Seeing Chemistry Through Sound: A Submersible Audible Light Sensor for Observing Chemical Reactions for Students Who Are Blind or Visually Impaired

Cary A. Supalo
Rodney A. Kreuter
Aaron Musser
Josh Han
Erika Briody
Chip McArtor
Kyle Gregory
Thomas E. Mallouk
The Pennsylvania State University

Abstract: In order to enable students who are blind and visually impaired to observe chemical changes in solutions, a hand-held device was designed to output light intensity as an audible tone. The submersible audible light sensor (SALS) creates an audio signal by which one can observe reactions in a solution in real time, using standard laboratory glassware such as test tubes or beakers. Because many observations in the chemistry laboratory are visual, the SALS device enables students who are blind and visually impaired to perform a broader range of experiments independently. It is believed that this active participation will inspire more of these students to pursue careers in the science, technology, engineering, and mathematics (STEM) professions. The SALS device can be further refined to provide vibratory and visual outputs for students with learning or physical disabilities.

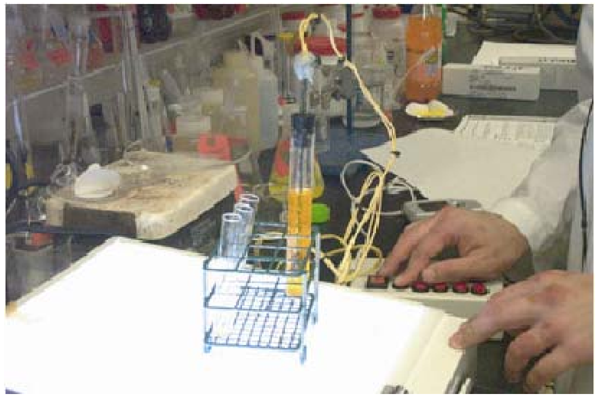
Key Words: Audible, Blind, Visually impaired, Chemistry, Reaction, Sensor

Introduction

One of the main problems for students with blindness or visual impairments who wish to participate independently in a laboratory curriculum is the lack of talking and/or accessible tools (Scadden, 2005). The most common adaptation is for the student to work with a sighted laboratory assistant. The assistant's responsibility is not to do the experiment, but rather to carry out the student's instructions. This is to be done even if the student gives an incorrect instruction. The only exception to this guideline is when the safety of those directly involved is compromised (Burgstahler, 2005; Flair & Setzer, 1990; Lunney & Morrison, 1981; Miner, 2001; Pence, Workman, & Riecke, 2003; Supalo, 2002, 2005; Tombaugh, 1981).

Most sighted students do not have difficulty making laboratory observations at the level of an introductory chemistry course. However, many of the observations in the chemistry laboratory are visual in nature. The goal of this project has been to design a simple and inexpensive tool that will allow students with blindness and visual impairments to perform

Figure 1. Monitoring a color change in a chemical reaction using the SALS and a light box.



their laboratory experiments in the same independent manner as their sighted peers. Such tools may allow these students to get involved in laboratory experiments at an earlier age (Tallman, 1978), and could help them stay involved and interested in science.

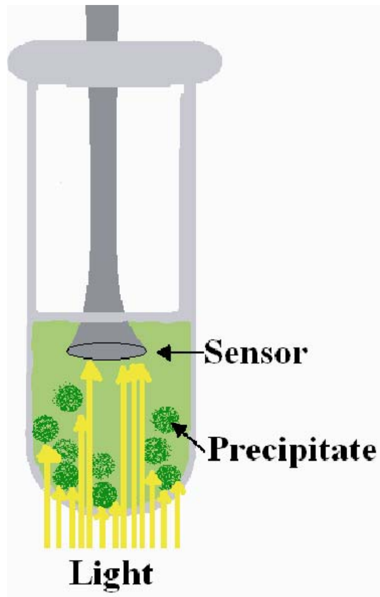
The submersible audible light sensor (SALS) is a device that qualitatively registers color change or precipitate formation with sound. The design is user-friendly, cost-effective, and functions in real time. The SALS is based on a photocell that measures light intensity changes. The photocell is encased in a transparent "wand" that is small enough to allow measurements to be made in ordinary test tubes or beakers. The test tube or beaker is placed over a light box, an inexpensive white light source normally used for tracing or drawing, as illustrated in Figure 1. As a reaction proceeds, the varying light intensity at the tip of the sensor wand is converted electronically to an audible tone. The chemical change (e.g., how cloudy or dark the solution becomes) is indicated by a more pronounced change in pitch, usually from high to low.

