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RESEARCH ARTICLE

APPLICATION OF A DIY RGB-COLOR MOBILE PHONE MICROSCOPE IN THE STUDY OF BIOLOGY

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Abstract. The microscope opens a window into the microscopic world, revealing details essential to the study of biology. However, it is typically costly and impractical for fieldwork. This research intends to develop a DIY RGB color enhancement for liquid and solid lenses to improve RGB color functionality, thereby supporting the application of mobile phones as microscopes in laboratories and fields. Lichens (family Graphidaceae), lichen moths (family Erebidae), and bagworms (family Tineidae) were selected as biological specimens for examination, and images were captured using liquid lenses, whereas the solid lenses consist of yeast (*Saccharomyces cerevisiae*), mung bean roots (*Vigna radiata* (L.)), and hydra (*Hydra* sp.). The experiment demonstrated that the liquid lens achieves a maximum magnification of 6.1X, while the solid lens reaches 100X magnification. Sample sizes suitable for studying liquid lenses range from 1 to 5 mm, whereas those for solid lenses range from 10 to 1000 µm. Therefore, liquid and solid lenses can serve as alternatives to stereo and compound light microscopes, respectively. The analysis of RGB values from photographs captured with liquid and solid lenses revealed statistically significant differences among specimens, particularly for those obtained using the green color filter. These images showed enhanced resolution, improved visualization of specimen features, and a sharper distinction between the specimen and the background. This study enables the creation of RGB color liquid and solid lenses using accessible and low-cost materials. These lenses can be applied to studies on biology and related specific fields, including zoology, plant biology, and microbiology. They facilitate the examination of the structures of animals, plants, and fungi, specifically in laboratories and fields.

Keywords: DIY lens, microscope, mobile phone, RGB color, biology.

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1. INTRODUCTION

The microscope has served as an important instrument in biology for centuries, facilitating scientists' ability to observe and examine diverse biological specimens. Microscopes are currently designed for specialized applications in science, engineering, and medicine. For instance, numerous types of microscopes are currently available, including light microscopes, electron microscopes, scanning probe microscopes, X-ray microscopes, confocal microscopes, fluorescence microscopes, polarized light microscopes, ultraviolet microscopes, infrared microscopes, and high-speed atomic force microscopes [1-4].

The light microscope, the most widely used tool in scientific research, is typically classified into two main types: stereo and compound microscopes. Stereo and compound microscopes are highly effective tools for direct visual examination of specimens, allowing researchers to observe fine structural details. In addition, these microscopes can be connected to external devices such as cameras or digital sensors, enabling the capture, storage, and analysis of high-resolution images for further study and documentation. The additional devices incorporate a wide range of technologies, including mobile phones, laptops, LED displays, and other digital devices. Nevertheless, both stereo and compound microscopes present significant limitations, notably with respect to their cost and suitability for field applications. In recent decades, a noticeable trend has developed in the fabrication of DIY microscopes. Consequently, do-it-yourself (DIY) microscopes have been developed, which can potentially be constructed using inexpensive or affordable materials. The development and application of DIY microscopes have expanded in multiple scientific disciplines, ranging from science education [5-10] to biomedical fields, including clinical pathology diagnostics [11-13]. Examples of potential DIY microscope projects include 3D printing DIY microscope kits [6], water droplet lenses [8], DIY fluorescence smartphone microscopes [9], LEGO brick-based microscopes [10], ball lens mobile phone microscopy [11], and paper microscopes or foldscopes [12].

The primary objective of DIY microscopes is to provide an alternative to conventional microscopes. Furthermore, the majority of DIY microscopes are compatible with cellphone cameras, enabling straightforward collection of specimen images. These devices are becoming increasingly convenient for use in various contexts, such as laboratories and fieldwork. DIY mobile device microscopes are useful as an example of illustration and have been designed and constructed in different designs and operational principles to comply with multiple user requirements and objectives.

The next step involves evaluating the primary elements of a DIY mobile phone microscope, which typically include lenses, light sources, and attachments for securing specimens for examination using a mobile phone camera. In research on DIY smartphone microscopes, an insignificant minority often fabricates their own lenses [6,10]. Nonetheless, they typically employed commercial lenses and concentrated on constructing attachments to interface with samples for mobile phone cameras [7,12] and utilized high-intensity light sources in fluorescence DIY smartphone microscopes for research in biology [9,11]. The use of multicolor filters in DIY mobile phone microscopes has been limited to biological observations.

Moreover, previous studies have primarily emphasized the development of low-cost, accessible devices for magnification, without integrating color filtration techniques to improve image visualization. To address this gap, the present study developed DIY RGB color mobile phone microscopes by fabricating liquid and solid lenses for integration with mobile phone cameras. This functionality enhances image contrast, highlights specimen features, and facilitates the differentiation of organisms with similar external characteristics.

