Meets four or more NGSS benchmarks and two AAPT benchmarks
Level five modeling (intermediate college modeling)	Meets four or more NGSS benchmarks and three or more AAPT benchmarks
Level six modeling (advanced college modeling)	Meets all benchmarks

Table 2.4 Six levels were established to describe the expectations of scientific modeling as outlined in the MSR from introductory secondary schooling to advanced college.

2.4 Limitations

While the results of this research have supported our application of the situated learning model, it is important to recognize our limitations. Because our sample only includes undergraduates attending one institution, the results may not be easily generalized outside of this context. Although, it does represent a case that can be tested in other contexts.

Additionally, the data we were able to collect was restricted to written work because of Institutional Review Boards (IRB) constraints. In the future, with more comprehensive approval from IRB, video recordings of students working through labs could be collected to add further insight to the findings. This additional method of monitoring student work more closely would also help triangulate results. With more sources of evidence, we could bring to light the lesser-known effects that additional factors have on scientific modeling, such as the varying extent of scaffolding in each lab [20].

Chapter 3

Results

We aligned the results with the study's research questions. First, we present our findings for the changes in undergraduate perceptions of scientific modeling. Second, we show the development of undergraduate performance in the scientific process.

3.1 Changes in Undergraduate Perceptions

In the ECLASS, there was a series of questions that collected data on the degree to which students personally related to a statement compared to how "experts" related to the same statements. Between the beginning and the conclusion of the semester, the responses to four of these statements (see Fig. 3.1) showed significant movement. The score indicates the fraction of students with "expert-like" responses. In other words, as scores approach 1, more students are responding like experts. The dots indicate where the responses were at the beginning of the semester while the arrows indicate how much the responses shifted by the end of the course. While there was an increase in expert-like responses to questions 14 and 29, there was also a decrease in questions 27 and 28. The dot and arrow above the center line represent undergraduates in similar courses from a national sample, and the dot and arrow below the line represent undergraduates from our sample.

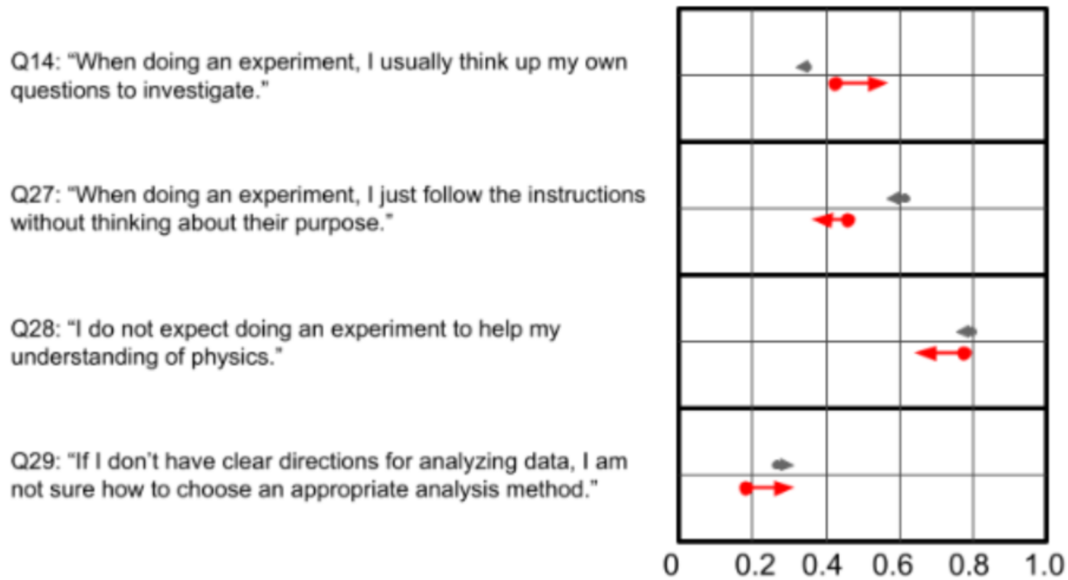


Figure 3.1 Compared to similar courses at other universities (top/gray arrows), the bottom/red arrows show the fraction of expert-like responses from our students and how their responses shifted over the course of the semester according to the ECLASS report.

From our own survey data, student responses revealed an increase in how the participants defined modeling and the applications for its use, as well as a decrease in the misconceptions and limitations associated with modeling (see Fig. 3.2). For example, participant's 1271 response to the question, "What is scientific modeling and why is it significant to experimentation?" shifted in the following way:

Before the MRI Lab: "I believe scientific modeling is addressing something that is difficult to capture since it is not easily visible. But the best way to learn it is with experimenting."

After the MRI Lab: "Scientific modeling uses models and examples to explain and predict the behavior of real objects or systems. Modeling is significant to experimentation because it can help to provide hypothetical models as part of experimental design and can be adjusted / corrected after experimentation to explain results of an experiment in a more concrete / applicable way to both experimenters and to the general scientific community."

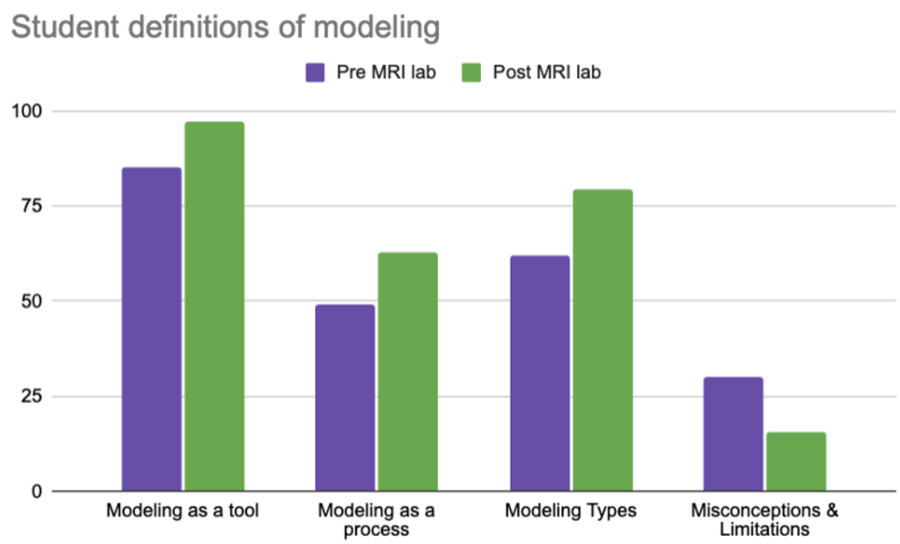


Figure 3.2 After participating in the situated learning of the MRI lab, there was an increase in the number of definitions and applications that students recognized in scientific modeling, as well as a decrease in misconceptions and limitations. The y-axis is the percent of students from our sample.

While their first response described using models when systems are "not easily visible," which could limit the use of modeling to those types of systems, their second response captures a more inclusive definition that highlights the ability to make predictions for any experimentation. We found that 65 percent of the participants experienced a similar shift in the positive direction.

