Cell Phone Still and Video Photomicrography: A Deeper Dive

Applications in outreach, educational and general microscopy

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Cell phone cameras and microscopes? Really? You CAN'T be serious…
- Anonymous

As is often the case with new technologies, my first encounter with cell phone photomicrography was at the hands of kids. Specifically, the two twelve-year-old girls who introduced me to the method. I owe them an extreme debt of gratitude for opening my eyes to what cell phone cameras can do when used with microscopes.

In October, 2010, I had a microscope display set up at a Science Technology Engineering and Math (STEM) outreach program in Riverside, California. I was at the Science and Technology Education Partnership (STEP) Conference (1) at the Riverside Convention Center. STEP is a very popular program where elementary, middle and high school kids are treated to hands-on displays from many areas of science and technology. Through generous grants from the participating sponsors, the kids, their teachers and chaperones, are brought to the conference by bus at no cost to them or their school districts. It is so popular that the 5,500 reserved student slots were filled up in eight hours for the 2015 conference.

It was my good fortune that the two aforementioned kids were much more comfortable with some of the available technologies than I. After looking through the microscopes at the specimens I had on display, they both whipped out their cell phones and proceeded to take pictures through the eyepieces.

I was pretty stunned, as it had never occurred to me to try that!

Why? I had a real camera for photomicrography.

I asked to see the results and was quite impressed with what they had captured. I whipped out my own cell phone, and took one too. Then another...

Fast forward toward the end of 2011. On the photomacrography.net forum I saw a link to a Kickstarter campaign to fund development and production of an adapter called Skylight (2), to facilitate cell phone camera use on a microscope. I was quite excited as it would solve the biggest problem with cell phone photomicrography, that of holding the phone in proper alignment while shooting. I contacted the designers and was fortunate to be allowed to test their prototype at another outreach event. I was impressed at how nicely it held the phone in place.

The Skylight worked well, but was designed for the smaller iPhone sized smart phones. Unfortunately for the designers, its introduction coincided with the advent of larger smart phones that didn't work with it, and their design was rather inflexible. I even had to take the case off of my Droid Charge to get it to fit properly. As a result of the compatibility problems, production stopped after the first run, and they are no longer available. I kept several I had bought on Kickstarter for outreach, demonstrating them to students, teachers and some clinical laboratory folks until I donated the last one earlier this year.

The Skylight was not something that could be rapidly installed and removed, so usually I didn't mount it on a microscope for the displays. Mounted, it made visual use of the scope problematic. Instead, I've concentrated on showing the kids and teachers how to take the pictures hand-held. While it's difficult to get really good shots hand-held without a fair amount of practice, adequate shots are easy with just a little instruction. The kids seem to really enjoy collecting a souvenir by taking a picture themselves. Cell phone photomicrography has allowed hundreds and hundreds of kids to take photos through the microscopes during the outreach events over the last few years. I've even had kids shooting hand-held videos of the pond water specimens! I have found too, that when one student is shown how to do it, and tries it, others pick up on the technique very quickly.

Cell phone photomicrography worked so well, that I decided cell phones and their cameras would become an integral part of my microscopy outreach demonstrations.

The "wow" factor definitely has its merits!

The more kids and teachers I could get to take pictures through the microscopes, the more I thought they might remember and share what they had seen. A fleeting glimpse through the scope, even with an explanation, fades from memory pretty fast. Not so a photo on their cell phone they can share.

Lots of concentration here.

One student and one camera for each eyepiece. How efficient can you get!

Students who are engaged, are students who are learning!

What have others had to say about cell phone photomicrography?

Surprisingly, very little has been published on the utility of using cell phone cameras in either general or educational microscopy.

Micscape Magazine published a photo gallery by Nicolas White (3) in the August 2004 issue, showing some of the photos he had shot through a student microscope with his cell phone camera.

Microbe Hunter Magazine published a very nice article by Suphot Punnachaiya (4) in the November 2012 issue, outlining the construction and use of a very simple and inexpensive adapter to hold a cell phone steady for photomicrography. If you do an Internet search for cell phone microscope adapter you will find several do-it-yourself methods, and a few commercial adapters available. As with everything on the Internet, some are very useful, and some are junk. Look carefully and critically. Read the reviews.

The few serious articles mentioning cell phone cameras and microscopy are generally concerned with adapting them to be used in medical or research situations in resource-poor areas of the world.