2. MATERIALS AND METHODS

2.1 Liquid Lens

2.1.1 Fabrication of Liquid Lens

This study is an extension of the earlier project, A fixed shape within a liquid-formed lens [14], focusing on improving the construction and application of liquid lenses. Figure 1 shows the overall components of the microscopes used in this study and the application of both liquid and solid lenses in connection with a mobile phone camera. We designed and fabricated the lens using a transparent acrylic sheet with a thickness of 1 mm and dimensions of 30 cm x 30 cm. A hot air blower, set to a temperature range of 100 - 200 °C, was used to gradually soften the acrylic sheet after it was cut to 2 cm x 2 cm. A convex lens was then formed by placing 7.5 mm spherical steel balls with a 2 mm curvature at the center of the acrylic sheet, followed by gradual cooling. Next, a separate 2 mm thick acrylic sheet measuring 2 cm x 12 cm was prepared, and the two acrylic sheets were adhered together using superglue. Next, a hole approximately 1 cm wide is created by applying pressure with a fabric sewing needle on the upper edge of one half of the convex lens. To fabricate the acrylic sheets with a clothespin, a hot air blower is used to soften the center of the sheets. A pencil is positioned, and the edges of the two sheets are bent toward the opposite sides, maintaining a gap of approximately 1 cm (Figure 1A).

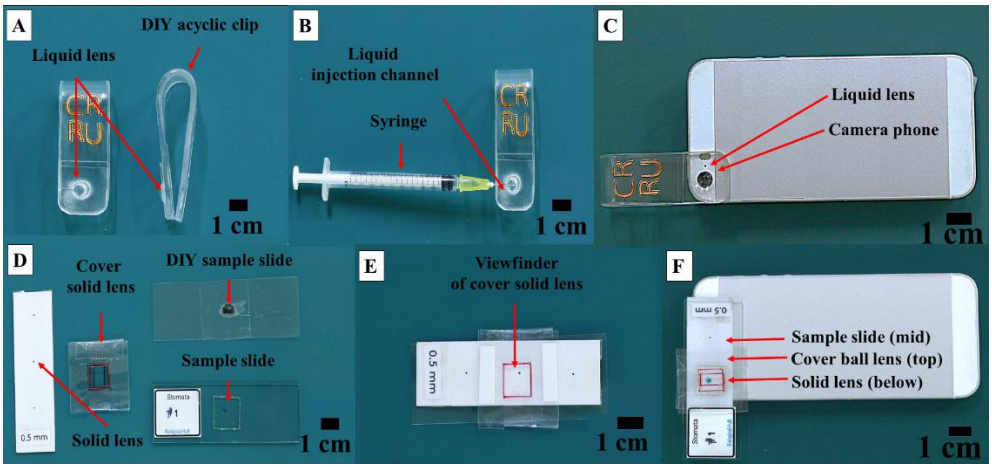

Figure 1: The liquid lens components include the process of introducing liquid into the lens body (A, B); the solid lens components consist of the assembly (D) and the completed solid lens (E). The application of both lens types with a mobile phone camera is shown for the liquid lens (C) and the solid lens (F)

2.1.2 RGB Color in Liquid Lens

The liquid applied to fill the lens is glycerin, with a refractive index of 1.50. This study employed 0.05 mg of powdered red, green, and blue food coloring combined with 5 ml of glycerin. Subsequently, combine and shake until the food color is fully dissolved in the glycerin, relying on red, green, and blue glycerin. The liquid used to fill the lens consists of natural glycerin, red glycerin, green glycerin, and blue glycerin.

2.1.3 The Process of Injecting Liquid Into the Lens and Utilizing a Mobile Phone Camera

A 1 ml syringe fitted with a 30 G x ½" (13 mm) needle was used to extract 0.2 - 0.5 ml of glycerin or glycerin mixed with RGB colors. The needle tip was inserted into the lens chamber through

the circular opening between the lens edge and the transparent acrylic plate (Figure 1B). The liquid was introduced slowly to prevent air bubble formation. After filling, the syringe was carefully withdrawn, and excess liquid was removed with tissue to ensure the lens was filled. Finally, an acrylic sheet secured with a clothespin was placed over the mobile phone camera to attach the liquid-filled lens, aligning the lens center with the camera for sample observation or imaging (Figure 1C).

2.2 Solid Lens

2.2.1 Fabrication of Solid Lens

In the fabrication of solid lenses using glass, glass bottles are cut into pieces measuring approximately 2 x 5 cm. These glass fragments are then heated with a firebird torch fueled by 375 ml of Buga flame gas at temperatures ranging from 300 to 1500 °C. Using forceps, the end of each glass strip is grasped and stretched to a length of 3 - 5 cm. The extended end is then manipulated in the flame while rotating to form a spherical shape, resulting in a ball lens with a diameter of approximately 0.5 mm.

2.2.2 Assemble the Elements of a Solid Lens for Application In Microscopy

Two sheets of A4 adhesive paper, each 0.5 mm thick and measuring 2 x 14 cm, are prepared. Both ends of each sheet are folded toward the center to form a 2 x 7 cm sheet. A hole is drilled at the center of each sheet, and the glass lens is inserted into the aperture. The adhesive backing is removed, and the paper is folded to cover the solid lens (Figure 1D). Next, a cover for the solid lens is fabricated by cutting a transparent sheet 0.5 mm thick into 3 x 9 mm pieces. Three sets of apertures are created on the sheet: two square apertures (1 x 1 cm) positioned 1 cm from the edge and two rectangular apertures (0.5 x 1 cm) at the center. The translucent sheet is then folded along the sides of the square and rectangular apertures, connecting at the centers. Finally, tape is applied to secure the folded edges and conceal the creases on the lens sheet.

