Probing Students' Understanding of Resonance

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Abstract. Resonant phenomena play a crucial role in magnetic resonance imaging (MRI), a widely used medical tool in today's society. The basic features of the resonance in MRI can be taught by looking at the resonance of a compass driven by an electromagnetic field. However, resonance in a oscillating magnetic field is not a phenomenon that is familiar to most students. Thus, as a precursor to creating instructional materials, we investigated how students applied their learning about resonance as traditionally taught to this novel system.

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INTRODUCTION

As part of the ongoing Modern Miracle Medical Machines (MMMM) project at Kansas State University, an activity is under development to teach the physics of magnetic resonance imaging (MRI) to introductory university students. In MRI, atomic nuclei resonate due to their interaction with magnetic fields [1, 2]. As part of the MRI activity, a system was developed that allowed students to have a compass resonate due to its interaction with magnetic fields. However, students are not generally familiar with this context of resonance from either their everyday lives or a typical introductory physics class. Therefore before we could develop this activity for instruction, we must address the question: *Can students apply the knowledge learned in the context of traditional mechanical resonance (e.g. the pendulum) to the context of a resonant compass interacting with a magnetic field?*

LITERATURE REVIEW

Very limited research has been conducted regarding student's knowledge and abilities to learn resonance. However, there are a few that looked at student's knowledge and abilities in related topics.

Three papers looked at transfer tasks. Two papers by Wollman studied student's ability to transfer knowledge learned from studying one type of pendulum to another, focusing specifically on the frequency of the two pendula [3,4]. Similarly, Ranney looked at students' abilities to transfer knowledge learned in the context of pendula to dropping/throwing tasks, emphasizing trajectories [5].

Some papers address student's difficulties and abilities in related contexts [6-11]. However, none of these studies directly address how students applied what they learned with one resonant system to one that is somewhat different.

THE NON-TRADITIONAL RESONANCE SYSTEM

Most definitions of resonance include two facets [12]. First, the system exhibits a natural oscillation frequency. Second, when a force is applied at that natural oscillation frequency, the oscillation amplitude increases. In introductory textbooks, resonance is traditionally discussed in the context of a pendulum, mass on a spring, and/or RLC circuits [12, 13].

The non-traditional system, pictured in Figure 1 and shown schematically in Figure 2, investigates the resonance of a compass in the presence of an applied magnetic field (due to either the Earth or a bar magnet). The bar magnet is optional.

Compass as a Resonator

A compass needle is a magnetic dipole. The torque, τ, on a magnetic dipole, m, in a magnetic field, B, is [14]

$$\vec{\tau} = I\vec{\alpha} = \vec{m} \times \vec{B} \qquad (1)$$

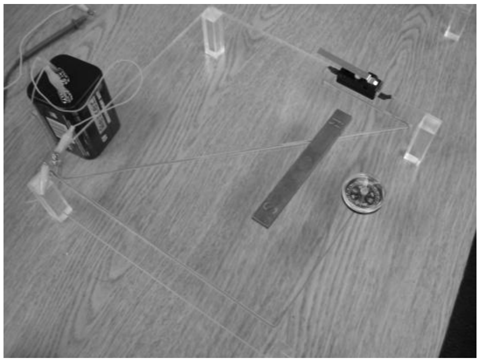

FIGURE 1. Picture of the novel resonance system.

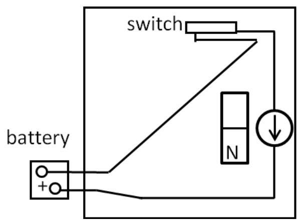

FIGURE 2. Schematic of the novel resonance system.

where I is the needle's moment of inertia and α is its angular acceleration. This equation is analogous to the torque on a pendulum [13]. By analogy, the oscillation frequency, f, of the compass needle is

$$f = \frac{1}{2\pi}\sqrt{\frac{mB}{I}} \qquad (2)$$

and depends on both the physical properties and the magnetic properties of the compass needle as well as the strength of the applied magnetic field. The applied magnetic field in this case is either the field due to the Earth or a bar magnet, not the field due the wire. The field due to the wire only serves to provide the "kick" to the compass, causing the amplitude of the compasses oscillations to increase when tapped at the oscillation frequency.