Microscopes being in short supply in these areas, the concentration generally seems to be in add-on devices. These turn the cell phone into a rudimentary bright field, dark field, or fluorescence microscope, or even a spectrophotometer, to use as a diagnostic aid (5,6). One group has designed a microscope specifically adapted to using a cell phone camera to display and record the image (7,8). Another has designed a paper origami microscope with hopes it can be used productively in education and medical diagnosis (9). A cell phone camera would be used to record the image. The major benefits envisioned for these devices range from telemedicine, where the images are transmitted somewhere for more accurate diagnosis, to the possibility of automated cell counting and analysis, by software loaded onto the cell phone itself. Often these adapters use single lenses for the microscope portion. In effect they are modern Leeuwenhoek microscopes, with all the limitations and difficulties that entails.

What I will concentrate on now, is not an adapted single lens system, or a purpose built combo cell phone and microscope, but the use of pretty much any cell phone camera, with pretty much any microscope.

What's the best thing about cell phone photomicrography? You probably already have the camera with you and ready to go.

The second best thing is that it will work, at least hand-held, with virtually any microscope. Historically, microscope camera systems have been expensive, time-consuming, and difficult to use. Most microscopes, with the exception of very expensive research systems, make no allowance for cameras at all. And while some of the newer student microscopes include relatively low-resolution digital cameras, most still do not. Those that do include them are more expensive and may become obsolete when their cameras do, unlike regular microscopes which can last for many, many years. With a cell phone camera, all these limitations are removed. Even with research microscopes, generally sporting dedicated and very expensive camera systems, users might find it easier on occasion to take a quick snapshot with a cell phone than deal with the complexity of the research camera software systems and image export.
Using my cell phone camera, I have successfully photographed through several AO and Swift student microscopes, vintage microscopes such as Leitz and B&L botanical scopes, a 1903 Leitz monocular scope,

another 1951 Leitz that once belonged to a friend's veterinarian father, and several stereoscopes from Olympus, Leitz, AO, B&L, and Zeiss. More contemporary microscopes I've tried include AO 10's and 110's, a Nikon Labophot 1, and the Olympus BH-2 and BX families. While I hedge my bets with "virtually any", I have yet to find a microscope I couldn't work with. It even works with a replica Leeuwenhoek.

Vintage scopes that previously required complicated camera setups can now be employed to good effect photographically. No longer are they just for display or non-photographic use. No need for trinocular heads, photo ports, or projection eyepieces. All you need is the microscope and a cell phone with a camera.

Students can now photograph specimens through their microscopes with ease for reference, class projects, science fair presentations and the like, and quickly share the results on social media if they wish. Even in hospitals, lab techs on the off shifts can utilize cell phone cameras to email or text images to on-call pathologists or supervisors for more rapid feedback, or capture an image of a rare cell that might be difficult to find again in the morning.

Tablet cameras, iPads and others, work well too. They are a little more cumbersome to use though, and commercial support mechanisms are rare. The methods, however, are the same.

All in all, using a cell phone camera for photomicrography opens up a wide range of imaging possibilities previously unavailable to students, teachers, hobbyists, and even professional microscopists.

I'm not suggesting for a moment that these cell phone cameras replace the powerful, dedicated research cameras, high quality HD or 4K video cameras, or even high resolution Digital Single Lens Reflex cameras (DSLR's). These cameras use standard, carefully engineered, camera attachment mechanisms. Particularly in low light, fluorescence, and other difficult exposure conditions, cell phone cameras are still woefully insufficient. They generally have smaller sensors, and are more difficult to control in white balance, shutter speed, and ISO, as most lack manual controls for the cameras. Auto focus and auto exposure is handy, but can be annoying when shooting video if you forget to turn them off. The digital zoom can make size calibrations and measurements harder to accomplish as well. There are apps available to allow some manual camera control though, but the amount of control enabled varies by manufacturer and software version. However, every time you upgrade your cell phone, you upgrade your camera. So, the cameras will continue to get better and better.