2.2.3 RGB Color Filter in Solid Lens

Permanent markers are used to apply red, green, or blue colors to the opposite side of the sample, transforming the DIY or standard slide into an RGB color filter. The color is applied to ensure adequate coverage over the area of interest. Once the ink has dried and adhered to the slide, the RGB filter-equipped slide is ready for analyzing specific biological or scientific samples.

2.2.4 Applying a Solid Lens Installed With an RGB Color Filter in Connection With a Mobile Phone Camera

A transparent adhesive tape, 0.5 cm wide and 6 - 7 cm long, is affixed to the solid lens cover, either vertically or horizontally, to connect the lens to a mobile phone camera. The viewfinder of the solid lens cover is adjusted to optimize visibility of the lens, sample slide, and camera (Figure 1E). The solid lens sheet is then positioned inside the cover, with the sample placed at the front using either natural color or an RGB color filter. This setup allows vertical, horizontal, or lateral adjustment of the lens sheet and sample slide to obtain the desired specimen view (Figure 1F). Visibility of sample variations can be enhanced using sunlight or artificial light as the background.

2.3 The Biological Samples

The examination and visualization of specimens within a liquid lens consisted of one group of lichens (family Graphidaceae), one lichen moth (family Erebidae), and one bagworm (family Tineidae). All specimens were documented in their natural environments, ensuring they remained undisturbed and

in their original locations. The investigation and photography of specimens using solid lenses required fresh specimens organized on standard slides, including one yeast colony (*Saccharomyces cerevisiae*) and roots from ten mung bean seedlings (*Vigna radiata* (L.)). In addition, one unstained permanent slide of hydra (*Hydra* sp.) was obtained from the Biology Program, Faculty of Education, Chiang Rai Rajabhat University.

2.4 Equipment Settings, Image Capture Details and Scale Calibration

The experimental setup for the liquid lens relies on using an iPhone 5 equipped with an 8-megapixel resolution and an *f*/2.4 lens aperture. For imaging, laboratory conditions used illumination of 300 - 700 lux and room temperatures of 25 - 30 °C, with the camera set to ISO 400 - 800, shutter speed 1/60 - 1/125 s, and white balance 4000 - 4500 K, whereas field conditions used illumination of 400 - 1,000 lux and temperatures of 30 - 37 °C, with the camera set to ISO 100 - 200, shutter speed 1/60 - 1/125 s, and white balance 5200 - 5500 K. Images were captured by deploying a mobile phone camera in conjunction with a liquid lens featuring a diameter of 7.5 mm and a radius of curvature measuring 2.0 mm. Before collecting images, we position a 10 mm scale slide next to the specimen to provide a scale reference for the photographs. This procedure is necessary for the assessment of the true dimensions of the specimen, along with scale calibration to incorporate a scale bar in the images. The photograph was captured at a distance of approximately 10 - 15 cm, and no digital zoom was employed during the image capture process. Following the capture of images with the mobile phone camera, the true dimensions of the samples were assessed by comparing a ruler against the mobile phone display. We then used the values from the images to calculate the magnification of the liquid lens (4). The Zeiss Primo Star standard microscope was used to observe the samples, providing a magnification of 400X, with images captured via a mobile phone camera. Additional specimens were observed using the DIY solid lenses, each 0.5 mm in diameter, also integrated with a mobile phone camera for imaging. The collected samples include images at 400X magnification from a microscope, without and with RGB color filters (red, green, and blue). To ensure accurate measurement and calibration of the solid lens images, a stage micrometer of 1 mm (1000 μm) was used as a reference and compared with an ocular micrometer with 0.01 mm (10 μm) divisions. This calibration allowed precise measurement of specimen dimensions and proper alignment of the scale bar in the captured images.

2.5 RGB Color Measurement and Statistical Analysis

RGB color values were obtained from specimen photographs captured with the liquid lens using GIMP software version 2.10.36. These images were snapped with an uncolored glycerin lens, in addition to glycerin combined with red, green, and blue color filters. Specimens imaged with the solid lens were photographed both with and without RGB color filters, and the results were compared to images obtained using a standard 400X microscope objective. The RGB values were determined using the color pickup tool, which sampled pixel values from five specific locations: top-right, top-left, bottom-right, bottom-left, and the middle of the image. The software computed the RGB values by employing a sample average with a radius of 100, producing the average RGB values for the whole image. The RGB values from each gathered photograph were analyzed to ascertain the differences in color proportions. For comparisons between images captured with and without each RGB color filter, independent t-tests were conducted for each color (red, green, and blue) to assess whether the filter significantly altered the respective color intensity.

2.6 The Principles of Physics and Calculating Magnification

The statement delineates a relationship between specific lens features, the object distance (p), and the image distance (q) of an image produced by a thin lens. Consider a lens characterized by an index of refraction (n) and two spherical surfaces with radii of curvature (R_1 and R_2). Furthermore, R_1 represents the radius of curvature of the lens surface that first encounters light from the object, whereas R_2 signifies the radius of curvature of the lens against an opposite surface [15].

Figure 2 illustrates ray diagrams showing the propagation of light in accordance with the lens maker's equation for both a liquid lens and a solid lens. The creation of a concave lens by combining two convex lenses (Figure 2A) can potentially clarify the light's pathway from the source through the aperture of the convex lens (the thin lens). Light enters the lens from the side characterized by a radius of curvature (R_2) and a center of curvature (C_2), subsequently passing into another concave lens on the side defined by a radius of curvature (R_1) and a center of curvature (C_1). Subsequently, the light beams converge at the focal point, denoted as point *f*.

The lensmaker's equation presents a mathematical depiction of the relationship [16]:

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad (1)$$

According to the sign convention for refraction at a curved surface, the radius (R) is considered positive if the center of the sphere is located to the right of the vertex and negative when it is situated to the left. Consequently, if the center of the sphere is positioned on the left, $R < 0$; if it is centered on the right, $R > 0$.

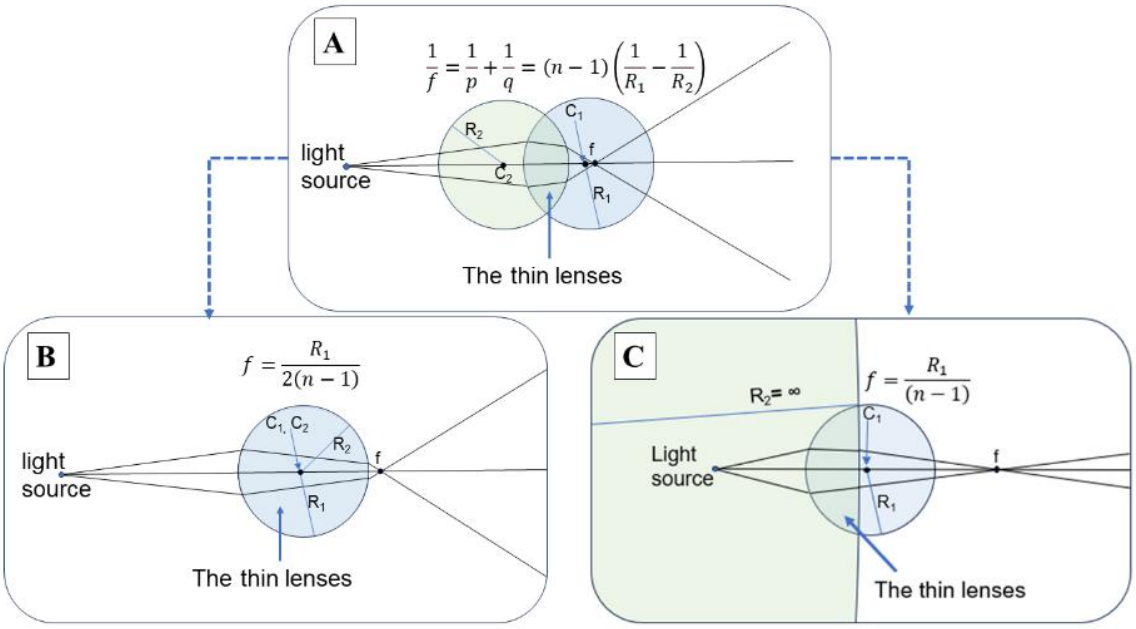

Figure 2: Ray diagrams depict the propagation of light according to the lens maker's equation: (A) when $R_2 = \infty$ in a liquid lens, (B) in the case of a liquid lens with $R_2 = -R_1$, and (C) in a solid lens

2.6.1 Liquid Lens

The focal lengths of the liquid lenses fluctuate according to the liquids enclosed in them. In this experiment, we used glycerin with a refractive index (n) of 1.47. The measured focal lengths were compared with the calculated values. To determine the focal length of a liquid lens, utilize the inverse of the focal length (f) applicable to a thin lens. Figure 2B illustrates that the liquid lens possesses a constant plano-convex configuration, with R_1 and R_2 established at infinity for all positions. Thus, the focal length can be determined using Equation (2):

$$f = \frac{R_1}{(n-1)} \quad (2)$$

2.2.2. Solid Lens

The solid lens maintains a spherical shape, with R_1 and R_2 consistently equal to -R_1 at all points (Figure 2C). Therefore, the focal length can be calculated via Equation (3):

$$f = \frac{R_1}{2(n-1)} \quad (3)$$

Magnification is commonly measured when examining a lens through which light rays from an object traverse, employing both liquid and solid lenses. The geometric structure illustrates the lateral magnification of the image, denoted as M, according to Equation (4):

$$M = \frac{h\prime}{h} = -\frac{q}{p} \quad (4)$$

In this equation, h' defines the height of the image produced by the lens, whereas the value h represents the height of the original object. The negative symbol signifies that the image generated is inverted in relation to the object. Lateral magnification is directly proportional to the ratio of image distance (q) to object distance (p) from the lens. Following the capture of images using the mobile phone camera, the actual dimensions of the samples were assessed by overlaying a ruler with the phone screen. The recorded values obtained from the images were later utilized to compute the magnification of both the liquid and solid lenses (4).

3. RESULTS AND DISCUSSION

3.1 DIY RGB Color Mobile Phone Microscopes and Applications in Biological Specimens

The experiment successfully demonstrated the viability of integrating liquid and solid lenses with mobile phones for microscopy applications. The lens manufacturing technique focused on the use of cost-effective materials easily accessible in common supermarkets and stationery stores. Additionally, accessible housing or recycled materials can also be employed in the production of lenses and related lens components. The manufacturing expenses for DIY lenses are approximately $0.20 for a single liquid lens and $0.50 for a solid lens. In comparing the budget for this study with previous research on DIY mobile phone microscopes, which followed specific financial parameters, it was found that the cost was similar to that of the Foldscope by Cybulski et al. [12], developed at a budget of $1.16. Budget allocations vary significantly between the mobile phone microscope applying a reversed ball lens developed by Switz et al. [13], which operated on a budget of $6, and the smartphone fluorescence microscope created by Schaefer et al. [7], with a total budget of $50. The integration of mobile phone microscopes in DIY smartphone microscope projects presents challenges due to the variability in materials implemented in component fabrication across different research initiatives. A comparison of the budget with preliminary studies provides a useful reference and framework for future DIY phone microscope projects.

This study selected glycerin as the liquid lens because of its greater refractive index (n) relative to other liquids, including plain water (n = 1.33) and vinegar (n = 1.30). An increase in refractive index

leads to a shorter focal length, resulting in greater magnification [17]. Furthermore, glycerin significantly diminishes air bubble formation during the injection process and ensures stability within the lens. The fabrication of solid lenses employed bottle glass, yielding a refractive index exceeding 1.50. The variation is attributed to increased magnification and improved image clarity. The refractive index of bottle glass is comparable to that of borosilicate glass (n = 1.50 - 1.51) but is lower than that of crystal glass (n = 1.70) [5].

The focal length of the liquid lens was calculated to be 8.0 mm, providing a magnification of 6.1X. In contrast, the solid lens has a diameter of 0.5 mm, a focal length of 0.2 mm, and provides a magnification of 100X. The lens diameter showed a negative correlation with magnification and a positive correlation with both diameter and focal length. As magnification increases, both the focal length and diameter of liquid and solid lenses decrease [18]. A reduction in lens diameter results in a decreased radius of curvature, leading to an increased angle of light refraction and enhancing magnification power [15]. The measured lens diameter and magnification results are closely compatible with those reported in previous research, specifically the types consisting of commercial sapphire ball lenses of 0.3 mm in diameter [12]. The lens size utilized in this study is considerably smaller than the diameters of other DIY lenses specified in earlier studies, with particular examples measuring 1 mm [9], 2 mm [5], and 6 mm [13]. The magnification values obtained in this study were significantly lower than those reported in other studies. Previous research has shown magnifications of 100X in agarose material, 171X in borosilicate glass, and 208X with crystal glass [5], and a solid lens with a maximum magnification of 350X [9]. While the achieved magnification is lower than that of other studies, a comparison of image sizes captured with the solid lens and those from a microscope camera at 400X magnification indicates that it is sufficient for the scientific examination of specimens measuring between 10 and 1000 µm. When samples are smaller than 10 µm, digital zoom on mobile phones can enhance specimen visibility, facilitating a more comprehensive examination. Thus, the magnification of the liquid is effective for analyzing the details and overall characteristics of samples measuring between 1 and 5 mm. These lenses facilitate the photography of living or preserved animal and plant specimens on slides, and they are also employed for the study of small vertebrates, invertebrates, and microorganisms in both the laboratory and the field.

Photographs captured with liquid lenses exhibited lichen (Family Graphidaceae), lichen moth (Family Erebidae), and bagworms (Family Tineidae), while those captured with solid lenses contained yeast (*Saccharomyces cerevisiae*), mung bean (*Vigna radiata* (L.)), and hydra (*Hydra* sp.). The photos captured with the glycerin-infused lens provide enhanced viewing of specimen capabilities compared to images acquired with a mobile phone camera with magnification. Nevertheless, an ambiguous separation remained between the specimen and the background of the image. Figure 3 depicts photographs of lichen, lichen moths, and bagworms captured with a liquid lens connected to a mobile phone camera. The lens containing green glycerin yielded the most effective visualization of lichen line patterns (Figure 3A), urticating hairs of the lichen moth (Figure 3B), and the silk-lined bag of the bagworm (Figure 3C). Consequently, the blue and red hues exhibit substantially reduced clarity because the captured images are largely dominated by blue and red colors, which obscure the fine details of the specimens. Photographs taken with a solid lens devoid of color filters and dye stains provide a general perspective of the object, although they lack distinct features.

Figure 4 shows photographs of yeast, mung bean root, and hydra captured with a solid lens in connection with a mobile phone camera. The green color filter displayed the clearest vision of yeast colonies (Figure 4A), the xylem of mung bean roots allowed for the transfer of water (Figure 4B), and the tentacles of hydra assisted in movement and prey capture (Figure 4C). Nevertheless, the blue and red color filters exhibited inadequate clarity.

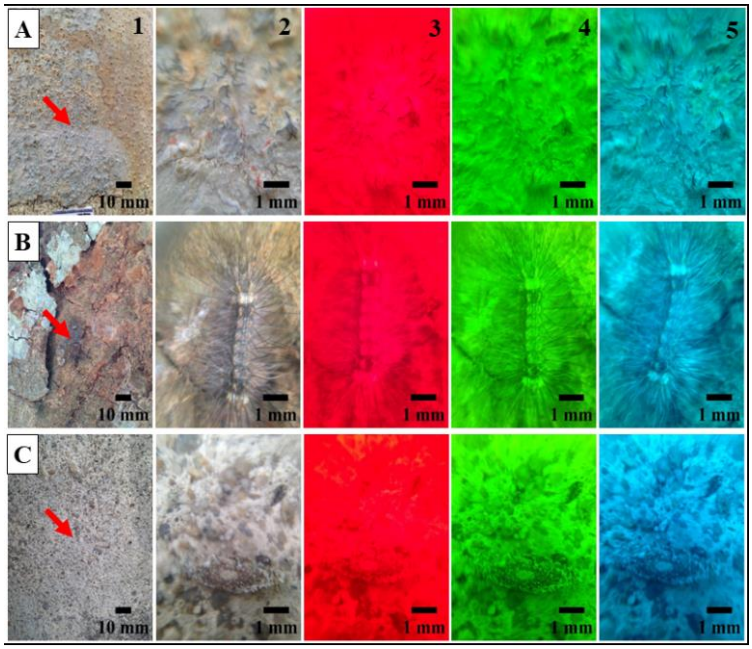

Figure 3: Photographs of lichen (A), lichen moths (B), and bagworms (C) were captured using a mobile phone camera without zoom (Column 1) and with a liquid lens containing glycerin (Column 2) and glycerin mixed with red (Column 3), green (Column 4), and blue (Column 5) color filters. Arrows indicate the positions of the specimens in each image

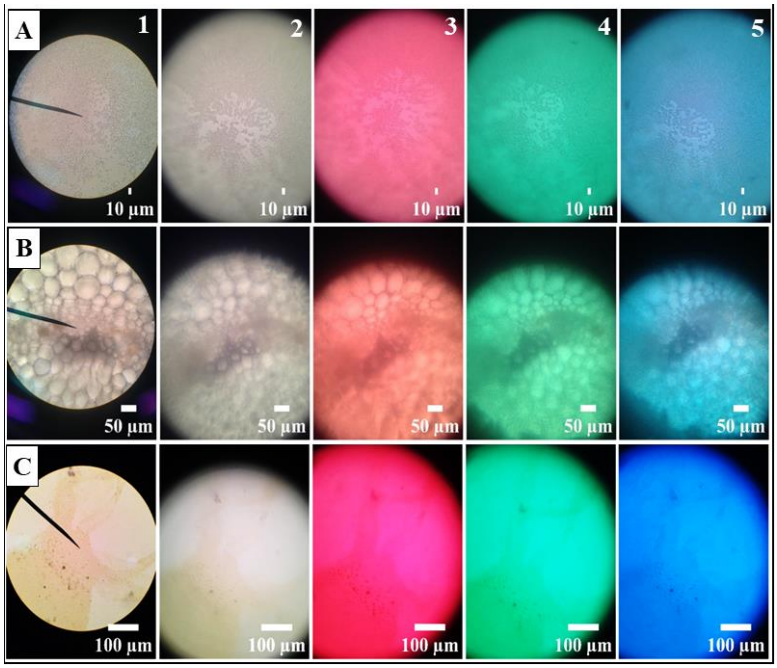

Figure 4: Images of yeast (A), mung bean root (B), and hydra (C) were obtained under different conditions: with a 400X light microscope (Column 1), using a 0.5 mm diameter solid lens without a color filter (Column 2), and with the solid lens combined with red, green, and blue color filters (Columns 3-5), respectively

3.2 RGB Color in DIY Mobile Phone Microscopes

Table 1 presents the RGB color examination of images captured from specimens without and with RGB color filters. The RGB analysis demonstrated that the green color consistently increased in images captured with the RGB green filter compared to those without filters. For example, lichen specimens showed an increase from 149 ± 14 to 209 ± 13, lichen moths from 137 ± 24 to 193 ± 19, bagworms from 146 ± 12 to 200 ± 44, and yeast from 156 ± 6 to 179 ± 19. In contrast, mung bean roots decreased from 209 ± 24 to 168 ± 21, and hydra from 195 ± 9 to 151 ± 14. Red and blue channels showed only minor differences across all specimens. The green color filter showed a significant increase compared to images without a filter (lichen: $t = -8.21$, $df = 9$, $p < 0.05$; lichen moths: $t = -3.7$, $df = 8$, $p < 0.05$; bagworms: $t = -2.63$, $df = 8$, $p < 0.05$; yeast: $t = -2.25$, $df = 8$, $p < 0.05$; mung bean root: $t = -2.91$, $df = 8$, $p < 0.05$; hydra: $t = -2.44$, $df = 8$, $p < 0.05$). In contrast, the red and blue color filter showed no significant differences for any specimen ($p > 0.05$). These results indicate that the green color filter consistently enhances the visibility of specimen features. By emphasizing the green color, fine structural details, edges, and textural differences become more distinguishable, facilitating observation and identification.

Table 1: Average RGB color values obtained from images captured without and with RGB color filters.

	Images without RGB color filters			Images with RGB color filters		
Sample	Red	Green	Blue	Red	Green	Blue
Lichen	157 ± 14	149 ± 14	132 ± 17	166 ± 9	209 ± 13	130 ± 14
Lichen moths	139 ± 21	137 ± 24	134 ± 16	140 ± 16	193 ± 19	141 ± 20
Bagworms	145 ± 14	146 ± 12	146 ± 14	157 ± 9	200 ± 44	148 ± 12
Yeast	167 ± 11	156 ± 6	150 ± 7	169 ± 14	179 ± 19	156 ± 9
Mung bean root	194 ± 15	209 ± 24	173 ± 18	198 ± 7	168 ± 21	167 ± 42
Hydra	193 ± 15	195 ± 9	172 ± 12	195 ± 16	151 ± 14	158 ± 12

Figure 5 shows a comparison of the operation of the liquid and solid lenses without and with RGB color filters. The experiment indicated that the presence of natural glycerin in the liquid lens and the absence of a color filter in the solid lens facilitate the examination of the specimens. The enhancement of the distinction between the specimen and the background is inadequate (Figure 5A, C).

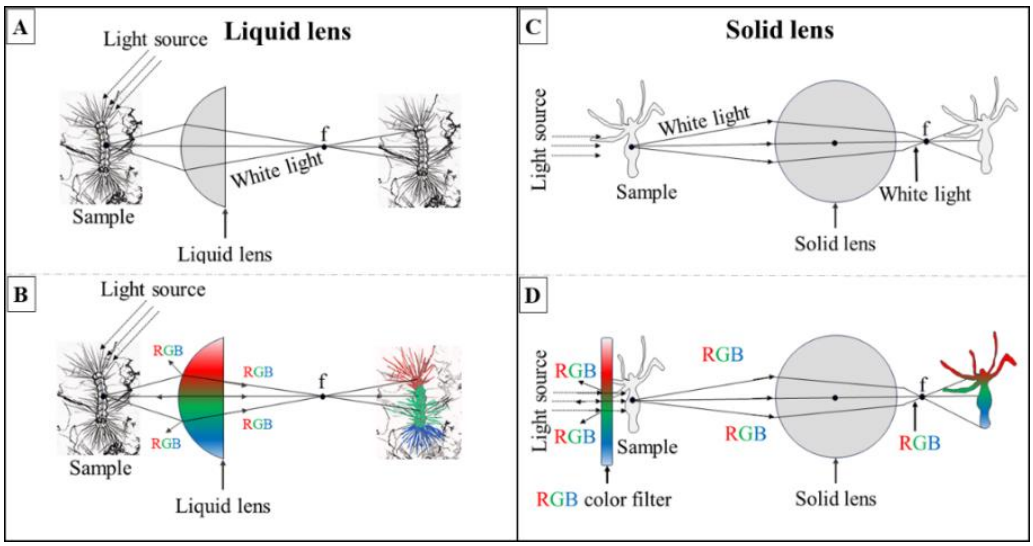

Figure 5: The diagrams illustrate the operation of the liquid lens (A) compared to the RGB color filter in the liquid lens (B), and the solid lens (C) compared to the RGB color filter in the solid lens (D)

Our research indicated that adding RGB color to glycerin and then putting it into the liquid lens improves the magnification of specimen images while keeping the original properties and making it easier to see the details of the specimen. This result is additionally in agreement with the documented RGB color values. In samples where RGB color was not employed for the liquid and solid lenses, the RGB values were relatively similar. This data indicates that the RGB colors are uniformly distributed within the image, contributing to a consistent distribution of RGB colors across both the specimen and the backgrounds. The colors exhibit homogeneity, making it impossible to differentiate between specimen and background details. It was observed that the RGB values in the sample photos increased in accordance with the color applied during the experiment when RGB color was utilized on both liquid and solid lenses. The application of green colors between liquid and solid lenses produced significantly higher green color values compared to red and blue colors. Figure 5 (B, D) illustrates that RGB color light emitted from the specimen traverses the RGB color filter in the liquid lens, thereby decreasing light reflection and minimizing transmission loss. This approach produced a significant enhancement in the clarity of specimen details. The RGB color light from the specimen is subtracted as it passes through the solid lens. The sequential process enhances the probability of reduced light and scattering during transmission (Figure 5D). The study and experimental results correspond with findings from investigations utilizing monochromatic red, green, and blue filters.

In studies involving mouse embryos, cricket stomachs, and gnats, the use of monochromatic green filters consistently enhanced sharpness, clarity, and contrast across various microscopic conditions. The green wavelength (540 nm) generates the highest contrast among the various colors in the material, therefore improving image visibility. The green color contrasts with most colors in the specimen image, excluding green and yellow. The colors identified are red, orange, blue, purple, black, gray, and brown [19]. In addition to analyzing the RGB colors of the specimen and its background, it is also essential to investigate the specimen's absorption and reflection spectrum. This factor affects the selection of color filters to enhance specimen clarity. A study by Scafide et al. [20] found that yellow light filters with wavelengths of 415 and 450 nm are better than white light at finding bruises on the skin because hemoglobin has a narrow absorption peak within these wavelengths. Integrating RGB color into liquid and solid lenses for scientific specimen imaging enhances clarity in specimen details. Moreover, it enables specimens to display multiple colors while enhancing the distinction between the specimen and the background. The RGB color can minimize the sample preparation method by reducing the requirement for chemical staining and the time necessary for staining, thus facilitating the examination of specimens as required. The application of RGB color in both liquid and solid lenses enhances the examination of scientific specimens in laboratory and fieldwork.

4. CONCLUSIONS

This study developed affordable liquid and solid lenses with RGB color filters for mobile phone microscopy. The liquid lens was effective for macroscopically observable specimens, such as lichens, lichen moths, and bagworms, whereas the solid lens was suitable for microscopic specimens, such as yeast, mung bean roots, and hydra. In both lens types, the green filter consistently enhanced image clarity, making fine details, edges, and textures more distinguishable than with red or blue filters. These results demonstrate that RGB-enhanced DIY lenses can provide a practical alternative to conventional microscopes, broadening access to microscopy for the study of plants, animals, and microorganisms.