THE ACTIVITY

In order to prepare the students for the nontraditional resonance context, the activity begins with hands-on activities and computer visualizations which allow students to discover basic properties of magnets, compasses, and magnetic fields. The students are introduced to the apparatus used to explore the resonance of the compass, including looking at the deflection of a compass needle as a function of distance from the wire.

After these preparatory investigations, the activity begins to investigate the concept of resonance. It starts with the traditional context of a pendulum. The students predict then measure the dependence of a pendulum's period on both mass and length. This is followed by in an introduction to the concept of frequency.

The activity then shifts gears to look at the dependence of the oscillation of an undamped compass needle above a wire in the novel context. The students are asked to investigate how a compass's oscillation frequency depends on type of compass, distance above the wire, and the proximity of a bar magnet placed parallel to the wire.

The students then briefly return to the pendulum in order to consider driving frequencies and their relationship to the pendulum's natural oscillation frequency. Afterwards, the students are asked similar questions in the context of magnetism. At this point, the students were asked four questions probing their understanding of the material covered thus far.

After completing the four questions, the student's knowledge of resonance of a compass is applied to the context of nuclear magnetic resonance and MRI.

METHODOLOGY

The research was conducted in a teaching and learning interview [15] based around the MRI activity. The nature of a teaching/learning interview allows for some prompting and probing of student understanding. However, the interviewers consciously kept such prompting to a minimum in order to more accurately gauge the direct student interactions with the materials. The interview was 2 hours long with the resonance portion at the midpoint. The data sources for this study include: audio and video recordings, full transcripts, students' notes and written responses to the four questions and the researchers' field notes.

Demographics

The target audience for the larger MRI activity is introductory students in an algebra-based sequence (especially pre-meds). However, due to inaccessibility of the target audience at the time of the study, 8 students from the Kansas State REU program were interviewed for this initial research. The physics backgrounds of these eight students were varied; however, they can be summarized as follows:

- Four have taken upper-division electricity and magnetism while four had not
- Four have taken upper-division classical mechanics, 2 did not indicate if they had or had not, and 2 had not taken it.
- Four explicitly stated that they did not remember covering resonance in any class.

SUMMARY OF DATA

Because the interview was based around a written activity, the students all encountered the questions in the same order. The data below are organized in chronological order.

Pendulum Period or Frequency

The resonance section begins with the pendulum. Students constructed a pendulum and were asked what they knew about the period of a pendulum. They then predicted and measured the dependence of the period on mass, followed by its dependence on length. One student, after making her measurements, compared the pendulum's dependence on length to the motion of planets, stating:

I think it was faster when it was shorter, which makes sense if you think about it with the planets, because the ones that are closer to the sun have got shorter periods ...

The students then read a short paragraph describing the dependence of the pendulum's period on gravity, stating that the period was independent of amplitude, and introducing the relationship between period and frequency. When asked, 7 students were able to state the variables on which a pendulum's frequency depends.

Compass Period or Frequency

At this point, the activity switched to look at the novel system. First, they were asked to measure the frequency of oscillation of a compass placed directly above the wire. The oscillation of this compass is the standard for comparison during future questions.

The students were then asked to start looking at the resonance of a compass placed 2-3 cm above the wire. While it is not impossible to measure, the students were told that "eyeballing" was an acceptable method for comparing the period of the raised compass to the standard. Five concluded that the period (or frequency) was independent of height, though one needed prompting from the interviewer. Two students commented specifically on the amplitude of the oscillation not mattering. One of them, even after measuring slightly different periods for the two compasses, argued:

They should be the same, because it said that amplitude doesn't matter ... like it doesn't matter how far you pull back the pendulum. ... it should still have the same frequency, so they should be the same.

An additional student felt the frequency should be the same but was unconvinced after watching the two compasses and could not justify his intuition.

The compass was next replaced by a compass with a much smaller needle and an obviously higher natural frequency than the standard. All the students acknowledged this, with seven commenting on its higher frequency or shorter period. Five of them even commented on why this might be, with 4 of them focusing on the physical properties (length or moment of inertia) of the needle and the last on the material of the needle. The focus on the physical properties, rather than the magnetic, might be due in part to relating back to the pendulum.

Next, a bar magnet was placed on the apparatus parallel to the wire. All the students acknowledged that the frequency changed; 7 gave the correct dependence of the frequency or period on the distance between the bar magnet and the compass. Two students made explicit statements connecting the compass to the pendulum.

Student 1: The frequency of the compass has to depend on the magnetic field, might be similar in a way the pendulum was dependent on the length of the string.

Student 2: ...it's the strength of the field that determines the strength of the force, the torque on the needle. ... I guess I can think about it in terms of the pendulum. If you increase gravity, then intuitively the pendulum is going to swing faster because it's more attracted to the center of the Earth ...

Increasing Oscillation Amplitude

The next question began by stating that for the compasses the oscillation is created by holding down the switch. It then asked what the equivalent action is for the pendulum. All the students were able to state that they were the source of the pendulum's deflection.

The students were next encouraged to consider how to "kick" the pendulum in order to increase its amplitude. They were also prompted to think about "kicking" a swing as a child. There were two parts to this question. First, how can you increase the pendulum's amplitude? Second, how often do you have to perform this action? To the first question, 3 of the 8 students immediately indicated that you would have to push the pendulum. Three more suggested or tried shortening the length of the pendulum before moving onto pushing it. One of the last two initially suggested that you could increase the amplitude by pushing on the string and then moved to pushing on the pendulum bob while the last needed some prompting from the interviewer before coming to the conclusion of pushing the pendulum. Most (7 of 8) realized that the frequency of their "kick" had to be the same as the frequency of the pendulum, though two of them required prompting from the interviewer before reaching this conclusion.

The students were then asked the same two questions in terms of the compass. Most (7 of 8) immediately jumped to the conclusion that the frequency had to be the same as the compass's oscillation frequency. Five even said this in conjunction with the need to tap the switch at the proper frequency. Without prompting, 3 referred back to the frequency (or period) they measured earlier.

Question Responses

Two of the 4 questions posed to the students after the resonance section dealt explicitly with resonant systems. The first of these 2 questions asks if the oscillation frequency of the apparatus used in the novel context changes when it is taken to a planet with a smaller magnetic field than Earth's. All answered the question that frequency would change with one student commenting that:

> *The period of a pendulum depends on gravity, and since the oscillation of the compass are acting as a pendulum, it will also depend on the external magnetic field.*

The other 7 students justified the frequency changing by commenting either on the frequency depending on the external magnetic field or the situation being similar to the one in the activity with the bar magnet.

The second question presented a picture of a horizontally oriented mass on a spring and asks if it is a resonant system. Seven of the eight students believed that this would be a resonant system, with 3 commenting that it would have a natural/resonant frequency and 2 stating that it would behave like the pendulum. The eighth student did not feel that it would be a resonant system unless it was reoriented vertically. This student clearly articulates both requirements of a resonant system, writing:

> *When the mass on the spring was set into an oscillating up and down motion and an outside force pushed the mass at the same frequency as the spring, then it would be a resonant system.*

CONCLUSIONS AND FUTURE WORK

This research asks if students can apply the knowledge learned in the context of a pendulum to the context of an oscillating compass. Our data show that, with some guidance, these upper-division students showed a general understanding of resonance. Specifically, the students could identify that the static magnetic field plays the same role for the compass that the gravitational field does for the pendulum resonance and that resonance is independent of amplitude in both contexts.

However, additional work is necessary. We would like to further test the activity as a whole with introductory students. It will be interesting to see if introductory students have the same difficulties with the material as these upper-level undergraduates as well as compare the responses of the 2 groups.

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