We took a closer look at the changes in student perceptions within the misconceptions and limitations category by analyzing the types of limitations students used to describe modeling. Distinguishing limitations from misconceptions, we considered unnecessary constraints on modeling to be limitations while incorrect statements about modeling were categorized as misconceptions. For example, when participant 9618 stated, “Scientific modeling uses physical representations to explain a concept,” they were not necessarily incorrect, but they did limit models to being physical representations and thus could have excluded the possibility of mental or mathematical models. Figure 3.3 evidences a decrease in student-held limitations that scientific models are only useful in difficult to observe systems and that models are primarily physical or visual representations of those systems. Simultaneously, however, there was also an increase in two of the limitations: models only portray one or two principles and models can only be simple. While it is good practice to use simple and familiar models, they are not necessarily constrained to simplicity. The most frequently occurring limitations shifted from the idea that models are only useful in difficult to observe systems to the stipulation that models must be simple. One participant's (3621) change in response looked like this:

Before the MRI Lab: "Models are used when it is either impossible or impractical to create experimental conditions where scientists can directly measure outcomes. A model allows them to ignore the uncertainty and not have to deal with the potential legal or ethical problems, and still observe phenomenon."

After the MRI lab: "Scientific modeling is when you take a concept or phenomena that is difficult to view directly and create some sort of simplified version or model of it in order to view the effects. We will be using physical models as well as mathematical representations."

3.2 Changes in Undergraduate Performance

To dive deeper into the level of scientific modeling that students performed at before, during, and after the MRI lab, we used the MSR rubric outlined in the methods section to categorize students into 6 levels. Because PHSCS 108 is an introductory physics course for non-majors, we expected students to begin the semester performing primarily at secondary school levels of scientific modeling.

Figure 3.4 displays the levels of student engagement with scientific modeling in lab 3. This lab took place approximately a month into the semester. The data shows that most of the sampled students performed at the introductory and advanced secondary levels of modeling (levels 1 and 3).

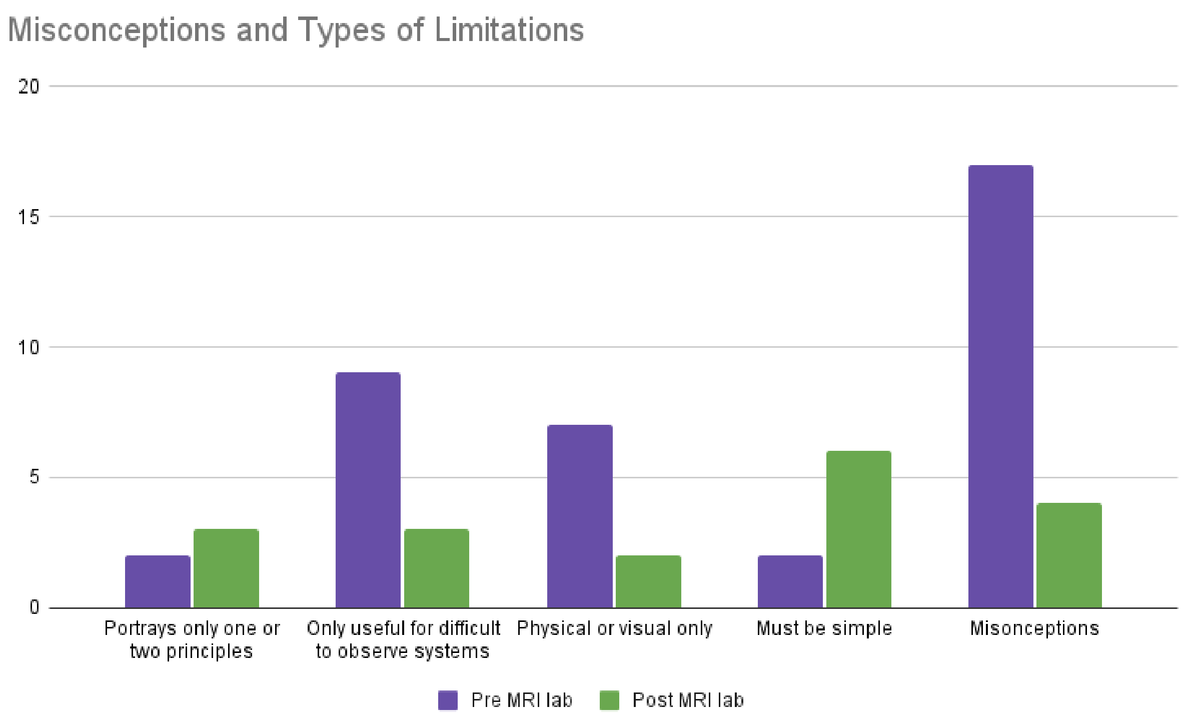


Figure 3.3 After the MRI lab, the number of limitations students used decreased significantly and the most common one shifted from only using models for difficult to observe systems to an assumption that models must be simple. The y-axis indicates the number of instances students used a particular limitation.

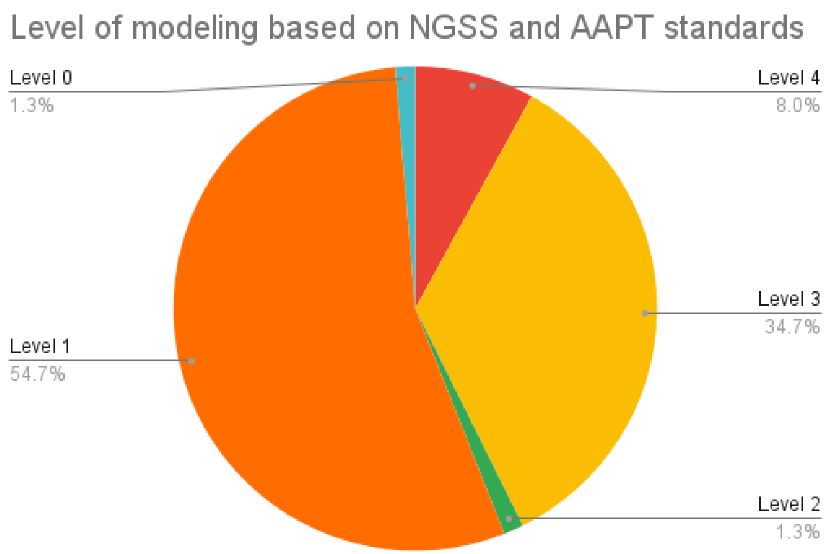


Figure 3.4 Student levels of performance for lab 3 (prior to the MRI lab) were primarily high school levels with just a few performing at an introductory college level of scientific modeling.

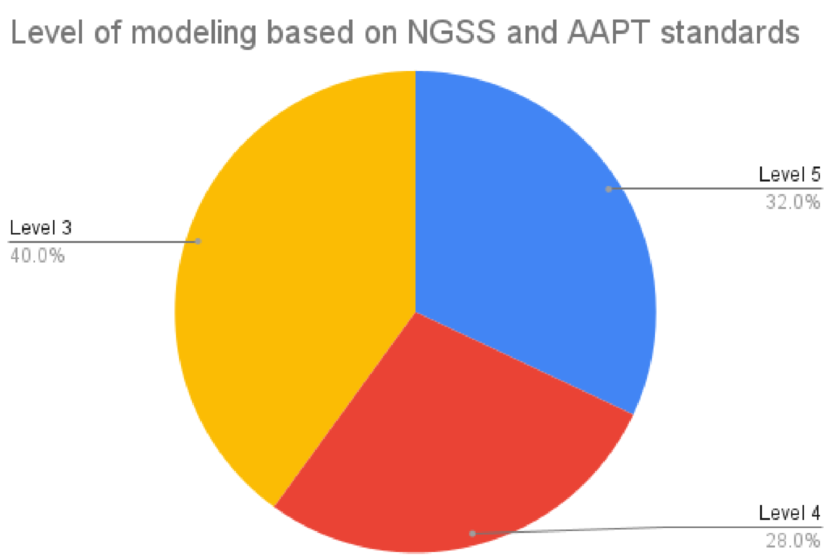


Figure 3.5 For the MRI lab, students performed at higher levels. Sixty percent of the students were participating in introductory and intermediate college levels of scientific modeling. The rest of the students were maintaining an advanced high school level.