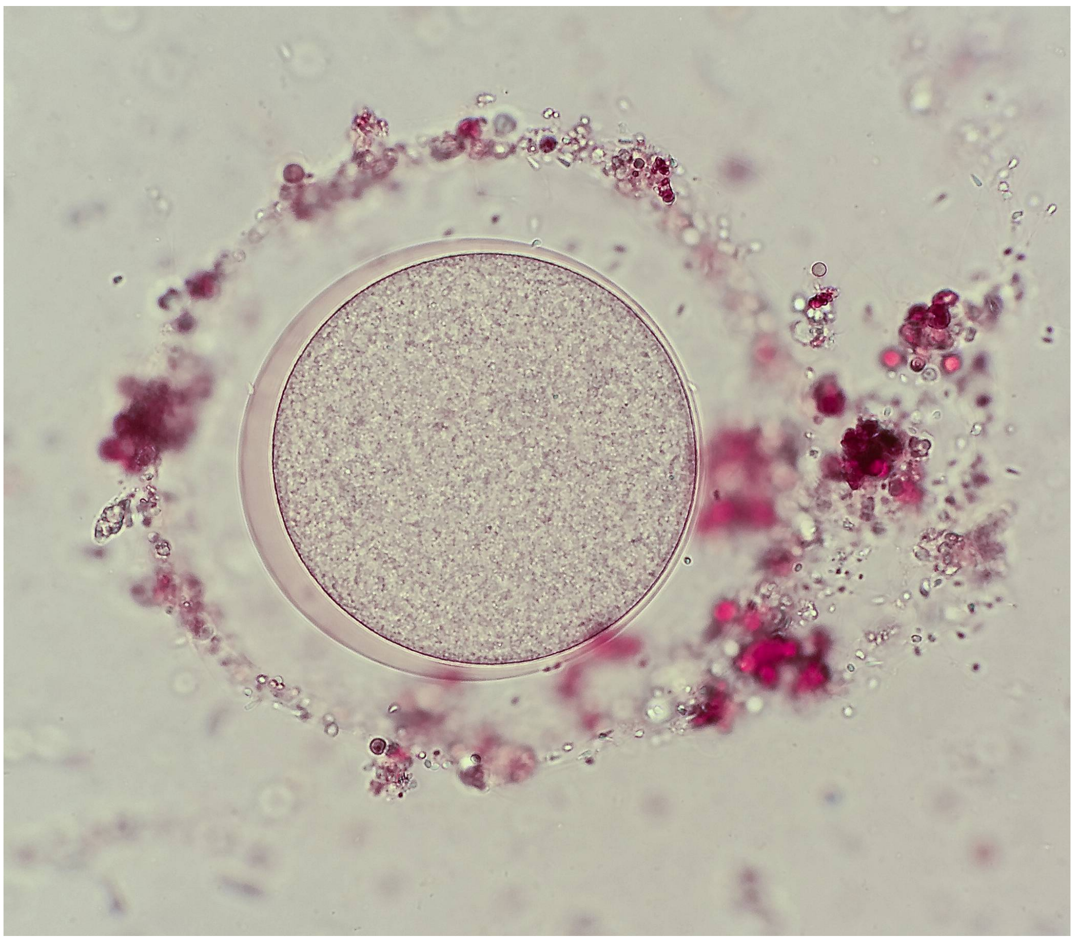
What I am suggesting is that in situations where previously no photographic image recording was thought practical or even possible due to microscope design, lack of appropriate equipment, or time constraints, good quality still and video photomicrography is now relatively easy.

I believe this method can be a game changer for the educational market. Teachers now have the ability to create their own, specialized, high quality content using images shot through a microscope. Students, too. No need for expensive, dedicated microscope cameras, and no more low resolution eyepiece or document cameras are needed either. Only the microscope and their personal cell phones are required.

So, just how good can a cell phone photomicrograph be?

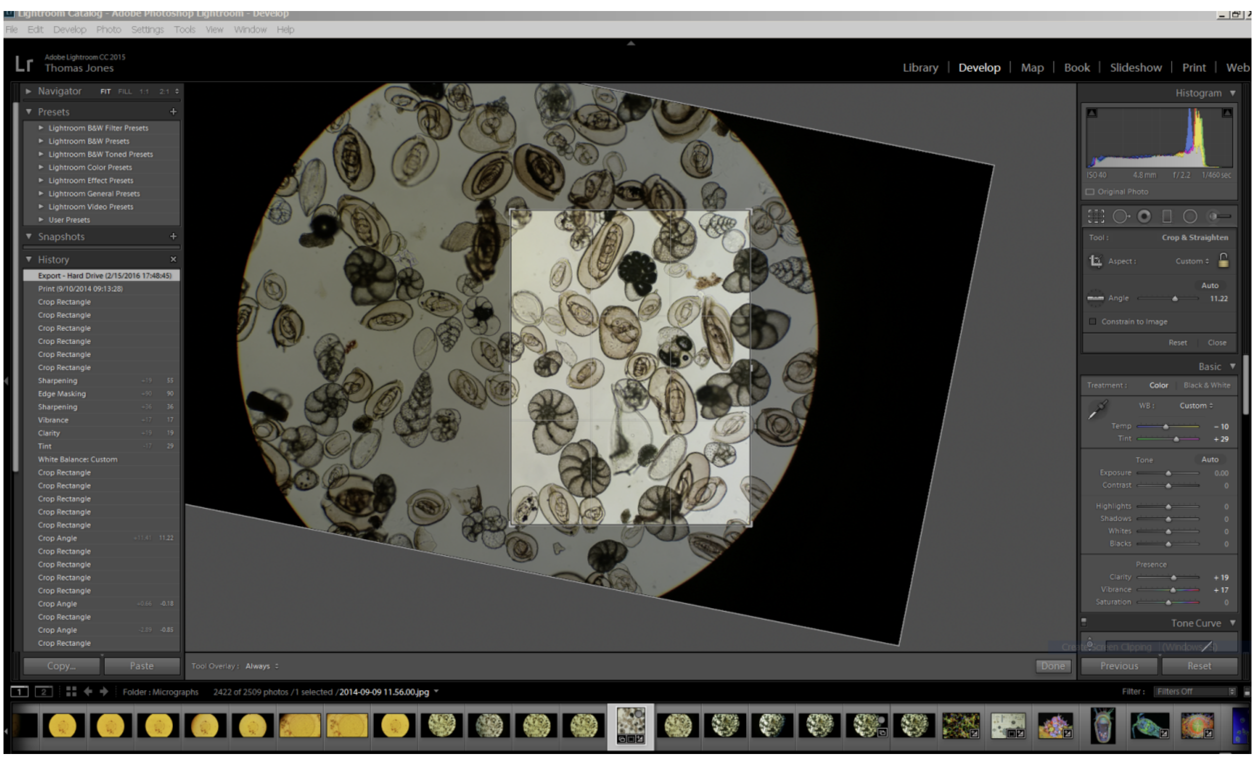
Very good. How about publication quality, or better, even hand-held? And with some kind of camera support method, cell phone cameras can produce very nice video as well.

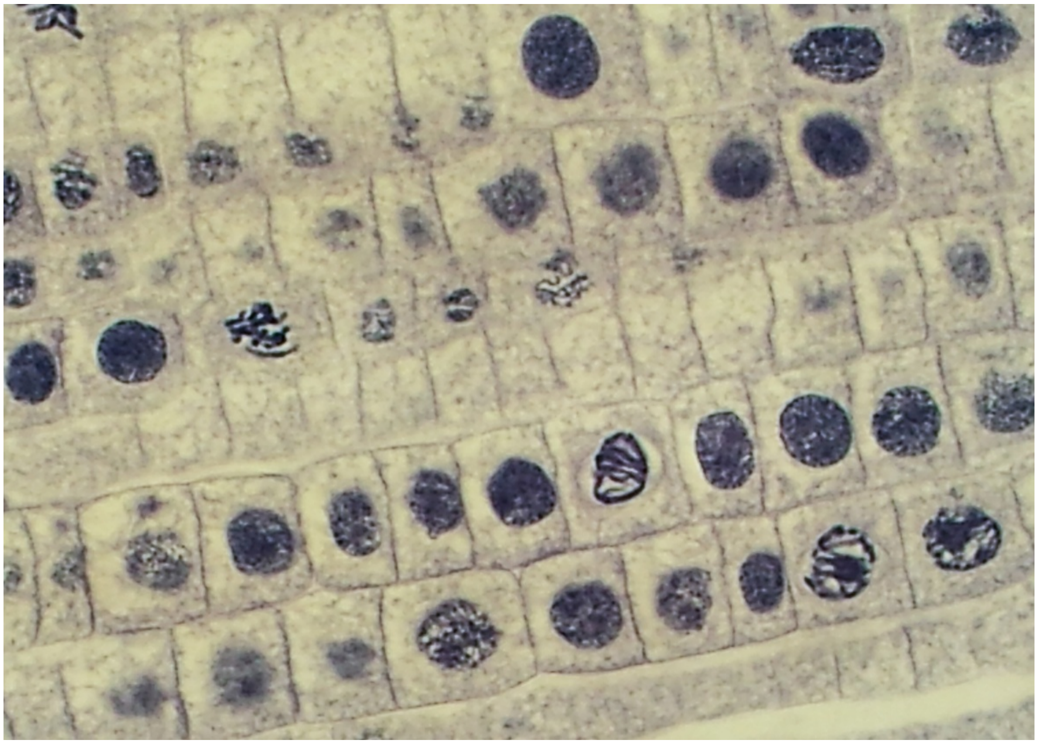
The newer cell phone cameras are very good; much better than just a few years ago. I have shot hand-held images that hold up nicely to 11 x 14 inch prints. My almost two-year-old Samsung Galaxy S5 for example, is 16 megapixels, shoots nice stills, and will shoot very nice video up to 4K (Ultra High Definition actually, at 3840 x 2160 pixels). In general, the biggest problem now is properly aligning the phone and holding it steady.



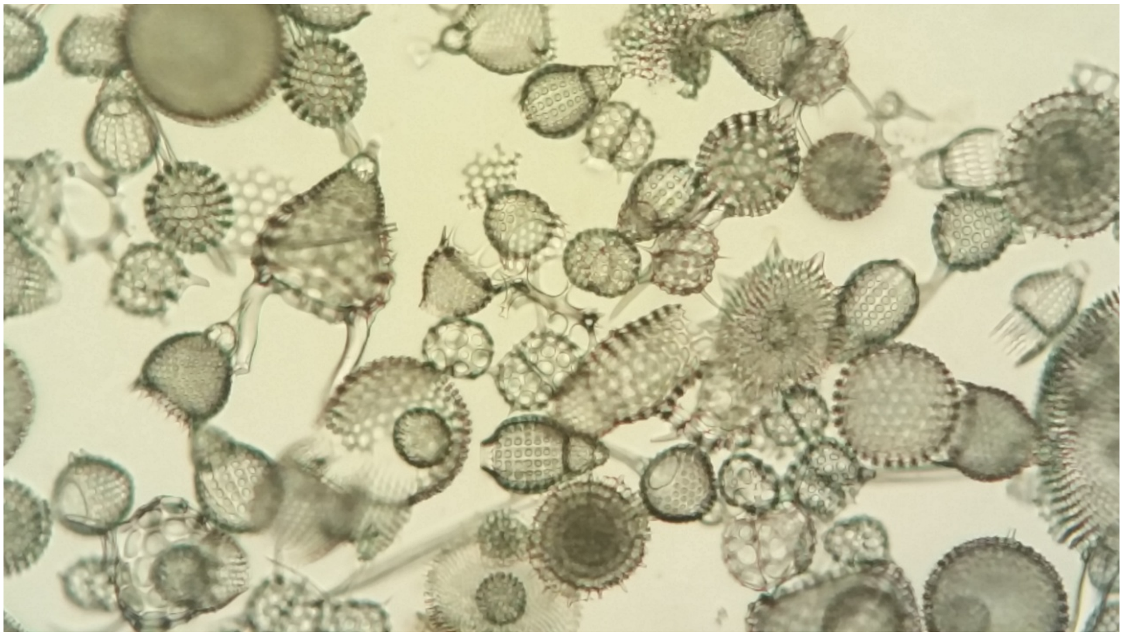
This is a photomicrograph of a recently fertilized Purple Sea Urchin egg, showing the fertilization membrane. It was shot hand-held, using a Samsung Galaxy S5 cell phone camera, through an Olympus BH-2 BHTU microscope. The occasion was a marine biology workshop held at Santa Monica City College, and put on by Professor Ed Tarvyd for members of the Microscopical Society of Southern California. Post processing in Adobe Lightroom included color balance, since I had forgotten to set the camera on incandescent, cropping, and some minor sharpening.

Above is a photomicrograph of a Watson slide of foraminifera. Also hand held with a Samsung Galaxy S5 and a BH-2 microscope. To show how well these images can hold up to enlargement, the next image below is a screen shot of the original file in Lightroom, showing the image crop I applied.

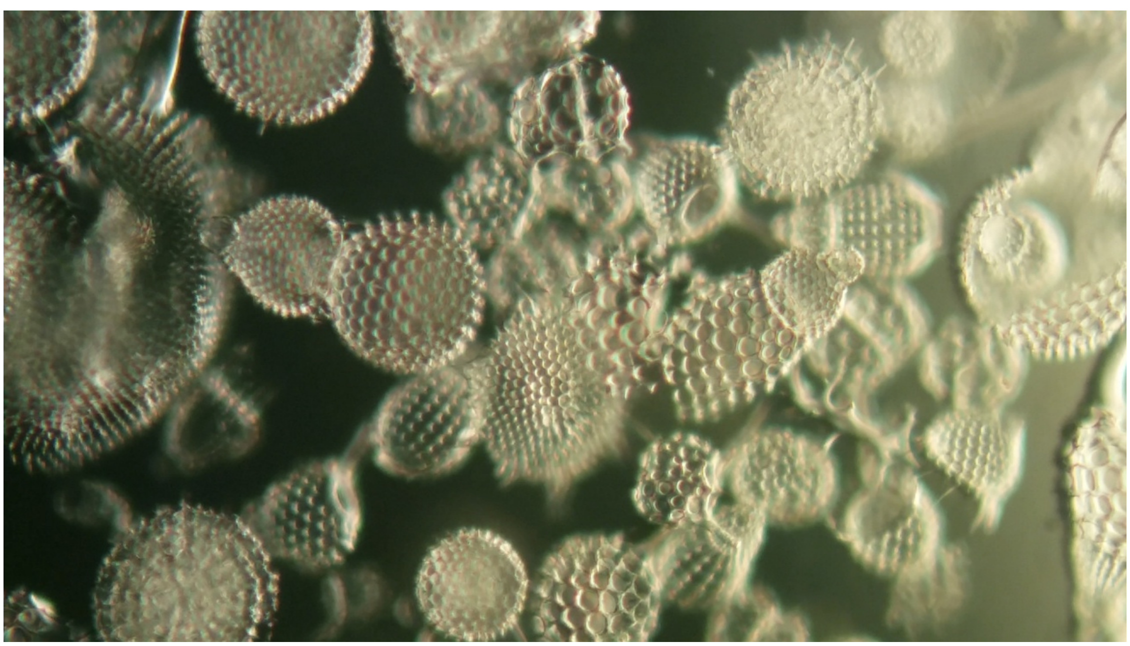




Above is a photo of a standard teaching slide of onion root tip, showing the chromosomes in mitosis. It was shot using my older Samsung Droid Charge cell phone camera, outdoors, supported by the now-discontinued Skylight. Again, the microscope was an Olympus BH-2. The photo below is of a Hornell slide of *Obelia geniculata*, taken with the Samsung S5 using the MiPlatform (see below) as support, through a Swift M2250 teaching scope. The disc diaphragm was offset to create strong oblique lighting.



The above image is of a C. Baker *Polycystina* slide from Cleland Hill, in Barbados. It was shot through a 1951 Leitz microscope, using an offset mirror to produce oblique lighting. The camera was the Samsung S5, and also used the MiPlatform for support. The lower image is a frame grab from 4K video of the same slide, using the same cell phone camera. The mirror is offset even more to provide oblique and dark field illumination. It's really a pity modern microscopes are not capable of this simple but effective trick. You will find a link to the video in "Tips for better video photomicrography" below.



Before we get into adapters to support the phone, I'll next outline some of the benefits of cell phone photomicrography, and the procedure necessary to capture a still photograph through the microscope with a cell phone camera. These steps will generally apply to supported photomicrography as well, except the alignment procedure usually needs to be done only once. I'll outline the steps necessary for video a bit later.

Benefits of using a cell phone for photomicrography

1. <u>You probably have it with you</u>. There is often no need for a dedicated camera.

2. Image quality hand-held, if careful, is usually at least adequate, and can be very good. If the camera is supported, image quality can be even better yet, with most of your images being useable.

3. Any microscope is suitable. Student and vintage microscopes can easily be used.

4. Stills and video are both available on almost all newer cell phones.

5. Site photos and GPS coordinates can be useful for documentation of setups or field collections.

6. Time stamps on images may be helpful.

7. Audio recorder for video narration or notes to go with still photographs.

8. Provides an outstanding new tool for teachers and students.

9. Can easily email, text, or upload the photos or videos to social media or other places on the web.

Hand-held cell phone still photomicrography procedure

1. Line up the camera with the lens over the eyepiece and the camera optical axis parallel to the eyepiece optical axis. Think of the axes as arrows going straight through the camera lens from back to front, and right through the center of the microscope eyepiece, top to bottom. For best results, it is imperative they line up and coincide. Any tilt of the phone/camera relative to the eyepiece lens axis will result in uneven illumination, an offset image, and perhaps focus problems.

2. As you center the camera lens, you will see a very bright, blown out light. Chase the light until you get the camera centered over it.

3. Auto focus and auto exposure will kick in and the image should appear as the camera focuses.

4. Adjust the camera lens center and distance from the eyepiece until the image circle is in clear focus. If you are using an eyepiece with a pointer, that pointer should be in perfect focus as well (not like the *Obelia geniculata* image above).

5. Automatic camera adjustments should make final focus and exposure corrections.

6. Zoom in to eliminate the image circle if you wish. This will involve using the phone's digital zoom and is difficult to do without a stabilization platform of some kind. Stabilized it's easy. There may or may not be a discernible quality difference between in-camera digital zoom, and doing it in post processing with software such as Lightroom or Photoshop. I have not yet experimented with that.

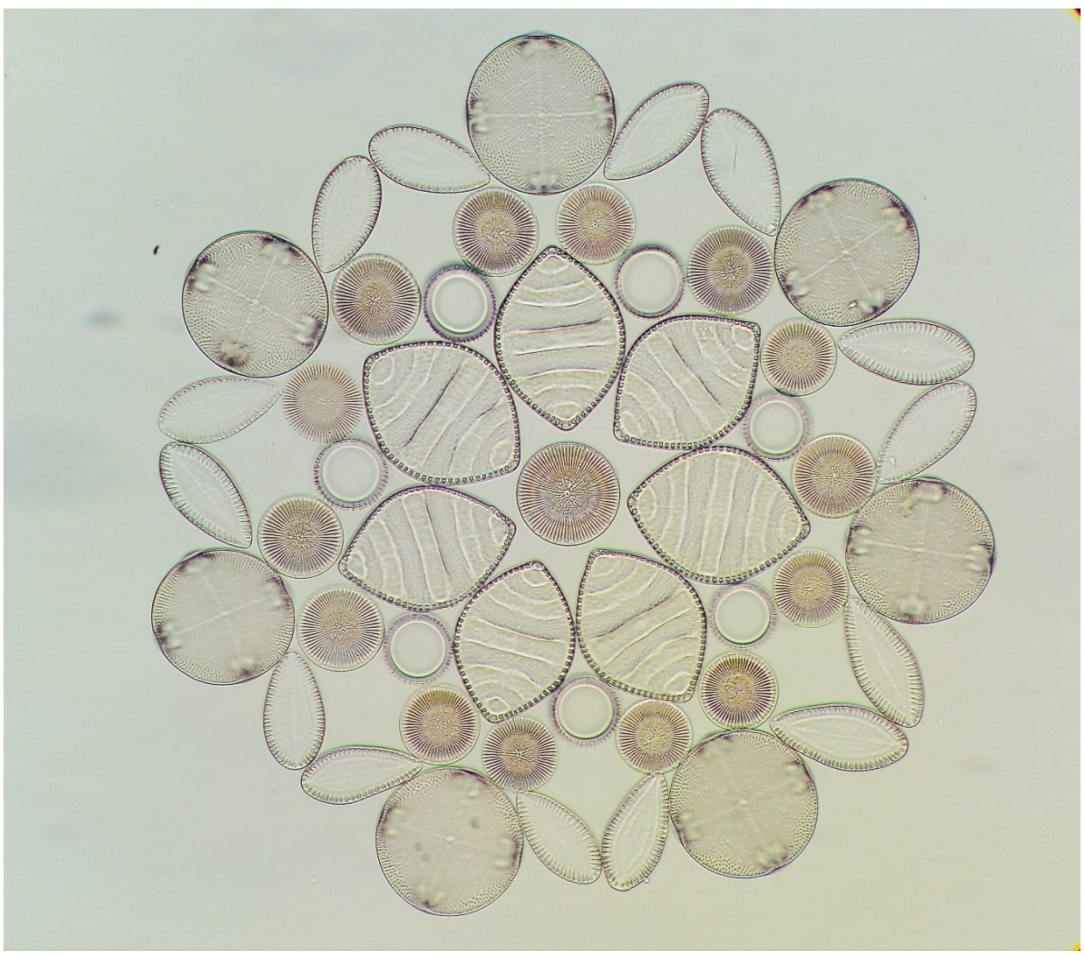
7. Take the picture.

As I mentioned, the hard part is holding the phone steady and in the proper position. It's doable, for stills, with a little practice. However, most shots will not be centered properly, so the yield isn't that good. It's best to use some kind of camera support platform, even for stills. If you don't have a support system handy though, it's well worth the effort to shoot multiple shots hand-held.

For video though, it's absolutely crucial to use a support mechanism.

Here is a link to a short video demonstrating the technique: https://youtu.be/BR-WieVtizg

The resulting hand-held still photo from that video, after changing the camera to incandescent white balance, is below. It is of a Kemp diatom arrangement, shot through the BH-2, with oblique lighting from an offset phase condenser. The actual image file looks better than is reproduced here, and is very crisp.



Tips for better still photomicrography

1. <u>CLEAN the lenses first</u>. Cell phone camera lenses tend to have a lot of fingerprints and dirt. Eyepieces are often dirty, too, particularly with student microscopes.

2. Start with a well-focused image in the eyepiece. Focusing with the cell phone screen alone is difficult.

3. Turn off the flash to prevent reflections off the eyepiece.

4. Set camera white balance to the kind of light source you are using. Generally that will be incandescent. On most microscopes you can adjust the light intensity too, as necessary, for the best background color match.

5. Set still image size to highest resolution available.

6. Use a stabilizing device if at all possible. At the very least, try to brace your hand on the microscope while shooting to prevent as much camera movement as possible. Be careful not to tip, or otherwise move the microscope.

7. Optical zoom - using a higher magnification objective - is always preferable to digital zoom. Individual microscope and eyepiece combinations will require different levels of digital zoom to remove the image circle from view.

8. You can make something to stabilize the phone yourself if you like, or buy a commercial version.

Camera support and stabilizing system requirements

1. Needs to keep camera optical axis and eyepiece optical axis lined up, and not slip or sag.

2. Fit the microscope and cell phone you have.

3. Allow for adjustment to focus in and out from the eyepiece.

4. Keep everything stable.

5. Should allow camera rotation for best field of view and specimen orientation, and horizontal video.

6. Maintain desired camera orientation during shooting.

7. Be reasonably easy to mount to the microscope, and remove when finished.

8. Not get in the way of microscope operation.

The MiPlatform - a very good commercial camera support system

Late in 2015, I discovered the MiPlatform cell phone support system for microscopes. It is the most capable, and easiest to use, all around adapter I have found.

It is available in the U.S. from Scientific Device Laboratory (10,11), and List price is $189 in the U.S., plus shipping. It is available outside the U.S. from Trajan Scientific (12). Trajan doesn't list the price on their website that I can find.

The platform and clamping mechanism of the MiPlatform is capable of holding and stabilizing virtually any sized cell phone, but not tablets, and holding it to almost any microscope eyepiece. It won't work where there is no eyepiece or microscope barrel to clamp onto, so you can't use it with vintage botanical style dissecting microscopes. For those the hand-held technique is necessary. Pretty much anything else though, will work. The eyepiece clamp will take a wide range of sizes from the older, small, 23mm size, through at least the large, 30mm wide-field eyepieces on the Olympus BX and SZH series microscopes. It is a very well thought out adapter, and in my mind, well worth the money.

Supported cell phone still photomicrography procedure:

1. Set up the support device on the microscope, whether it is the MiPlatform, another commercial one, or something you have devised and built.

2. Place the cell phone onto the support platform and line up the camera lens as in the hand-held procedure above. Once the alignment is correct, tighten the clamping mechanisms until they are only snug. Also, consider using rubber bands to hold the phone in place on the platform so it doesn't fall off.

3. Do a final alignment of the camera as it will rarely stay exactly in place during the tightening step.

4. Move the support platform toward or away from the eyepiece until the image circle, and the pointer, if present, are in clear focus. Camera autofocus will focus the microscope image. Lock it in place.

5. Continue as with the hand-held procedure.

Video photomicrography with a cell phone

This is where I was really surprised. I didn't expect the quality to be as high as it is. It's not the wasted resolution or empty magnification I had feared.

Most modern smart phone cameras will shoot high-resolution, full HD video at 1080p (1920 x 1080 pixels). Many of the newest will shoot DCI 4K (4096 x 2160 pixels) or Ultra High Definition (3840 x 2160 pixels). Full HD on a decent cell phone will generally result in video that is much higher resolution than any analog video standard. That means that in full HD you can now shoot, with your cell phone, higher resolution video than was available anywhere just a few years ago. 4K is much better yet. With student or hobbyist scopes, the microscope itself can be more limiting than the cell phone video cameras.

Supported cell phone video photomicrography procedure

1. Set up the support device on the microscope as in the still photomicrography procedure above. Be sure to have the camera horizontal to avoid the problems inherent in "vertical video", unless the specimen absolutely requires it. I have modified my MiPlatform so it will stay horizontal if I like. See Tips below for details. For a tongue-in-cheek discussion of problems inherent in vertical video, see (13).

2. Before you start, set up the camera for video. Set the resolution to the maximum possible, and set the white balance to match the illumination you are using. Again, generally that will be incandescent.

3. Line up the camera with the lens over the eyepiece and the camera optical axis parallel to the eyepiece optical axis. Think of the axes as arrows going straight through the camera lens from back to front, and right through the center of the microscope eyepiece, top to bottom. It is imperative they line up and coincide. You will need to constantly readjust the camera clamps while doing this. Any tilt of the phone/camera relative to the eyepiece lens axis will result in uneven illumination, an offset image, and perhaps focus problems.

4. Adjust the camera lens center and distance from the eyepiece until the image circle is in clear focus. If you are using an eyepiece with a pointer, that pointer should be in perfect focus as well. You may need to loosen the eyepiece clamp to move the phone toward or away from the eyepiece to obtain good focus.

5. As you center the camera lens, you will see a very bright, blown out light. Chase the light until you get the camera centered over that light.

6. Auto focus and auto exposure will kick in and the image should appear as the camera focuses.

7. Automatic camera adjustments should make final focus and exposure corrections.

8. Once perfectly aligned and focused, tighten the clamp mechanisms to hold the cell phone in place over the eyepiece. Recheck the alignment and retighten as necessary. Consider adding a couple of rubber bands to hold the phone onto the platform.

9. Zoom in to eliminate the image circle if you wish. This will involve using the phone's digital zoom. There may or may not be a discernible quality difference between in-camera digital zoom and doing it in post processing with software such as Adobe Premier Pro CC (part of Adobe's Creative Suite and $$$), Blackmagic Design's DaVinci Resolve (very capable, and it has a free single user version), or another video editing package. I have not yet experimented with that. If you are shooting in 4K, you will have much more zoom available due the huge increase in resolution inherent in that format.

10. