As a physics student in the teaching sub plan, my goal for a UROP project was one that I could use in my teaching career, but would still be interesting and useful. To this end, my advisor suggested that I work on building a more advanced version of one of the standard demos used in physics classes- the magnetometer. A magnetometer is a device that can be used to measure fluctuations in the local directionality of magnetic fields, and is typically used in physics classes to demonstrate that the Earth's magnetic field is not fixed, but rather changes direction, albeit rather slowly and not by great degrees. It is fairly easy to build what is called a "soda bottle magnetometer", but the typical designs are fairly crude. A piece of string holds up a mirror with a magnet on the back, which hangs in a bottle and reflects the beam of a flashlight. This is typically sufficient to at least show the changing of the field, but is a very imprecise and crude system. My goal with this project was to build a magnetometer that would be notably better, but still maintain a low cost and sufficient simplicity that it can be easily constructed by students.

I began by analyzing the various components of a typical soda bottle magnetometer, so that I could focus on improving each of them and create a cohesive and efficient end product. The most obvious change that first presented itself was to replace the typical flashlight with a laser pointer, as the more precise and constant beam allows a much greater degree of accuracy. The laser pointer is wired to a small power supply which allows it to run continuously when plugged in, rather than having to deal with holding down a button, or something similar. Next, the typical method of suspending the mirror in the bottle is to merely attach a mirror with a weak magnet on the back to a piece of string that hangs out of the bottle, typically with a knot in the string to hold it at the proper position. This is a terribly inefficient system for many reasons. Something as large as a piece of string will have a great deal of friction with itself, which limits the motility of the mirror as it hangs. By attaching the magnet directly to the mirror you induce a magnetic field across the entire thing, which is also imprecise, as it won't behave like a small lever arm, which is ideal for something like this. Leaving the string just tied at the top leaves the possibility in place for the knot to slip some and the mirror's alignment to be disrupted, and for air to flow through extra space at the top and disturb the system, an effect that I observed with an early trial to be not insignificant. Finally, as the bottle must be cut open to place the mirror and other elements inside, it has to be sealed in some way, typically with tape. However, the tape may peel off and need to be replaced, which will disrupt the magnetometer as a whole, and may not provide a proper seal.

To address these issues, the following steps were taken: The string was replaced with a long hair, which was the thinnest material with a good tensile strength that could be found, and is able to hold the mirror without difficult as well as be a single thin filament which won't have notable damping from the mirror's pivoting motion. To hold it in place in the bottle and to prevent air flow, the hair was glued to the cap using a hot glue gun, and the hole through which it is threaded was also sealed with glue. Instead of a typical weak magnet attached to the back of the mirror, a strong yet small neodymium magnet was attached to a piece of straight wire, which creates a proper lever arm that gives greater freedom and allows more sensitivity to torque, which is necessary for observation of the changes in magnetic field. Additionally, a note card was placed between the wire and the mirror to help prevent interference of magnetic field on the mirror itself. Lastly, instead of taping the bottle shut, hot glue was used to create a small seal around the entire bottle which won't degrade or interfere with the magnetometer's function.

With these changes made, the magnetometer's design was already much better than the original from which the idea was drawn, with little increase in difficulty of assembly or price. The last step was to make sure that the system could be properly used by anyone and would give accurate results independent of changes in local condition or user. To this end, the laser was mounted in a piece of plywood, and secured with hot glue, at a height level with the mirror. A piece of ruler was glued in place below it so that simple and accurate distance measurements could be taken. The board was placed standing straight up exactly one meter from the soda bottle, and a neutral position for the pointer was marked. From this point, data could be easily taken, with a change in position of the laser of 1 cm corresponding to a 1 degree shift in the directionality of the magnetic field. Thus, anyone who is able to set the system up with the sufficient one meter of space is able to accurately measure changes in the Earth's magnetic field's direction over time.

One notable issue with this design actually lies in its efficiency-that is it is highly sensitive to changes in magnetic field. Being as the Earth's magnetic field is relatively weak, especially compared to local disturbances such as the usage of electronics very close to the setup, it is quite easy to get interference on the magnetometer. The simple solution to this, however, is merely to set the system up in an area free of electrical and magnetic interference such as from power cables or other magnetic sources. Still, it bears consideration.

Overall, this project was very successful, and properly demonstrated that a highly efficient magnetometer may be simply and cheaply constructed in a classroom setting. This is a great project for teaching students about an interesting and potentially useful piece of information about the Earth's magnetic field, as well as engaging them more fully in their learning by allowing them to do, rather than just hear. Captioned images of the final result are included on the following pages, with captioning.

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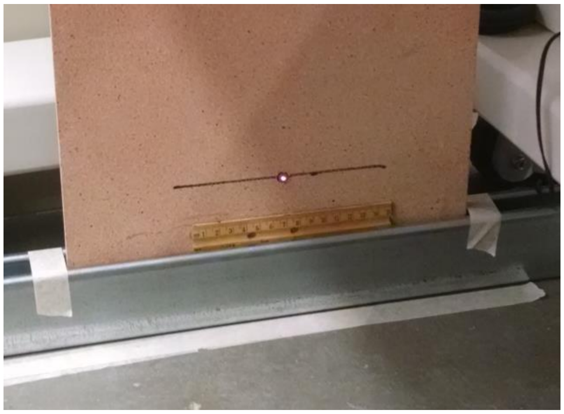

Figure 1 (above) shows the board with laser pointer and ruler.

Figure 2 (below) shows the full setup with the bottle positioned one meter from the board and laser.

Figure 3 (above left) shows a front view of the bottle, with the mirror hanging approximately in the middle, and some sand in the bottom as a weight to hold the bottle down such that it isn't disturbed by local vibrations.

Figure 4 (above right) shows the bottle from a side view, such that the wire and magnet on the back of the mirror may be seen attached to the notecard.