In the MRI lab, levels of student modeling performance increased to primarily introductory and intermediate college levels of modeling (levels 4 and 5, see Fig. 3.5). Observing the improvement in both the quality and quantity of student scientific modeling validated our efforts to situate learning through models that interest them. Wanting to verify that the modeling practices the undergraduates learned in the MRI lab could persist, we also assessed the participants' modeling performance in lab 8 which takes place later in the semester.

While some students did drop back down to lower secondary levels of modeling (levels 1 through 3) in lab 8 (see Fig. 3.6), more than 50 percent maintained the introductory and intermediate college levels of modeling (levels 4 and 5). In summary, we measured an improvement in the participants' engagement in scientific modeling. In lab 3, 92 percent of the participants engaged in scientific modeling below the college level, near the end of the course only 49 percent of the participants engaged below this level.

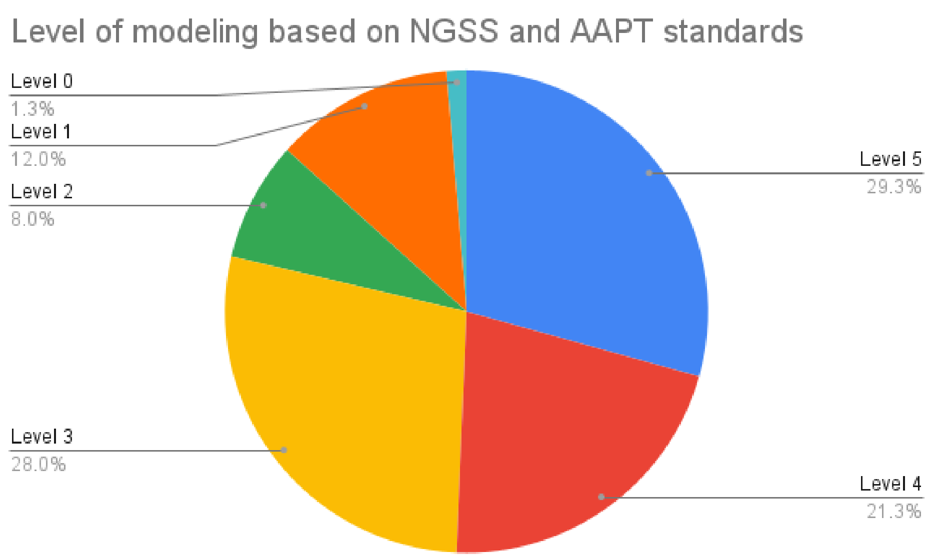


Figure 3.6 For a lab 8, many students were still maintaining the introductory and intermediate college levels of scientific modeling while others dropped back down to beginner, intermediate, and advanced high school levels. The occasional level 0 indicates students who did not participate in scientific modeling at all.

3.3 Discussion

For pre-medical undergraduate students, engaging in scientific modeling can be an enhanced learning experience when labs are appropriately scaffolded and situated to applications in the medical field. The following sections discuss the importance of modeling and situated learning in classrooms, how scaffolding benefits students, and suggestions for implementation in each section.

3.3.1 The Importance of Modeling in Science Classrooms

Based on our previously outlined learning goals for non-major physics college courses, we hope to see students engage with scientific modeling in a way that describes specific scientific phenomena in simple ways that are both familiar to them and can provide grounds for predicting outcomes [9, 10]. The shifts in limitations and misconceptions in Fig. 3.3 show students aligning more closely with that expectation after participating in the MRI lab. These improvements were made without direct instruction on the importance or application of scientific modeling; students learned the principles by engaging in the modeling of the MRI Lab themselves [5]. We suggest that introductory lab courses build modeling into their curriculum by both providing relevant and interesting models for the students to work with and by encouraging the undergraduates to construct their own models to describe the phenomena they are studying.

The fraction of expert-like responses from our class to the statement, "When doing an experiment, I usually think up my own questions to investigate," (see Fig. 3.1) increased over the course of the semester, and it did so when other similar courses usually experience a decrease. This increase may be attributed to the opportunities to create and experiment upon their own questions and models that helped the students better utilize scientific processes in their work [8].

3.3.2 Scaffolding Modeling in Introductory Labs

Participation in scientific modeling, as measured by the MSR, appeared to change given the amount of scaffolding present in each lab [20]. Lab 3 was heavily scaffolded and did not provide much room for students to freely explore the models presented. We designed the MRI lab on the other end of the scaffolding spectrum. We encouraged scientific modeling and the undergraduates were left to define, design, and experiment with a model they created themselves. Lab 8 had similar freedoms in the design process and opportunities to model. In this lab, there was scaffolding to help the students in a new aspect of modeling which engaged them with opportunities to revise their models (see Appendix A for copies of each lab). For introductory lab courses, we encourage instructors to follow a similar pattern, asking their students to engage in more and more of the modeling process as the semester progresses.

The decrease of expert-like responses for questions 27 and 28 may indicate that the cognitive load of diving into the scientific process without the traditional step-by-step scaffolding of a cookbook lab may have been a frustrating experience for the students [24]. (Roth et al., 2020). There is a balance that science teachers must find between providing too much scaffolding and not providing enough. An appropriate amount of scaffolding is a powerful tool, especially when used in a situated learning environment [16].

3.3.3 Situated Learning and Student Interests

The MRI Lab was the only one in our sample that situated the student learning in an environment relevant to the students' future careers. Situated in this way, students performed at a higher average MSR level than they did in Labs 3 and 8. Situating the learning of these pre-medical undergraduates likely improved their ability to understand and engage with scientific models and construct further knowledge in their own fields of interest [13]. Because the MRI Lab related to a relevant topic of interest, our students learned principles that will remain applicable to them [14]. For example, our physics class of pre-medical students may have benefited from a lab on MRI machines, but a class of civil engineers might have benefited more from a lab on power lines and city electrical grid systems.

3.3.4 Conclusion

From our findings, we suggest that physics teachers working with non-physics majors encourage active participation in scientific modeling to prioritize giving students scientific skills more than scientific facts [6]. We also encourage these instructors to scaffold and situate their labs and investigations within the interests and career aspirations of their students. This will help the undergraduates because they will likely be working with those contexts in their futures and will be better able to recall the principles they used in those learning environments [15].

Appendix A

Copies of Labs

Included are copies of lab 3, the MRI lab, and lab 8.

A.1 Lab 3

Lab 3 explores circuitry, including topics of resistance, current, voltage, and power.

DC Circuits and Measurements Pre-lab Assignment

I. Required Reading/Watching

Previous page

Circuit vocabulary: https://www.khanacademy.org/science/physics/circuits-topic/modal/v/circuits-part-1

Circuits: https://courses.physics.illinois.edu/phys102/sp2018/handouts/handout7.pdf

II. Resources for completing the pre-lab quiz and lab activities

Current: https://cnx.org/contents/Ax2o07Ul@13.1:3ct4v3c5@7/Current

Resistance: https://cnx.org/contents/Ax2o07Ul@13.1:peIFjTvw@11/Resistance-and-Resistivity

Series and Parallel: https://cnx.org/contents/Ax2o07Ul@13.1:FLqArfdc@7/Resistors-in-Series-and-Parall

Include an overview of a topic you were interested in and would like to investigate in the lab. Include a brief description of the method you would use to investigate it:

____

____

____

____

____

DC Circuits and Measurements Lab

I. Qualitative analysis of circuits

Caution: The light bulbs will burn out if there is more than 3.2 V across them.

A. **Observational Experiment:** Use a battery, one wire, and one light bulb. Try different arrangements of these elements to make the light bulb glow. You may unscrew the bulb and/or remove the battery from their holders, if desired. Find a pattern.

B. **Observe:** Build the following circuits, and observe the relative brightness of the light bulbs. Each circuit below will use two batteries in series (~1.5 V each) as the voltage supply.

Circuit description	**Draw the circuit diagram**	**Relative brightness**
1 light bulb		
2 light bulbs connected in series with each other (You cannot make a path through the circuit without going through both bulbs.)		
2 light bulbs connected in parallel with each other. (You can make a path through the circuit that goes through only one or the other of the bulbs.)		

C. **Observe:** Observe the relative brightness of a single light bulb.

Circuit description	**Draw the circuit diagram**	**Relative brightness**
1 battery		
2 two batteries with the positive terminals connected to each other and the two negative terminals connected		
2 two batteries with the positive terminal of one connected to the negative terminal of the second		

D. **Explain:** Batteries and DC power supplies (like the one you will use later in this lab) maintain a constant potential difference across two points. Based on your observations from this and other labs you have completed so far, explain what the battery must do in order to maintain a constant potential difference.

E. **Develop Model:** Develop an analogy for the circuit. The analogy should be consistent with observations.

II. Conceptualizing the observed behavior

A. **Develop Model:** Use your observations from the previous section and your understanding of conductors and batteries to develop analogies for electrical circuits. Do this by first filling in the table with any similar components to a system that you identify.

Circuit element	Water system analogy	Busy ski slopes
Moving electrons		
Connecting wires	Pipes with water in them.	
Battery		
Light bulb		Narrow trail

B. **Explain:** Now use your analogies to describe what the observed properties of the particular system would be.

Electric circuit	Water system	Busy ski slopes
Bulbs in series are dimmer than bulbs in parallel		
Bulbs in parallel each have the same brightness		
When batteries are in series, the bulbs glow brighter		
When two batteries are in parallel, the bulbs glow the same amount as with one battery		

III. Quantitative measurements of circuits

From this point forward you will be using the DC (Direct Current) Power supply instead of the batteries. The power supply can maintain a constant voltage that is set by the user. **Warning: Be careful not to set the voltage above the recommended value as it could damage equipment.** You will be measuring quantities of the circuit by using a multimeter. In voltmeter mode, the meter measures the difference in potential between the post labeled with a V and the one labeled with a COM. In ammeter mode (you will use this later), it measures the current running through the meter.

A. **Observe:** Measuring the voltage of a parallel circuit

1. Build the circuit shown below with your power supply set to about 3 volts (do not exceed 3.2 V). Take care to build it correctly to ensure accurate measurements.
2. Set your multimeter to the voltmeter setting.
3. Place the negative end of the multi-meter (wire connected to COM) at the star.
4. Place the positive end of the multi-meter at each successive dot to measure the voltage (with reference to the COM position) at that location.
5. Record your findings for each dot. (Be sure to check the units on the voltmeter.)

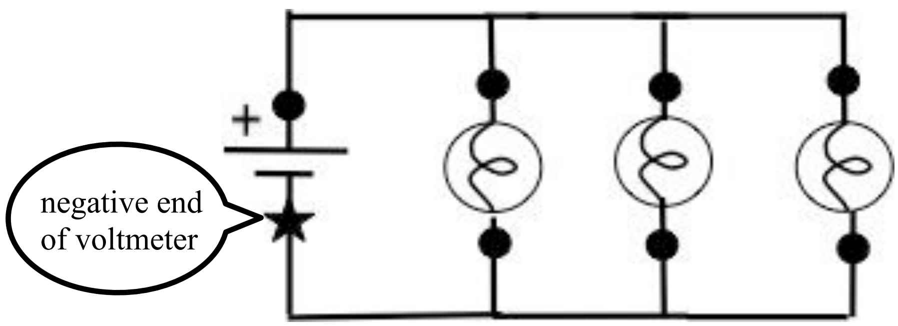


Figure 1

B. **Represent:** Some values you measured are only slightly different from each other. You may consider similar values to be the same in this case. Other values that you measured are significantly different. Use the colors in the list below to color code the wires of the circuit above. Regions with the same voltage should be the same color. Don't color the bulbs.

Color	Levels of voltage found within the circuit
Red	High
Orange	Moderately High
Yellow	Normal
Green	Moderately Low
Blue	Low

C. **Analyze:** What patterns do you see in the data? Include uncertainty in your analysis.

D. **Develop Model:** Consider your answers and the exercise you just completed. Use your observations to further develop your analogies.

Electric circuit	Water system	Busy ski slopes
Voltage		

E. **Explain/Design:** You saw in part A-C that the voltage difference across each of the bulbs and the battery were the same. One of your friends says that that the voltage across the light bulbs is only the same because the light bulbs are identical and that if one of the light bulbs were more resistive, the voltage across each bulb would be different. Based on the analogy you have developed, explain why you agree or disagree with your friend. Suggest an experiment to test your prediction using only the given equipment.

Explanation: Experimental design:

F. **Testing Experiment:** Use the procedures below or your own design to test your friend's idea.

1. Mark dots on the schematic to illustrate where you will take measurements to test the prediction from part E.

2. Build the circuit using 3 volts as your input. Take care to build it as illustrated.

3. Start from left to right when building the circuit. Take care to build it correctly. It may help to start from the positive end of the power supply and build it clockwise.

4. Measure the voltages and label them on the schematic.

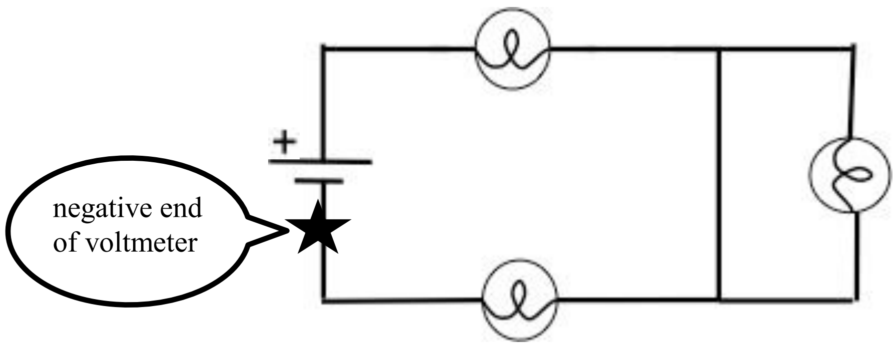


Figure 2

Include observations, analysis, and conclusions. Also, respond to the questions: What do you observe that helps respond to your friend's prediction? Is the voltage drop across parallel paths the same? What is required to light a bulb? What do you notice about the bulbs in series?

IV. Measuring Current

In this part of the lab, you will set your meter to the ammeter setting (A). Recall that in this setting the meter will tell you how much current is running through the meter. Note: There are two differences in how this measurement is performed, including attaching the wire to a different port of the meter and the attaching the wire in a different way on the circuit.

A. **Explain:** Fill in the table below.

Electric circuit	Water system	Busy ski slopes
Current through a wire		

****Study the slide show that compares voltage and current to a water pipe analogy.****

B. **Predict:** Based on the water analogy, predict a set of rules that you expect current to follow in both parallel and series configurations.

Prediction (include hypothesis it is based on):

C. **Observe:** Use the procedures below.

1. Using the same circuit from the previous section. Set you multimeter to measure the current by setting the dial to the A and plugging the positive wire into the hole labeled 10 A.

2. For each measurement, disconnect the circuit wire at the location where you intend to measure the current and connect one side of the meter to each disconnected point. The paired stars and dots on the schematic are there to help you identify how and where to connect the meter. Make sure the positive side of the meter (10 A) is on the star side.

3. Record all of your measurements in the space provided. (Units are amps).

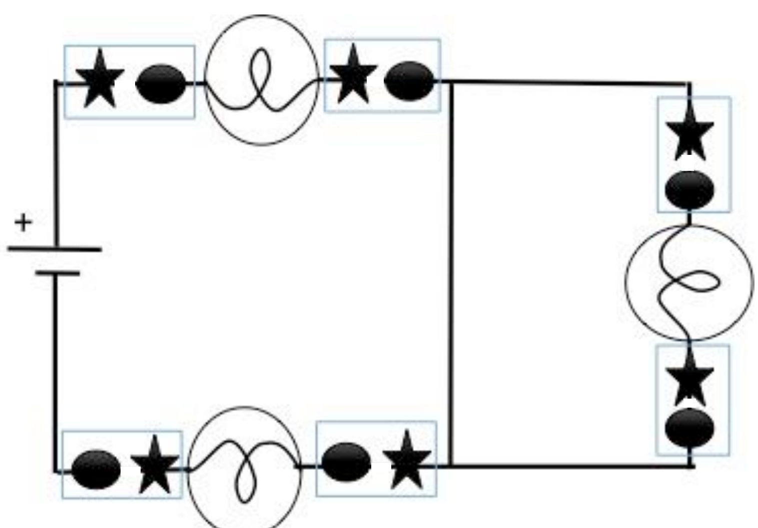


Figure 3

D. **Analyze:** Based on your observations. Discuss and respond to the following prompts.

Compare the current going into the circuit with the current through the other parts of the circuit. What pattern(s) do you notice?

Does the observed pattern match your prediction? What can be concluded based on the observed results in comparison to your expected results?

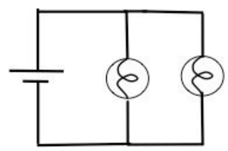
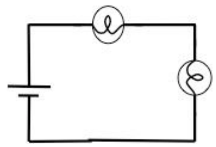
What do you expect the current to be in the extra wire? Why?

E. **Explain:** A friend says that when the power supply is set to a certain voltage (say 3 V) it will always emit the same amount of current. Based on this your friend predicts that removing the wire that is in parallel to the second (unlit) bulb will cause the second bulb to light up without affecting the brightness of the other two bulbs. Explain whether you agree or disagree with your friends assumptions and why.

F. **Observe:** Remove the wire and record your results.

Current into the circuit	Brightness of first bulb	Brightness of second bulb	Brightness of third bulb	Current into second bulb

G. **Analyze:** Record the generalizable rules you discovered in the table.

	Voltage	Current
Parallel 		
Series 		

The behaviors that you observed agree with **Kirchhoff's Junction Rule.** The rule explains what happens when there is a junction in a circuit. Simply put, current must be conserved. There is an activity that models this concept in the review section. It may help you remember this rule.

V. Resistance in a circuit

The concepts you investigated above are foundational concepts for understanding other rules and laws of circuits. There is one more concept that we may not have been explicit about but that you are likely familiar with, *V=IR.* This equation states that if a voltage is applied, current will flow at a rate that is determined by how much the circuit elements resist the flow. Using the foundational concepts in combination with this equation, one can derive equations to explain how combinations of resistors affect a circuit. As you may know, they are:

$$R_{series} = (R_1 + R_2 + R_3 + \ldots + R_n)$$

$$R_{parallel} = \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots + \frac{1}{R_n}\right)^{-1}$$

You should become familiar with how they can be used in a circuit as you complete the remaining sections. If you want more practice on this topic later, go to:

- Series circuits: http://www.physicsclassroom.com/class/circuits/Lesson-4/Series-Circuits
- Parallel circuits: http://www.physicsclassroom.com/class/circuits/Lesson-4/Parallel-Circuits
- Combo circuits: http://www.physicsclassroom.com/class/circuits/Lesson-4/Combination-Circuits

At this point in the lab we are going to start using resistors instead of light bulbs. While bulbs resist flow and give us a nice conceptual view of what is going on, they are more complicated than resistors because their resistance changes depending on their temperature.

A. **Predict:** Use the following table to predict the voltage, current, and resistance in two circuits. Both circuits use a 3 V power supply and have two resistors (500 Ω and 1000 Ω). The difference is that in one circuit the resistors are connected in series and the other they are connected in parallel. Note: this is similar to what we did in the first section with light bulbs.

Type of Circuit	Total Voltage	Total Resistance	Total Current
2 Resistors in series			
2 Resistors in parallel			

Your predictions should follow **Ohm's law** below:

total voltage = total current x total resistance

V = I x R

volts (V) = amps (A) x ohms (Ω)

B. **Observe:** Use voltage and current to determine the resistance of the resistors. Use Ohm's law.

C. **Observe:** Measure the resistance of resistors in series and parallel. Use Ohm's law. Does the resistance of the circuit follow the equations described on the previous page?

Observations (series):
Observations (parallel):

VI. Feel the Power?

The amount of power in a circuit and in the individual pieces of a circuit is:

Power = Current x Voltage

P = I x V

Watts = Amps x Volts

These equations should make sense if you remember that:

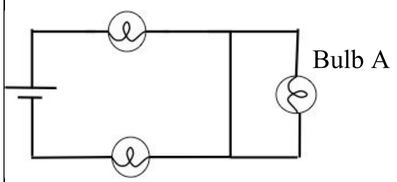
V = Potential Energy per unit charge,

I = charge per unit time, and

P = Energy per time.

The equation for power makes sense if you consider that the potential energy lost by a single charge moving from one potential to another is PE = qV. Since, current is charge per time, power is just a measure of how many charges lose potential energy per time.

A. **Analyze:** Using the values you measured earlier, calculate the power for bulb A.



B. **Explain:** A friend says that the circuit in Figure 7 below will use more power than the one in Figure 6 because the voltage is the same but Figure 7 will have more current. Do you agree with your friend and why.

C. **Testing Experiment:** Find the total power and the power in each resistor for the following circuits. (Include units) Make measurements and calculations to complete the tables. You may save yourself time if you think about the rules you identified for current and voltage in series and parallel.

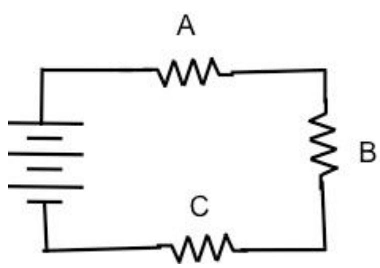


Figure 6

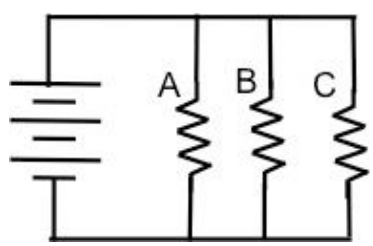


Figure 7

Figure 6	Resistance	Voltage	Current	Power
Resistor A	500 Ω			
Resistor B	1000 Ω			
Resistor C	1500 Ω			
Total		3 Volts		

Figure 7	Resistance	Voltage	Current	Power
Resistor A	1500 Ω			
Resistor B	1000 Ω			
Resistor C	500 Ω			
Total		3 Volts		

V. Review, Conclusions, and Applications

A. **Predict** how the brightness of the of the remaining two bulbs will be affected if one of the bulbs is removed from the circuit shown below. Explain your reasoning.

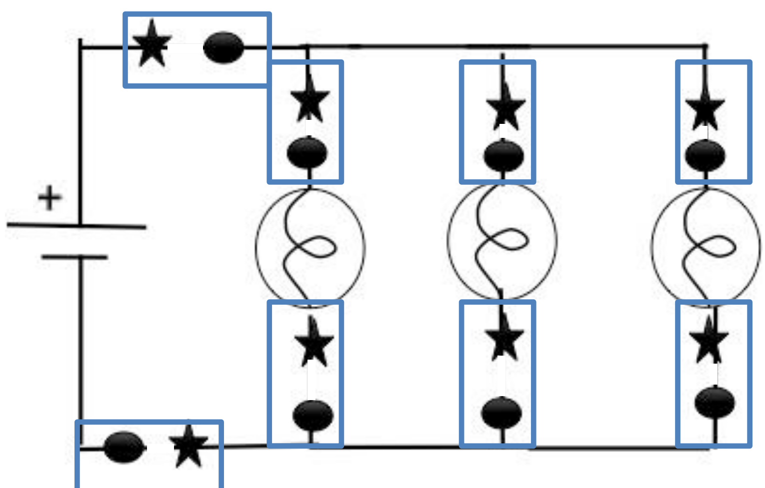


Figure 4

B. **Observe/Analyze:** Perform the experiment. Record your results. What affects the brightness of the bulb?

C. **Represent:** Visualizing current with string

1. Find the group of strings that are tied together at one end. The combined strings together represent the total current from the power supply. (Note: The total current for each figure may be different.) Each individual string represents a fraction of the total current. So, 3 out of 6 strings would be 1/2 the total current, 2 out of 6 would be 1/3 the total current, etc.

2. Place the knot at the positive voltage input of Figures 3 or 4.

3. Use the strings to illustrate how much current is present at different parts of the circuit.

4. Label each figure with symbols like the ones in Figure 5. The number indicates how many strings and the arrow indicates the direction of the current.

Figure 5

Explain how this representation of current agrees with water being pumped through pipes. For instance, what does the term conservation of current mean?

D. **Observe:** Use the figure below to determine the proper order for calculating the equivalent resistance of a circuit with resistors in both parallel and series.

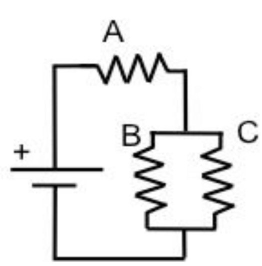


Figure 8

Figure 8	Resistance	Voltage	Current	Power
Resistor A	1500 Ω			
Resistor B	1000 Ω			
Resistor C	500 Ω			
Combo B & C				
Total		3 Volts		

Explanation of method for determining equivalent resistance:

A.2 MRI Lab

The MRI lab explores electricity and magnetism, including the magnetic fields produced by current-carrying wires.

Magnetic Fields Lab

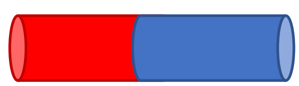
I. Magnetic Field Mapping

Just as with electric field lines, magnetic field lines can be used to illustrate the direction (arrows) and magnitude (density of the lines) of the magnetic field. Magnetic field lines are easier to demonstrate visually than electric field lines since some materials, like small pieces of iron, can become magnetized and strongly align with the magnetic field. Iron filings will help you obtain a qualitative view of the field map. Keep in mind that it does not give you a very good quantitative measure of the field at each point, nor does it indicate the direction of the field. Complete the following tasks:

- Place the thin tray containing iron filings on top of the magnet
- Tap the tray rapidly to allow the iron to realign to the magnetic field.
- Remember that the filings provide clues about the magnetic field lines; it is up to you to analyze the results to determine the direction of the magnetic field lines.

A. **Observe:** Use a bar magnet, the horseshoe magnet, and the iron filings sheet at your station to sketch the field lines.

Sketch:



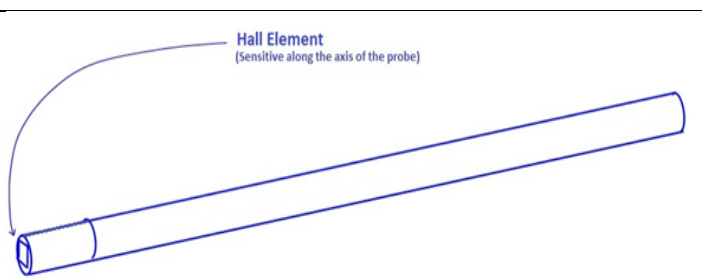


Figure 1 - The Hall element measures along the axis of the probe, as shown.

II. Magnetic Field Sensor

Iron filings can give you a rough idea about the directionality of the field at different points around the magnet. However, they tell you nothing about the magnitude of the field. To get this information you will need to use a magnetic field sensor. To understand how the field sensor works we must first talk about flux and flux density.

A. **Explain:** A friend says that when you place your hand out of the car while traveling down the freeway, the force on your hand is greater when the palm of your hand faces perpendicular to the ground than when it is parallel to the ground. Explain to your friend why this happens.

This example is a good model for **magnetic flux,** which is the measurement of the total magnetic field in a given area. You can think of it like counting the number of field lines. **Flux density**, B, is like the number of field lines per area and is measured in Tesla (T). *Note: Field lines represent a concept and are not actually moving like the air particles in the previous example. In fact, one may ask whether field lines are even a physical reality or just a mathematical construct.*

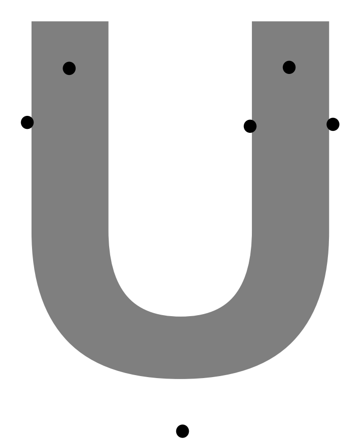
The Hall element (located at the tip of the rod) is used to record the magnetic field, or magnetic flux density. **The Hall sensor is sensitive to orientation**. To measure the magnetic field, the field lines need to pass through the white circle. So while you may expect a very large reading with the probe placed near the pole of a magnet, the reading may be low if the probe is not oriented in the same direction as the magnetic field lines. The magnetic field is a vector so one could also say that the sensor reports the vector component of the field that is parallel to the tip of the sensor. Discuss this as a group until everyone understand how the sensors read the magnetic field strength. Let's explore this further:

In order to determine the direction and magnitude of the field:

- Zero the magnetic field sensor away from the magnetic field you wish to measure.
- Slowly change the orientation of the element at a specific location.
- Watch Logger Pro as it displays the measurement until it reads a maximum.
- The maximum reading occurs when the tip of the probe is pointed in the direction of the field.

Note: a positive reading refers to positive flux and a negative reading refers to negative flux.

B. Analyze: Use the magnetic field sensor to measure the magnitude and direction of the magnetic field of the horseshoe magnet at several locations. Make sure you at least mark the field direction and strength in mT at the marked locations. You can represent the direction as an arrow and write the magnitude next to it.



III. Source of Magnetic Fields

You may have wondered about what is causing the magnetic fields that you measure. In this section you will investigate this question. To do this we will combine what we have learned from using both the iron filing sheet and the magnetic field sensor.

A. **Observational Experiment:** A friend says that magnetic fields can be produced by moving charged particles. At your station is a large coil wire (solenoid) connected to a power supply. Start by turning the current on your power supply to 2.0 A. Use the magnetic field sensor, the turn table, and a bar magnet to sketch the magnetic field lines. Use the sensor to determine how the field strength varies inside of the coil and as you move farther away from the coil.

B. **Experiment**: Now determine the relationship between the current in a wire and the magnitude of the magnetic field produced. Decide how you will measure this and consider plotting your measurements.

TURN OFF POWER SUPPLY WHEN YOU ARE NOT USING IT.

As you move forward you may find the Right-Hand Rule to be useful in predicting and measuring of the fields.

Right Hand Rule for Current Carrying Wires:

If you point the thumb of your right hand in the direction of the current (the direction positive charges would move), your fingers will curl in the direction of the field lines.

IV. Alternating Current in a Coil

A. **Predict**: Alternating Current occurs when negative and positive voltages are reversed at a set frequency. What do you predict will happen to the magnetic field if you use alternating current in a solenoid?

The small solenoid at your table is hooked up to a power amplifier plugged into the computer. You can output alternating current with application called "Vernier Power Amp." Before you open the app, make sure that the "Speakers (USB Audio Device)" are turned all the way to 100. (You can find this by clicking on the speaker icon on the bottom right of the computer screen). Then open the program.

Test your prediction with the magnetic field sensor. You will have to start the Vernier Power Amp program and collect data on Logger-Pro.

Setting up Logger-Pro for data collection:

- Type ctrl+D which will pull up the Data Collection parameters. Type 60 for the duration of the experiment and increase the sample rate to 1,000 samples/second.
-  This button on the top bar will auto scale the graph.

B. **Observational Experiment**: What do you notice about the magnetic field measurements as you plot it over time? What do you notice about your graph as you change the frequency?

C. **Observe**: By increasing the voltage to 10 V on the Power Amp app and holding a bar magnet loosely near the center of the solenoid, you can feel this effect. Record your observations.

V. What is Resonance?

Consider a parent pushing their child on a swing. How do you know when someone is pushing a swing in resonance with the natural frequency of the swing? Conversely, what happens if a swing is pushed too fast or too slow? How does this relate to resonance?

You can observe resonance in a bar magnet by placing the bar magnet in the magnetic field produced by solenoid with alternating current. Place the magnet on a rotating stand and place it next to the opening of the coil of wires as shown in Figure 4.

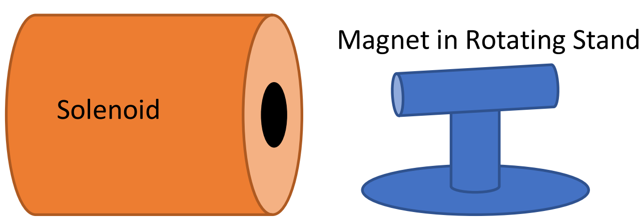


Figure 4

A. **Observe/Analyze:** Set the voltage to 2 V. Adjust the frequency of the generator. Record your observations.

Note: You can adjust the frequency by typing in the frequency into the bar. You can also use the arrows which increase the frequency in steps of 1 Hz. As you tune into the resonant frequency, it is helpful to be able to increment in smaller steps. To do this, when you are in the 0-1 Hz range, you can type 0.250 and then use the up and down arrows to increment in 0.001 steps. In the 1-10 Hz range, you can type 1.00 and go up in 0.01 steps. And in the 10-100 Hz range you can type 10.0 and go up in steps of 0.1. It should be noted that you will need to repeat this process each time you get to a new integer frequency, meaning when you step from 2.49 to 2.5 you must type a zero after the five to continue stepping in 0.01 Hz increments. For this lab, it will never be necessary to go above 20 Hz.

B. How can you tell when you have reached a resonant frequency? Explain.

C. What did you group determine the resonant frequency of the bar magnet to be?

D. Can you think of some way we could benefit from the principles learned in this part of the lab? What application can use these concepts?

Turn off power supply and vernier power amp. Organize all equipment on the table.

Appendix B

Magnetic Resonance Imaging:

Design an Experiment & Construct a Scientific Model

General Directions: Your lab group will need to give evidence of the following:

- *Formulate a research question that can be answered with the available equipment.* Propose a hypothesis or model. Identify which aspects of the model you are testing.
- *Design an experiment that can answer the research question.* Select appropriate methods to collect data. Identify and manage both the variables of interest and confounding variables. Use analysis methods, including experimental uncertainty analysis, to evaluate your findings. Revise and repeat to increase the likelihood that your experiment can conclusively test your model (*e.g.*-reduce uncertainty, improve methods, etc.).
- *Collect and analyze quantitative data.* Use available resources to collect quantitative data. Take appropriate steps to minimize measurement error. Make appropriate conclusions based on measurement uncertainty.
- *Construct and explanation or model.* Use the analysis of your data to either write an explanation of your findings based on evidence and reasoning or create a scientific model that answers your proposed research question.
- *Create complete records of all parts of your experiment in your notebook.*
- *Communicate your results in a formal report.*

Your lab notebook should contain a clear account of your experimental procedure and results such that another person could replicate your experiment. The reader should be able to determine: how you collected your data, what equipment you used, how it was configured, what you changed along the way. Sketches and graphs are often very important.

Exploration of Magnetic Resonance Imaging (MRI)

In lab 4, you worked with coils to create electromagnets. You observed resonance. The large coil wire used in last week's lab is a good model of the electromagnets used in MRI machines. Using the large coil as a model MRI, you will investigate magnetic resonance and apply what you learn to medical imaging.

***Available equipment*:** Large solenoid, smaller solenoid, adjustable power supply, vernier power amplifier, magnetic field sensor, clear turn table, various magnets, and ruler.

Intro to MRI: Magnetic Resonance Imaging is an example of a physics principle applied to medicine used by doctors to diagnose medical conditions through a detailed scan of the body.

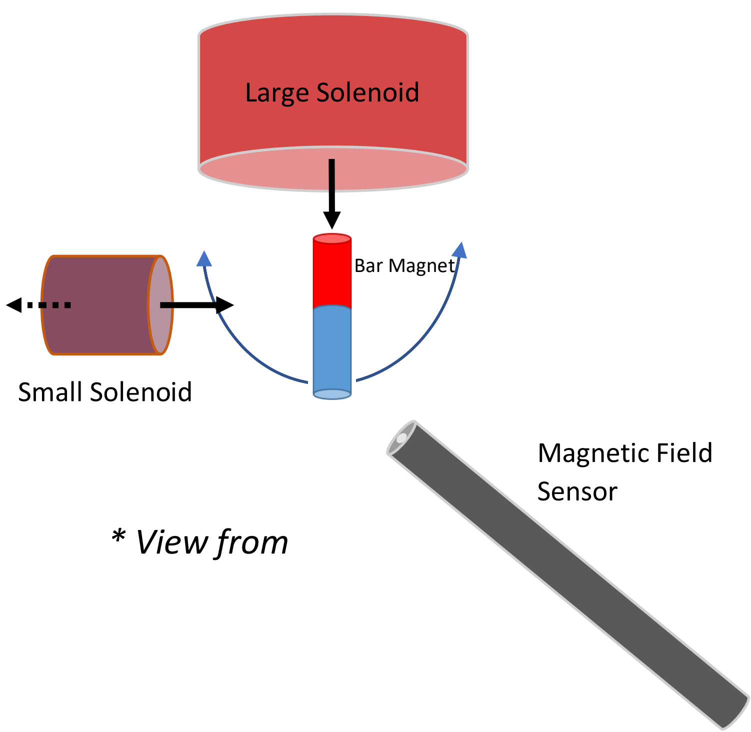
MRI allows doctors to evaluate organs, blood vessels, and lymph nodes in the human body and are commonly used to detect tumors.

An MRI machine works by aligning water molecules inside of a human body with a large uniform magnetic field. The proton of a hydrogen atom behaves very similarly to a small bar magnet, so we can think of it as having a north and a south pole. Once the molecules align with the uniform magnetic field, a different coil produces a gradient magnetic field along the axis, meaning the strength of the magnetic field varies along each slice.

Radio waves are emitted from several other coils, which causes the hydrogen atoms to oscillate in phase with the radio waves or in other words to **resonate**. Eventually, the hydrogen atoms will fall out of phase. Detectors on the MRI can track the time this takes, which differs for different types of tissue. A grayscale image is produced that represents the volume of tissue. In an MRI image, lighter colors represent areas of high-water concentration while the darker areas represent areas of greater fat.

MRI is a very complicated area of both medicine and physics. We do not have the equipment to create the detailed, gray-scaled scans that MRI machines in hospitals can, but you can explore the concepts of magnetic resonance with a simplified **model of an MRI** machine and a bar magnet that represents a single hydrogen atom in the body.

Experimental Design: Example Set Up for MRI



Place the bar magnet on the clear turntable. Place the table just outside of the coil and in the center.

To do this experiment, you will need to set up the magnetic field sensor in an orientation that will allow you to detect the motion of the magnet as it oscillates. A table stand, crossbar clamps, and rod are available to help you orient the magnetic field sensor so that it can measure changing magnetic flux as the bar magnet oscillates. You will want to zero the sensor beforehand. As a starting point you can orient the circular end of the sensor so it is pointing towards the end of the bar magnet at about a 45-degree angle. In this orientation, the sensor will read a high magnetic field strength when the bar magnet moves towards the sensor and a low magnetic field strength as it moves away from the sensor. As you design your setup, you may choose to adjust the orientation to optimize your signal.

Recommended Measurement Settings: Make sure everything is set up correctly by opening Logger-Pro while the magnetic field sensor is plugged in. Turn on the power supply connected to the coil and make sure it reads 0.2 A. The bar magnet will align with the magnetic field produced. Type ctrl+D which will pull up the Data Collection parameters. Type 120 s for the duration of the experiment and increase the sample rate to 1,000 samples/second.

To test your setup, push on one end of the bar magnet so that it starts to oscillate and run the program. You should see a sinusoidal graph. See the tips below as you consider the data you collected.

Some tips:

-  This button on the top bar will auto scale the graph.
- If it looks like the peaks of the sinusoidal graph has been flattened it is because the flux that the sensors can read has reached its max. You can either zero the sensor again while the magnet is stationary or change the orientation of the sensor so that it is picking up on less of the magnetic flux caused by the large coil.
- Make sure the sensor does not interfere with the oscillations of the bar magnet. If the bar magnet hits the sensor while oscillating, you will need to move the sensor farther away.

Connecting the set up to an MRI machine: The large coil is connected to a DC power supply and creates large magnetic field gradient similar to an MRI machine. The small coil is connected to alternating current, and though different from an actual MRI, is representative of the radio wave signals that cause hydrogen atoms to resonate. (Note: The system you are using does not resonate at radio wave frequencies.)

Choose an Experiment

To create an MRI image, you need to be able to differentiate between different types of tissue. You also need to be able to pinpoint the location of that tissue in 3D space. You will only have time to investigate one of these features. For this part of the experiment, you can investigate one of the following: variable bar magnet mass, strength of either magnetic field, position of the bar magnet relative to the fields, or a variable of your choice (ask your section TA for help/equipment for this option).

In your lab notebook:

- Note your group's chosen variable and constants. Explain why each of these areas would be important to study for imaging purposes of an MRI machine. What is the model we are using?
- Develop a research question that you will be testing. What are the dependent and independent variables? What other variables do you need to control and how are you going to do that?
- Design an experiment to measure the effects of changing your independent variable. Sketch your set-up and describe what measurements you are going to take. Clearly identify what your model predicts so you know what the potential results will indicate.
- Collect your data.
- Observations: Write any observations you make as you conduct your experiment.
- Analyze: How can organize my data in a meaningful way (graphs, tables, …)? Ask yourself what do the results mean? Is there any data that needs to be re-collected? What are your sources of error?
- Sensemaking: Use your analysis to construct an explanation or scientific model that can answer or provide details for your research question.
- Conclusion.

A.3 Lab 8

Lab 8 has a focus on modeling lens optics.

Name: ___________________________________ Section: _________

Revisions and Explanations of Findings

Many times when an experiment is done for the first time, things don't go as planned. As scientists perform their experiments, they notice things they can improve about their experiment, so they iterate their experiment, performing it many times in many different ways. Then, when scientists have perfected their experiment and found their results, they communicate their results to the scientific community, and sometimes to the general public as well. In this lab you will focus on iteration and communication in science.

Learning Outcomes

1. Collect, analyze, and interpret real data from observations of phenomena.

2. Develop abstract representations of real systems studied in the laboratory, understand their limitations and uncertainties, and make predictions using models.

3. Analyze and display data using statistical methods and critically interpret the validity and limitations of these data and their uncertainties.

4. Present results and ideas with reasoned arguments supported by experimental evidence.

Revisions and Explanations of Findings Lab

Last week we did a lab about limitations of the thin lens approximation. We practiced designing experiments and created our own models based on what we observed. One of the most important parts of being a scientist is being able to clearly communicate your findings with the scientific community and the general public. In this lab, you will review your findings and your model, and then you will present your findings to your peers in a conference poster format.

I. Refining the Model

A. Review your experiment:

At the end of the last lab, you built a preliminary model that could explain the results of your experiment in order to give clarity to one of the limitations of the thin lens approximation. In part I of today's lab you will return to your model and collect additional data to refine and improve it.

Original Model:

Write up the details for your original model. Make sure to include any figures and explanations that are salient to the model:

What are some of the limitations of your current model?

B. Plan for Revision: Considering the lab work you did last time and your current limitations, what can you do to improve your model? What additional data could you collect? What additional analyses could you do?

C. **Observation/Analysis:** Following your above plan, organize your new data or analyses.

D. **New Model:** Use this space to illustrate your new model. Make sure to include all of the relevant details, illustrations, and explanations.

Reflection: How is your current model different from the original? What are some of the limitations of this version? If you had more time or resources, how could you iterate on this model further to improve it?

II. Communicating Your Results

A. **Know Your Audience:**

Communicating with a community of scientists (or your classmates) is very different from communicating with the public. What do you think some of those differences may be?

B. **Create a presentation for the scientific community (your classmates):**

Using your final model, create a one-slide presentation (a virtual poster) that you can display on the classroom monitors using the provided template. This slide will include your hypothesis, your experiment, your analyzed data, and your model. It should be detailed and put together as if you were to present these results at an academic conference.

C. Share your results:

The last 45 minutes of class will be separated in three 15 minute rounds. You will need to divide your lab group into three “presenter groups” (one for each round). During the presentation time, one “presenter group” will remain with your poster to answer questions and describe your model while the other members of your group move around the classroom learning about what your fellow classmates discovered. You will switch the “presenter group” each round.

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