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Teaching College Physics to a Blind Student

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The Americans with Disabilities Act (ADA), which was signed into law in 1990, requires that universities make reasonable accommodations to allow students with disabilities full access to classes and programs. At Purdue University, the Office of the Dean of Students (ODOS) has a large and knowledgeable staff charged with arranging appropriate accommodations, which include considerable technical support for the blind and visually impaired. As a participant in this effort, one of the authors (EF) has acted as a faculty liaison between the ODOS and the Physics Department.

In the fall of 1996, the Physics Department was asked by the ODOS to assist in enabling a student, whom we identify as CW, to take the standard pre-med physics courses[1] (Physics 220-221). The necessary support consisted of note takers in lecture, a specialist in the lab, a reader/scribe for quizzes and exams, and a tutor for both lecture and lab. Additionally, the ODOS arranged for various items to be brailled, including the homework, exams, and examples or diagrams that the instructor or any of the authors thought would be helpful. Primary responsibility was assumed by two of the authors (MP and MB) who, as graduate teaching assistants, were familiar with the course content. MP acted as CW's tutor during both semesters and as lab specialist during the first semester, while MB was lab specialist during the second semester.

General Background

CW is a very bright and highly motivated female student, who was a first-year senior during the 1996-1997 academic year. She had a high grade-point average, which indicated that she had the ability to cope with a broad range of subjects including sciences such as biology and chemistry. Nonetheless, physics posed special problems. Although CW attended the course lectures, it soon became apparent that she learned relatively little from them. This was not the fault of the lecturer, but rather a consequence of the fact that much of introductory-level physics relies on demonstrations as well as on visual material such as diagrams, pictures, coordinate systems, etc., all of which are formatted for sighted individuals. Additionally, the derivations of various results presented in class relied on mathematical manipulations, which CW could not easily follow.

To appreciate these and other problems faced by CW in learning physics, it is helpful to keep in mind some of the differences between how blind students and sighted students absorb information. Braille is read one character at a time, so information is necessarily absorbed sequentially. By contrast, sighted persons read words and phrases at a glance and can easily go back and forth over a section of text. CW is proficient in both reading and writing Braille, an ability that is not shared by a number of other blind students served by the ODOS. CW took notes and worked problems using a Perkins Braille Writer, which produces Braille text on specially treated paper. Partly because she was so proficient in Braille, CW tended to organize and manipulate information in a sequential way, even when this was not appropriate. Consider, for example, the familiar formula giving the Doppler-shifted frequency f' in terms of the emitted frequency f, the velocity v of sound, and the velocities v_s and v_o of the source and observer respectively[2]:

$$f' = f\left(\frac{1 \pm \frac{v_o}{v}}{1 \mp \frac{v_s}{v}}\right) \tag{1}$$

This equation written in Braille would resemble the following:

$$f' = f \times (1 \pm (v_o \div v)) \div (1 \mp (v_s \div v)) \tag{2}$$

Eq. (2) would be more difficult to read and manipulate than Eq. (1), even for a sighted person. It becomes all the more difficult to deal with for a blind individual who must read it one character at a time.

Not only did CW rely heavily on sequential processing of information, but prior to our involvement she did not appreciate that sighted individuals were not so constrained. To explain this to CW, we had her place both hands on a page of Braille text and attempt to read the page "all at once." (A sighted reader may carry out a similar exercise by picking up an unfamiliar complex object and trying to relate its components to one another "all at once.") Of course, she was unable to accomplish this, but she was at least able to appreciate that a sighted person might absorb information differently. (It is interesting to speculate whether a person could be taught to read Braille using all ten fingers simultaneously.)

Not only was CW constrained to read an equation one character at a time, but she had to remember all the previous characters while manipulating equations algebraically to solve a problem. [To appreciate the difficulty of doing this, the interested reader may try reproducing an unfamiliar equation from *Physical Review* by writing it sequentially as in Eq.(2)]. The challenges faced by CW in doing algebra can be attributed to a lack of basic skills in manipulating algebraic equations. Although CW had taken algebra and trigonometry courses in both high school and college, methods for solving problems had either been forgotten or had never been correctly learned. CW admitted to having gotten through algebra by memorizing how to solve certain specific types of problems, rather than by learning and understanding general approaches and methods applicable to all problems. To improve CW's skills, MP devoted time to presenting a number of algebraic shortcuts. Two simple examples of relations that were not obvious to CW were

$$\frac{a}{b} = \frac{c}{d} \Leftrightarrow ad = bc \tag{3a}$$

and

$$\frac{1}{a/b} = \frac{b}{a} \tag{3b}$$

Once CW's algebra skills improved, her ability to apply physics equations to some problems improved as well.