Device Design and Use

As Figure 2 illustrates, light from the light box travels upward through a test tube or beaker to the photodetector in the sensor probe. If a precipitate is formed or if an initially colorless solution becomes colored, some of the light will be blocked. The output pitch, which corresponds to the intensity of light reaching the sensor, can be measured by using a standard chromatic tuner available in music stores.

The SALS may be used in conjunction with a camera phone, the Nokia 6620, which has unique software, called the Mobile Color Recognizer, available from CodeFactory (2006), that works with Mobile Speak. The user takes a picture, and the phone, via the speaker, tells the user the color. This color recognition feature can help the user interpret the observations. If the SALS has the same reading for two different solutions or suspensions (e.g.. sand in water, and a blue solution of copper sulfate), the camera phone can provide the user with additional color information. In a qualitative analysis experiment, a precipitate can be distinguished from a homogeneous color change by decanting the solution into an empty test tube and testing again with the SALS. The user knows by comparing the output tones if a precipitate has formed, and the color recognizer can inform the user of its color.

Figure 2. Schematic drawing of the operation of the submersible audible light sensor (SALS) in detecting the formation of a precipitate in a test tube.



Most of the experiments done in the general chemistry laboratory (titrations, qualitative analysis of solutions, oxidation-reduction, precipitation, flame tests) involve visual observations. Experiments from the Addison-Wesley Chemistry Laboratory Manual (Wilbraham, Staley, & Matta, 1995) were used as a representative set of experiments for adaptation with the SALS. The performance of the SALS was tested in detail by using one of these experiments, the iodine clock reaction. In this reaction, a starch-iodine indicator signals the changes that occur as an oxidation-reduction reaction proceeds. The times at which these relatively abrupt changes occur depend on the initial concentrations of reagents. The reaction involves sequential changes from colorless to blue, green, brown, and ultimately black, corresponding to an absorbance that appears initially in the red spectral region at about 600 nm and then gradually shifts to cover the entire visible spectrum. The tone output from the SALS changes by more than one octave over the 1-2 minute course of the reaction. In this adaptation of the Addison-Wesley experiment, a test tube is held by a test tube rack above a light box, with the SALS probe immersed in the solution as shown in Figure 1. The changing tone from the speaker can be compared to a reference tone stored in the SALS control box, or tracked more quantitatively by using a chromatic tuner. Once the student hears the change in tone, he or she can also use the color recognizer to determine the color of the solution in the test tube. This reaction can be performed while using a talking timer in order to record the times at which the color changes occur.

Construction and Operation of the SALS Device

The SALS system consists of three basic building blocks. The first is a cadmium sulfide (CdS) photocell. The second is a microcontroller with its power supply and user controls. The third is an audio amplifier and filter, which is used to power either a small speaker or headphones. The combined cost of the components (excluding the light box) is approximately $100.

Photocell. The heart of the SALS system is the CdS photocell. These devices have existed since the late 1800s. They are sometimes called photo resistors, photo conductive cells, photocells, or light dependent resistors. They should not be confused with silicon photocells. Unlike silicon photocells, which actually produce an electrical current when exposed to light, CdS photocells are really resistors whose resistance decreases in visible light. They were used as light sensors for early cameras because they are simple and sensitive. They also match much more closely the human eye's color sensitivity than any other inexpensive sensor in common use. The photocell is mounted inside a borosilicate glass tube, which is joined to a flat circle of glass at the bottom. The glass housing allows the sensor to be immersed in a wide variety of solutions. Photographs of the photocell in the glass tube and the controller box are shown in Figure 3..

Microcontroller. The microcontroller used in the SALS sensor is a PIC device from Microchip, which contains a built in analog to digital converter (A/D) and a hardware pulse width modulator (PWM). By placing the CdS cell in series with a fixed resistor, a voltage, which is dependent on the light incident on the CdS cell, is produced. This voltage is read by the A/D converter and converted to a number that is used by the software to produce a tone via the PWM.

Because micros can do only one task at a time, it is important that a micro with a built-in hardware pulse width modulator be chosen for this task. A PWM can be used to produce a tone completely in hardware, freeing the micro to do other tasks - such as polling the input buttons.

Power. Power for the SALS is provided by two 'AA' batteries in the controller box. A switching regulator converts power from the batteries into a stable five volt power supply for the microcontroller. At normal audio levels, battery life should be about 60 hours with alkaline batteries. Rechargeable NiCad or NiMH batteries may be used but charging is

Figure 3. The SALS sensor and controller box. The CdS photocell is encapsulated in a glass tube with a flat bottom window. An insulated cable connects the photocell to the controller box (right)

not provided by the unit.

Because the SALS is to be used by students who are blind and visually impaired, a power-on LED is not appropriate. Often these devices are left in the power on condition when not in use. To alleviate the problem of constantly replacing batteries, the SALS unit incorporates a software timer which shuts the unit off if no switches have been pushed for eight minutes.

Light source. Since the SALS unit uses light to measure reactions, the source of the light is important. The unit does incorporate some filtering, but if the light source is not constant, the tone produced will not be a pure tone. The most constant light source is natural daylight, but this is inconvenient for most chemistry experiments. Incandescent light sources generally have lower optical noise than the light from fluorescent lamps. However, a fluorescent light box placed below the test tube or beaker is most convenient experimentally. It is also possible to provide too much light (e.g., if an overhead projector is used as the light source), and in this case the sensor will saturate. No harm will be done, but the tone will not change if the sensor is saturated.

User controls. There are seven switches and a volume control associated with the SALS system. The switches are described in the following sections.

Power switch. This switch toggles the power. If the power is off when it is pushed, it turns the power on. The unit also sends the letter 'R' in Morse code to let the user know that the system is now running. If the unit is on when the power button is pushed, the unit sends the Morse code for 'PWR' and then shuts off the power. If no switch has been pushed for eight minutes, the system sends 'TIME' in Morse code and then shuts off.

Play. Samples the CdS cell and produces a tone proportional to the light incident on the cell when the switch is released. This button provides real-time tone readings that can be compared with tones stored in Memories 1 and 2, as well as the reference high and low tones.

High. Outputs the highest tone that the unit is capable of producing (2400 Hz). This reference high tone is used to obtain a qualitative comparison with the observed tone.

Low. Outputs the lowest tone that the system is capable of producing (250 Hz). This reference tone is also for comparison with the observed tone.

Store. Prepares to store the present condition of the sensor into one of two memory locations. If neither memory location is specified within eight seconds, the unit sends the letter 'L' in Morse code and returns to its normal tasks.

Memory location one (M1). If this button is pressed immediately after the store button, the present condition of the CdS cell is stored in memory location 1. If it is pushed at any other time, the value of the tone stored in memory location 1 is sent to the speaker. Note: Not all tones can be heard. On power up, the unit may contain a value outside the human hearing range. Only after a store has been done can one be sure the unit contains a 'reasonable' tone value.

Memory location two (M2). This is the same as M1 above but for memory location 2. This can be used to store an additional reference tone to be compared to the high and low tones, and any other observed tone.

Outcomes and Benefits

The SALS allows students with blindness and visual impairments to observe chemical reactions in 'real time.' By way of its audio output, the SALS provides an accessible medium that allows these students to experience chemical reactions in the laboratory in a manner similar to their sighted peers. It is the goal of this project to provide new opportunities for students to gather their own observational data directly. Such tools remove their barriers to entry in the study of laboratory science, and ultimately may help students with blindness and visual impairments to choose science, technology, engineering, and mathematics (STEM) careers (Miner, 2001; Pence, Workman, & Riecke, 2003; Scadden, 2005). Good problem-solving skills are an essential quality for a person who is to be successful in a STEM profession. Persons with disabilities are constantly honing their problem-solving skills by resolving accessibility issues they face in their daily lives. As a population, they are very effective problem solvers and their increased participation in STEM professions would add to the skilled workforce in these fields.

Assessment and Future Directions

The SALS has been tested in a number of adapted laboratory experiments from the Addison-Wesley laboratory manual, but so far it has not been used by students in an actual learning environment. Field tests and assessments of learning effectiveness will be carried out over the next two academic years at the Indiana School for the Blind. Based on feedback obtained from teachers and students who use the SALS, both hardware and software improvements will be made. Additional functionality will be added in future designs, allowing users to connect the sensor to a PC and obtain frequency data. This will allow for more quantitative comparisons of tone to frequency. An on-board visual display illustrating sound waves with respect to the output tone will be incorporated to aid students with learning disabilities, and other students who have difficulty learning through only one channel and require both a visual and audio input. A vibratory output device will be incorporated into the handset of the probe, thus allowing a student who lacks both visual and audio interpretation abilities to experience tactile output. This output will change in intensity as the color illustrated in the chemical reaction changes. Inexpensive complementary devices may be designed and built along the same lines as the SALS. For example, an inexpensive real-time color sensor is now in the final stages of prototyping.

Conclusions

The SALS is an inexpensive device that can be easily replicated for classroom use. The device reliably alerts the user to the formation of a precipitate and indicates color changes in solutions in real time. The sensor probe is small enough to fit into most standard chemistry glassware. The user can listen to the device through its internal speaker or with headphones.

The SALS will be tested with other chemistry laboratory experiments in order to determine its range of applications and limitations. We expect to adapt the SALS to a diverse range of chemistry experiments and non-laboratory applications. The SALS should allow a greater number of students who are blind and visually impaired to obtain their own observational data. Independent active learning in the laboratory may inspire these students to study science at more advanced levels, and ultimately to pursue careers in the STEM professions.

Acknowledgments

This work is part of the Independent Laboratory Access for the Blind (ILAB) project, supported by the National Science Foundation's Research in Disabilities Education program under grant HRD-0435656. Partial support for the project was also provided by the Pennsylvania State University Department of Chemistry and by the Penn State Learning Factory.

References

Burgstahler, S. (Speaker). (2005). *Equal access: Science and students with sensory impairment* (Cassette recording). Seattle, WA: Do-IT Center, University of Washington.

Code Factory. (2006). *Mobile speak*. Retrievd August 21, 2006, from http://www.codefactory.es/mobile_speak/mspeak.htm

Crosby, G. A. (1981). Chemistry and the visually handicapped. *Journal of Chemical Education, 58*, 206-208.

Flair, M. N., & Setzer, W. N. (1990). An olfactory indicator for acid-base titrations. *Journal of Chemical Education, 67*, 795-796.

Lunney, D., & Morrison, R. C. (1981). High technology laboratory aids for visually handicapped chemistry students, *Journal of Chemical Education, 58*, 228-231.

Miner, D. (2001). *Teaching chemistry to students with disabilities*. Washington, DC: American Chemical Society.

Pence, L. A., Workman, H. J., & Riecke, P. (2003). Disabilities: The role of a student laboratory assistant. *Journal of Chemical Education, 80*, 295-298.

Scadden, L. (2005). *Current status of people with disabilities in STEM education: A personal perspective*. Retrieved March 12, 2006, from http://rasem.nmsu.edu/Pdfs/symposium/scadden_s_nmsu_stem_paper.pdf

Supalo, C. (2002). Blind students can succeed in chemistry classes. *Future Reflections, 22*, 26-29.

Supalo, C. (2005). Techniques to enhance instructors' teaching effectiveness with chemistry students who are blind or visually impaired. *Journal of Chemical Education, 82*, 1513-1518.

Tallman, D. E. (1978). A pH titration apparatus for the blind student. *Journal of Chemical Education, 55*, 605-606.

Tombaugh, D. (1981). Chemistry and the visually impaired. *Journal of Chemical Education, 58*, 222.

Wilbraham, A., Staley, D., & Matta, M. (1995). *Addison-Wesley chemistry laboratory manual* (4th ed). Menlo Park, CA: Addison-Wesley.