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The Sound and Feel of Titrations: A Smartphone Aid for Color-Blind and Visually Impaired Students

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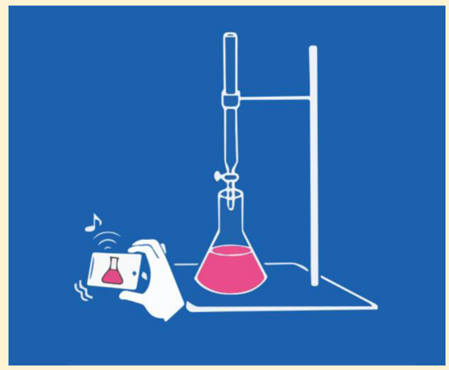
Supporting Information

ABSTRACT: An Android-based application has been developed to provide color-blind and visually impaired students a multisensory perception of color change observed in a titration. The application records and converts the color information into beep sounds and vibration pulses, which are generated by the smartphone. It uses a range threshold of hue and saturation coordinates of the HSV (hue, saturation, value) color space for detecting a color change specific to an indicator for, e.g., shades of pink for phenolphthalein-based titration, and informs the users before and upon attaining the end point. This approach can enable color-blind and visually impaired students to actively perform a fairly routine laboratory activity of titration.



KEYWORDS: *High School/Introductory Chemistry, Chemoinformatics, Computer-Based Learning, Hands-On Learning/Manipulatives, Titration/Volumetric Analysis, Minorities in Chemistry*

Chemistry, by nature, is a visual subject, and a laboratory setting can be a challenging environment for the color-blind and visually impaired (CVI) students to be self-supporting in carrying out their tasks.[1] Often, it is unfortunate that these students either choose to stay out of the chemistry laboratory by themselves, or face difficulties in actively participating in the laboratory activities, thereby relying on passive approaches of learning chemistry. Sometimes they depend on aid from their peers or labmates without visual problems for completing experiments involving colors.[2] Assistive technology that can translate a visual impact into other perceivable modes of senses can integrate these students in laboratory experiments, and open up new opportunities for them. Therefore, devising multisensory experimental approaches is crucial to enable the CVI students to gain a more purposeful, independent, and hands-on laboratory experience.

One of the several challenges that need to be addressed is the development of laboratory adaptations for enabling these groups of students to observe color changes in commonly performed experiments such as titrations.

Titration is a simple technique that involves finding an unknown concentration of a solution by reacting it with another solution of a known concentration. Conducting titration experiments is a routine task undertaken as part of high school and undergraduate chemistry laboratory curriculum. However, the end point, which is indicative of the completion of the reaction, is determined by a sharp color change because of the presence of an indicator. Therefore, this is not a viable activity for students with poor eyesight and for those who might be unable to perceive the color change due to color blindness. Previous studies addressing this problem have relied on a creative approach exploiting the sense of smell with olfactory indicators for observing an end point in an acid−base titration.[3−6] Additionally, several assistive tools and techniques have been developed in the past few years, for making laboratory experiments and chemical information accessible to visually impaired and students with special needs.[7−13]

Currently, a significant growth in the development of mobile learning environments is being observed. Hand-held devices, such as smartphones and tablets have become affordable and easily accessible to the student population throughout the world. A large number of chemistry-related applications, popularly termed as "apps", have been designed for hand-held devices.[14] A significant number of these apps are designed with an altruistic attitude without any commercial interest and are freely available to all. Development of assistive mobile technology to aid blind students in science, technology, engineering, and mathematics (STEM) is an ongoing effort. In recent years, some of the STEM-related apps included features such as an audio-enabled calculator,[15] use of devices like iPads for students with low vision to view classroom whiteboards clearly,[16] and an interactive audio−visual math tutoring app for middle school students with moderate visual impairments.[17,18] However, the number of chemistry-based "apps" that can be highly useful and an appealing learning method for visually impaired students is limited.

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In an attempt to extend the benefits of smartphones to a chemistry laboratory and to give a multisensory dimension to observe color changes, we designed and developed an Android-based application, the "Titration ColorCam" (TCC). The application uses the camera function of a smartphone to capture and quantify the information involved in a color change during a titration experiment. The quantified data is converted into both audio (beep sounds) and tactile (device vibration) feedback for the determination of an end point. Previously, various studies have employed audio feedback for aiding blind and visually impaired students for learning. These reports included audio-enabled conductivity and pH meters for titration,[19,20] audio information on the elements delivered through QR (Quick Response) code,[21] and also a sonified infrared spectrum.[22]

Also, we present a TCC-assisted titration end point detection laboratory method which can be beneficial to CVI individuals for performing an experiment. It can make the activity more engaging for sighted students.

■ METHODOLOGY

Development and Working of the Application

Titration ColorCam has been developed solely for the Android platform by Google Inc. The reasons for this are the ease of implementing Java programming language for application development, and the large market share of Android mobile devices.

In the past few years, built-in smartphone cameras have been used as digital color detectors.[23] In our app, color changes are quantified and detected by using color components of the HSV (hue, saturation, value) color space.

A summarized process scheme involved in the detection of color change includes the following steps:

1. The user chooses to point the camera near the area on the conical flask where the titrant is added dropwise to the titrand solution. The area viewed through a crosshair is stored by the camera function of the application when the device is pointed at the area of concern in the "record" mode.
2. The data stored in the stored pixel is converted to RGB (red, green, blue) values.
3. RGB data is then converted to the corresponding hex code value and HSV. The hex code is used to return the name of the detected color by cross-referencing with the color-name database.[24]
4. For a particular indicator, e.g. phenolphthalein, a hue coordinate (from HSV color space) range is specified. This range encompasses all the colors that can appear while performing titration using any of the commonly used indicators as given as an option in the app. Additionally, a saturation value (from HSV color space) threshold ensures that the app detects and responds to the color change above a certain background noise.
5. When the application signals a color change, the hue and saturation values of the detected color satisfy the conditions mentioned above. For notification of the change, the device generates beeps and vibration pulses. This auditory and tactile feedback assists a student to comprehend that a color change has occurred.

The screenshots (with added graphics for the beeps and vibrations) before starting the titration, close to the end point, and at the end of the titration are shown in Figure 1.

Capabilities

The list of indicators that can be used and the types of titrations which can be performed using the application are mentioned in Table 1. Apart from the mainstay aspect of TCC to translate color change into auditory and tactile feedback, we have implemented certain supplementary functions for the application to work as an analytical tool as well.

The user interface of the app features a tutorial for employing the application while performing a titration. An on-screen button is used to start and stop the application. For real-time data visualization, the RGB, hex code, HSV data, and the name of the detected color are displayed on-screen. When a color change is detected, a pop-up message appears on-screen. Also, it contains the functionality of continuously recording the color data within the application data in the device internal storage, a feature that can be useful for data analysis purposes. Additionally, the

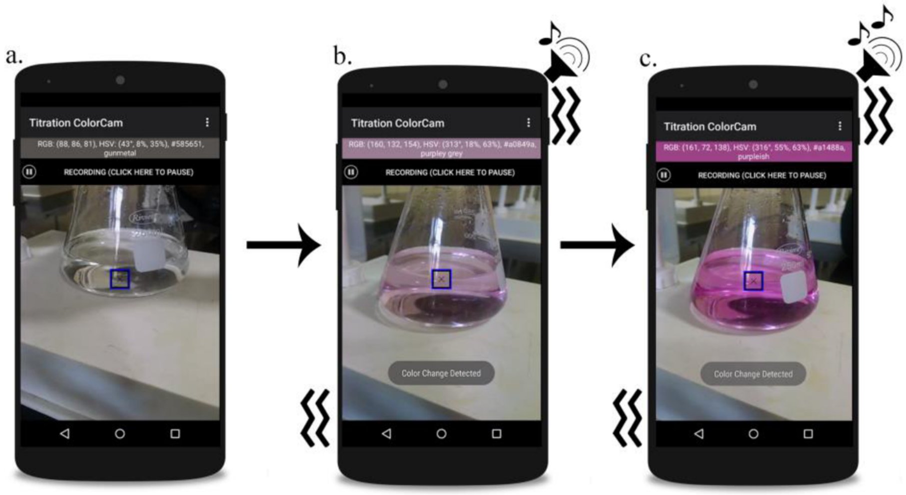

Figure 1. Screenshots while performing a titration using the Titration ColorCam (TCC) application. (a) Initial view before starting the titration. (b) Color of the solution as the end point nears. Short beeps and vibrations are generated upon appearances of pink color. (c) Persistent beeps and vibrations are generated on reaching the end point.

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Table 1. List of Indicators and Types of Titrations Supported by the Application

Name of the Indicator	Type of the Titration
Crystal violet	Acid−base
Cresol red	Acid−base
Thymol blue	Acid−base
2, 4-Dinitrophenol	Acid−base
Bromophenol blue	Acid−base
Methyl orange	Acid−base
Bromocresol green	Acid−base
Methyl red	Acid−base
Eriochrome black T	Complexometric
Bromocresol purple	Acid−base
Bromothymol blue	Acid−base
Phenol red	Acid−base
m-Nitrophenol	Acid−base
Phenolphthalein	Acid−base
Thymolphthalein	Acid−base
Starch	Redox

background color of the on-screen data display segment changes to the identified color.

■ DISCUSSION

The main motive for developing this app is focused toward enabling the visually impaired students to understand the perception of color changes through a modified multisensory chemistry laboratory experiment. The experiment involves the coordination of the hand-held device with the user through a feedback mechanism. The user slows down the addition of the titrant when the application responds with a beep and a vibration. Closer to the end point the number of beeps increases. An accurate detection of an end point by using the application is possible by responding to the sound and the vibration. The completion of the titration is indicated by a continuous sound and a prolonged vibration. This coordination between the user and the device can be improved by practicing and getting accustomed to the application. Through our application, a visually impaired student can autonomously perform a basic laboratory activity of titration with minimal assistance from their sighted peers. The error levels in the titer values obtained by using this application was compared to the ones obtained without using the app by a sighted student. The error levels were indeed comparable.

Here is a comment by an anonymous color-blind person who has used the app.

> *During an eye examination, I found out that I was color-blind. I see colors as a spectrum, and normally it is very difficult for me to name the color of an object. Particularly, I have trouble in distinguishing colors with overlapping hues (e.g., red and orange, or pink and purple). In my high school and undergraduate chemistry labs, I used to be mostly dependent on my sighted friends who would perform experiments involving color changes on my behalf. Although I have adapted to some extent to observe the color differences, I wasn't confident enough to perform an activity like titration that relies solely on observing a color transformation. Testing the Titration ColorCam app has been a wonderful experience for me. With a bit of training and instructions, I was able to perform the experiment independently. The beep sounds that the smartphone makes are a great method to alert for a color change and enable students like me to perform the experiment.*

Detection of a Titration End Point Using Titration ColorCam: Example of a Laboratory Activity

Caution must be taken for the experiments that involve acids, bases, and other corrosive chemicals. Proper laboratory training should be given to a student on the coordinated handling of a flask and controlling the drips from a buret prior to the introduction of the TCC app. For setting up a TCC-assisted titration experiment for the students, initial assistance from the teachers or a teaching assistant may be helpful for the demonstration of the application. It is recommended for a user to read the demonstration prior to using the application.

With a phenolphthalein-based titration as an example, the apparatus is set up against a white background in a room with sufficient ambient light. Fluctuation of light intensity in the titration flask may display erroneous false signals. Therefore, a light-source from the sides is always preferable compared to a top light-source. In a room with natural light, the apparatus is placed in a position where it faces the wall with the window to minimize the glare on the flask from sunlight (Figure 2). It is ensured that the device audio is set to a high volume and the vibration mode is turned on. The experiment is a two person activity. One person performs the titration, while the other person holds the device. For a hassle-free experiment, use of a tripod or a phone clamp to hold the device is recommended. Once the camera is on, the crosshair, i.e., the "x" mark on the screen, is directed to the center of the flask containing the titrand. It is important that the crosshair remains focused on the solution and should not point elsewhere during the swirling while performing the titration. Also, the smartphone device should be kept steady in a vertical position. When ready, the "Start Recording" button on the top part of the screen is clicked. The device generates beep sounds and vibration pulses with the appearance of tints of pink color in the flask. As the end point nears, the frequency of beeps−vibrations increases. At this point, the person performing the titration slows the drip rate. On reaching the end point, a long series of beeps will be heard and vibrations will be felt. At this instance, the dripping of the titrant is stopped, and the end point is noted. When completed, the "Pause Recording" button is clicked to stop. Several videos using various indicators have been provided as the Supporting Information. The suggestions for the

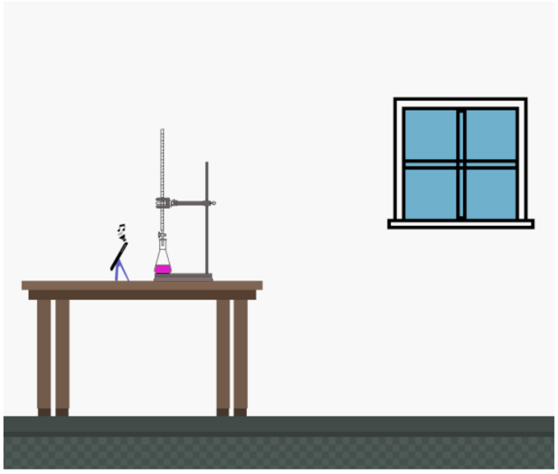

Figure 2. In a naturally lit lab, the titration apparatus and the smartphone (preferably on a tripod) should be placed in a position where the smartphone faces the wall with the window to minimize the direct light falling on the flask or the camera.

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setup for the experiments with the precautions have been provided in details in the Supporting Information.

CONCLUSION

Titration ColorCam can be freely downloaded from the Google Play Store on Android devices with platform version 2.2 and up. The detection of a titration end point using this application enables CVI students to participate independently in laboratory activities. The methodology presented can be effectively introduced to generate interest in science, technology, engineering, and mathematics (STEM) for students with visual impairments. The training process for getting acquainted with the application requires routine practice and concentration. Over time, it has promising potential to become a user-friendly mobile app to aid while performing a titration. In a future work, applications involving auditory−tactile feedback for other activities to aid CVI students will be an interesting challenge.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.7b00027.

- Instructions for using the application (PDF)
- Titration demonstration with app using phenolphthalein (AVI)
- Titration demonstration with app using bromocresol green (AVI)
- Titration demonstration with app using methyl red (AVI)
- Titration demonstration with app using erichrome black T (AVI)
- Titration demonstration with app using starch (AVI)

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Notes

The authors declare no competing financial interest.

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