As noted in the beginning of this section, CW was unable to absorb much from the lectures, and hence most of the learning took place in tutoring sessions lasting 6-8 hours per week conducted by MP. During these sessions MP would read the appropriate sections of text, explain them, and then assist CW in doing homework. These sessions revealed another problem, again related to the rendering of mathematical equations. If the text contained an equation such as

$$x = \frac{a+b}{c} \tag{4}$$

it was necessary that the equation be carefully read so that CW could transcribe it properly as

$$x = (a + b) \div c \tag{5a}$$

rather than as

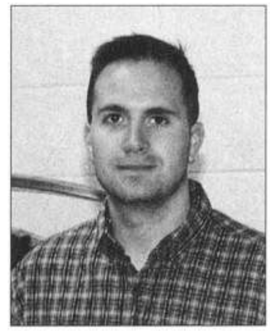
$$x = a+b \div c \tag{5b}$$

Evidently, simply reading Eq. (4) as "x equals a plus b divided by c" would not be sufficient. However, since this is exactly how the equation is likely to be enunciated in lecture, it is clear why information presented in lectures was difficult for CW to assimilate.

Use of Pictorial and Graphical Material

Along with the problems related to algebra, the most serious challenges for CW lay in understanding figures, particularly graphs. It has been the experience of author EF that even sighted students at this level often have difficulty interpreting graphs, and hence it came as no surprise that CW would also encounter obstacles. Graphical or pictorial material was presented to CW using a heat pen, which is a hot stylus for writing on special wax paper. The stylus melts the wax in such a way as to leave a raised impression that can be "read" by touch. CW used one or two fingers to follow the raised lines in the figure, so that the relevant information was gathered step-by-step. (By contrast, a sighted person can view such a figure at a glance and can readily distinguish among different curves.) Even after CW assembled the information, it was sometimes difficult for her to fully grasp the contents of a figure sufficiently to solve a problem independently. For this reason, verbal explanations were also required for her to solve problems involving geometric concepts.

An illustrative example is provided by the problem of determining the forces exerted on



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a ladder leaning against a building. Since CW had never actually seen a ladder in this position, she had difficulty initially connecting a verbal description of the problem with a figure. This difficulty was compounded by the problem of having to do the geometry necessary to resolve various vectors into components. CW noted that geometry had been her most difficult subject in high school, and some of the reasons are obvious. A typical geometry problem, such as finding a particular angle in a figure, is solved by using various theorems (e.g. alternate interior angles are equal) to evaluate all the angles related to the unknown angle. As each piece of information is used, a sighted person can fill in the figure, so that eventually it becomes clear how to determine the angle in question. However, a blind student would first have to remember all the preliminary results she had obtained, and then combine these to find the unknown. Since physically drawing with a heat pen is taxing, and erasing is impossible, it is clear why geometry was difficult for CW, both as a course and as a tool in physics.

In practice, raised line figures proved to be much less helpful to CW than conventional pictures are to sighted students. CW had trouble both drawing a picture herself and interpreting a figure from her Braille text. Our observations support the conclusions drawn from more formal studies[3-5] to the effect that perception of pictures requires a learning process in which the subject is taught to identify the components of a picture with real objects. Eventually, these observations motivated us to rely wherever possible on tactile models. Before discussing the methods we used, we offer an additional observation that will illuminate the serious obstacles faced by CW in tackling this course.

CW was asked by MB whether the vector $\vec{V}$ shown in Fig. 1 pointed toward the point P. She made several attempts to find the answer. CW first found $\vec{V}$ with her right index finger and determined the direction in which it pointed. She then moved her right finger to point P but was unable to determine whether $\vec{V}$ pointed toward P. Next she placed her left index finger on P and her right finger on $\vec{V}$ and was still uncertain. Only after she moved her right finger along the direction of $\vec{V}$, and it became clear that her right finger would not hit her left finger, was she able to state with confidence that $\vec{V}$ did not point toward P.

We conclude this section with two anecdotes that help to explain how CW organizes information. On one occasion, MP was in her office reading the text to CW, when CW turned to shut the office door to block out the hallway noise. When MP stopped reading to note that CW was closing the door, CW was surprised to learn for the first time that MP could see peripherally what was happening in the room while reading the text. CW had assumed that when a person's eyes are focused on reading, she could see nothing else, as is the case for someone reading Braille. In a related situation, MP was discussing how to solve a physics problem by making a table of the known quantities. A sighted individual is able to see and comprehend simultaneously multiple pieces of information in a table. However, CW was under the impression that only one piece of information could be seen at any one time, as in Braille. These two episodes suggest that information may have to be presented to blind students in a different way from that ordinarily used for sighted students, and may have to be tailored to each blind student's individual requirements.

Use of Tactile Aids

CW's difficulties in dealing with line drawings motivated us to try other methods for explaining various concepts. We began by supplementing the line drawings with a flexible French curve, which CW could form into a one-dimensional figure of arbitrary shape. We were pleased to find that from the outset CW could form the French curve into an accurate representation of a straight line, parabola, circle, or ellipse. Since these functions, along with sine and cosine, are the functions most frequently mentioned in this course, use of the French curve made it possible to discuss elementary graphs and how they might change if some parameter (e.g. velocity or acceleration) were varied.

One of the most useful tactile aids was a supply of children's clay or Play-Doh® and a number of unsharpened pencils. These materials were helpful in solving problems using free-body diagrams that could be constructed by inserting the pencils (representing vectors) into the Play-Doh (representing the body). The use of Play-Doh and pencils allowed CW to create and use free-body diagrams with minimal outside help. This aid was important in developing CW's understanding of how to resolve vectors into components and how to

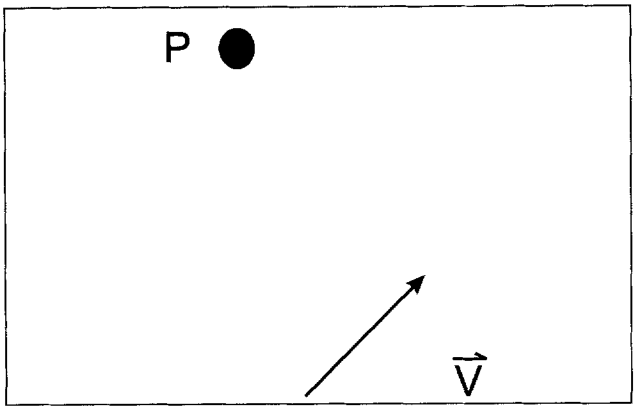

Fig. 1. CW was asked to determine whether the vector $\vec{V}$ pointed to P. See text for further discussion.

add vectors. The pencils were formed into a right triangle, so that CW could clearly perceive which vectors the hypotenuse and sides corresponded to. We found that once CW grasped free-body diagrams using Play-Doh and pencils, she could deal with them more readily when they were presented in the form of line drawings.

Line drawings using the heat pen were useful in discussing electric and magnetic fields, which are otherwise difficult to represent. We found that CW generally considered electromagnetism more difficult than mechanics, as is the case for most students. Especially difficult were concepts that required a 3-dimensional picture, such as the magnetic field produced by a coil of wire, or the electromagnetic torque produced by a force $\vec{F}$. A related problem was understanding the meaning of vector products. A sighted student employing the right-hand rule will typically use her index finger, middle finger, and thumb to represent the vectors $\vec{A}$, $\vec{B}$, and $\vec{C} = \vec{A} \times \vec{B}$, respectively. CW had difficulty maintaining the right angles between her fingers, so this exercise was not very successful. Another approach was to have CW grasp a soft drink can with her thumb pointing up. If the can is placed on a table representing the plane defined by $\vec{A}$ and $\vec{B}$, then her thumb points along $\vec{C} = \vec{A} \times \vec{B}$. This method met with limited success. There are undoubtedly other aids that we could have used, some of which may have been more effective. However, we felt that there was an underlying difficulty involved in dealing with 3-dimensional concepts which would have required much more effort to overcome. In particular, 2-dimensional drawings of 3-dimensional objects (such as a cube), or pictures using perspective, were useless for CW since she was incapable of interpreting these as being 3-dimensional.

Another approach that we found productive was to focus on physical examples to which CW could directly relate. Explaining relative velocity by calling on the student's experiences looking out the window of a moving train would not have been useful to CW. However, centripetal acceleration and tangential velocity could be associated with her experiences on a merry-go-round. Centripetal acceleration and normal forces could be explained in terms of her sensations on a roller coaster, specifically by comparing the feeling one has at the bottom of a loop with that at the top. Free-fall and gravitational acceleration were explained by relating them to jumping on a trampoline or bed. Two skaters pushing off each other on a frozen pond was an analogy we used to illustrate momentum conservation.

Where physical experiences were not relevant for explaining some concept, a physical demonstration was used. For example, when simple machines were discussed, we set up a demonstration of inclined planes and pulleys, using materials obtained from the lecture demonstration room. These allowed CW to use both her hands simultaneously to create a more complete picture than would have been possible from a study of a raised line diagram.

Laboratory Experiments

Both MP and MB made an effort to have CW participate in the lab experiments as fully as possible. The labs in mechanics were relatively easy to adapt for CW, since these often dealt with real objects that CW could weigh, push, or drop. CW was even able to time events if the moving components were rigged to make a sound at the beginning and end. One example was to find the period of rotation of a spinning bar. A piece of paper was taped up in such a way that when the bar came around it brushed the paper, thereby creating a sound by which the number of revolutions could be counted.

Labs in electromagnetism were more difficult to adapt, since most of the relevant information was displayed on various meters. In this case it was necessary for the lab specialists (MP or MB) to execute the lab while explaining to CW the sequence of events. However, CW was responsible for analyzing the data and writing up the labs, which she accomplished with assistance from the lab specialists.

Summary and Discussion

As more students with disabilities avail themselves of the accommodations that are mandated under ADA, we can expect that increasing numbers of blind students will be taking quantitative college-level physics courses. These students will challenge universities to adapt the curricula in these courses to make them more accessible and "user-friendly."

Apart from the accommodations already discussed, and allowances for extra time on exams, CW received no special treatment in this course. We followed the guidelines used by the Educational Testing Service for administering exams to disabled students. In general these allow substantially more time for blind students, and in practice CW was able to complete a standard one-hour exam written in Braille (with tactile diagrams) in three hours. The exams were administered by a reader/scribe who was a student hired by the ODOS for this specific purpose. The functions of the student included constructing figures following CW's instructions, and executing calculations that CW dictated. Finally, this student transcribed CW's answers onto an answer sheet.

CW received an A in both semesters of Physics 220-221. Our experience with her suggests that even a student blind from birth can deal successfully with a college-level pre-med physics course, if provided with appropriate faculty and student support. We emphasize the necessity of a one-on-one tutorial as the primary mechanism for learning.

Acknowledgments

The authors are indebted to CW for her permission to present the material in this paper, and to Professor John Finley and Janie Fischbach for useful discussions.

References

1. The text for this course was *Physics* by John D. Cutnell and Kenneth W. Johnson, 3rd ed., (Wiley, New York, 1995).
2. *Op. cit.* p. 509, Eq.(16.15).
3. Jan B. Deregowski, *Sci. Am.* **227** (5), 82 (1972).
4. E.H. Gombrich, *Sci. Am.* **227** (3), 82 (1972).
5 John M. Kennedy, *Sci. Am.* **276** (1), 76 (1997).

Potpourri

Metric Conversion Chart

10^{12} microphones	=	1 megaphone
10^{6} bicycles	=	2 megacyles
2000 mockingbirds	=	two kilomocking-birds
10 cards	=	1 decacard
10^{-6} fish	=	1 microfiche
453.6 graham crackers	=	1 pound cake
10^{12} pins	=	1 terrapin
10^{21} piccolos	=	1 gigolo
10 millipedes	=	1 centipede
10 monologues	=	5 dialogues
5 dialogues	=	1 decalogue
8 nickels	=	2 paradigms
2 snake eyes	=	1 paradise
2 physicians	=	1 paradox

via C. Hendrick

Double-Slit Experiment on Web

The double-slit experiment with single particles is often described as the perfect embodiment of quantum physics — simple yet profound. With this in mind, I arranged to have a simulation of the experiment made available on the Web for use by teachers and students (I am using it with my high-school students). It is at www.inkey.com/dslit/ and requires a browser with Java. At this site, the student can select the number of particles to pass through a pair of slits, and either augment the number with more or start over with the same or a different number. The simulation shows nicely the random points of detection, which, for a few particles, show no clear pattern but which, for more particles, gradually develop into the classical interference pattern. By taking pictures of the screen or the relevant part of the screen, the student can illustrate the development of the pattern in a printed report.

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●The pamphlet, ***"The Magnitude of Physics,"*** which was printed as a supplement to the December 1996 issue of *The Physics Teacher*, has been converted into an HTML document by John Lahr of the University of Alaska. It is available at www.giseis.alaska.edu/Input/lahr/magphys.html. Teachers and students of physics are welcome to link to this site or to download the source code for use on their own web sites.