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Author Contributions

All authors contributed toward data analysis, drafting and critically revising the paper and agree to be accountable for all aspects of the work.

Disclosure of Conflict of Interest

The authors have no disclosures to declare

Compliance with Ethical Standards

The work is compliant with ethical standards

References

[1] Van Wees, L., Singh, A., Obstalecki, M., Shade, P., Turner, T. & Kasemer, M. (2023). An assessment of polarized light microscopy as a characterization method for crystal plasticity simulations. *Materialia*, *31(4)*, 101872.

[2] Sanderson, J. (2020). Fundamentals of microscopy. *Current Protocols in Mouse Biology*, *10(2)*, 1-30.

[3] Inavalli, V. V. G. K., Muñoz, V. P., Draffin, J. E. & Tønnesen, J. (2024). Fluorescence microscopy shadow imaging for neuroscience. *Frontiers in Cellular Neuroscience*. *18*, 1330100.

[4] Fang, K., Yatim, M. M. & Nor, N. S. M. (2022). Ultrastructural morphology study and optimization of growth conditions for *Leptospira interrogans*. *Malaysian Journal of Microscopy*. *19(2)*, 119-130.

[5] Flores, D. P, & Marzullo, T. C. (2021). The construction of high-magnification homemade lenses for a simple microscope: an easy "DIY" tool for biological and interdisciplinary education. *AJP Advances in Physiology Education*. *45(1)*, 134-144.

[6] Grier, Z., Soddu, M. F., Kenyatta, N., Odame, S. A., Sanders, J. I., Wright, L. P. & Anselmi, F. (2018). A low-cost do-it-yourself microscope kit for hands-on science education. In Optics Education and Outreach V Proceeding of SPIE, United States, 14 Sept 2018.

[7] Schaefer, M. A., Nelson, H. N., Butrum, J. L., Gronseth, J. R. & Hines, J. H. (2023). A low-cost smartphone fluorescence microscope for research, life science education, and STEM outreach. *Scientific Reports*. *13(1)*, 2722.

[8] Myint, H. H., Marpaung, A. M., Kurniawan, H., Hattori, H. & Kagawa, K. (2001). Water droplet lens microscope and microphotographs. *Physics Education*. *36(2)*, 97-101.

[9] Smith, Z. J., Chu, K., Espenson, A. R., Rahimzadeh, M., Gryshuk, A., Molinaro, M., Dwyre, D. M., Lane, S., Matthews, D. L. & Wachsmann-Hogiu, S. (2011). Cell-phone-based platform for biomedical device development and education applications. *PLOS One*. *6(3)*, e17150.

[10] Vos, B. E., Blesa, E. B. & Betz, T. (2021). Designing a high-resolution, LEGO-based microscope for an educational setting. *The Biophysicist*. *2(3)*, 29-40.

[11] Breslauer, D. N., Maamari, R. N., Switz, N. A., Lam, W. A. & Fletcher, D. A. (2009). Mobile phone based clinical microscopy for global health applications. *PLOS One*, *4(7)*, e6320.

[12] Cybulski, J. S., Clements, J. & Prakash, M. (2014). Foldscope: origami-based paper microscope. *PLOS One*. *9(6)*, e98781.

[13] Switz, N. A., D'Ambrosio, M. V. & Fletcher, D. A. (2014). Low-cost mobile phone microscopy with a reversed mobile phone camera lens. *PLOS One*. *9(5)*, e95330.

[14] Kaewpanus, K. & Thepnurat, M. (2018). Fixed shape inside liquid-formed lens for apply on stereo microscope. In Proceedings of the 35th MST International Conference, Thailand, 30 Jan-2 Feb 2018.

[15] Serway, R. A. & Jewett, J. W. (2014). The Nature of Light and The Principles of Ray Optics. In *Physics for scientists and engineers, with modern physics,* 9th Ed. Ed. Serway, R. A. & Jewett, J. W. (Cengage learning, Boston), pp. 1057-1089.

[16] Gallegos, J. & Stokkermans, T. J. (2023). Lensmaker's Equation. In: StatPearls. Treasure Island, StatPearls Publishing, [Online]. [Accessed 15th July 2024]. Available from World Wide Web: https://www.ncbi.nlm.nih.gov/books/NBK594278/

[17] Laskar, J. M., Kumar, P. S., Herminghaus, S., Daniels, K. E. & Schröter, M. (2016). High refractive index immersion liquid for superresolution 3D imaging using sapphire-based aplanatic numerical aperture increasing lens optics. *Applied Optics*. *55(12)*, 3165-3169.

[18] Tang, V. D., Stokkermans, T. J. & Zhang, A. Y. (2023). Focal length. In: StatPearls. Treasure Island StatPearls [Online]. [Accessed 17th July 2024]. Available from World Wide Web: https://www.ncbi.nlm.nih.gov/books/NBK597385/.

[19] Piper, J. (2008). Multicolor contrast effects by monochromatic astronomic filters - utilization in light microscopy and photomicrography. *Microscopy Today*. *16(5)*, 20-27.

[20] Scafide, K. N., Sheridan, D. J., Downing, N. R. & Hayat, M. J. (2020). Detection of inflicted bruises by alternate light: results of a randomized controlled trial. *Journal of Forensic Sciences. 65(4)*, 1191-1198.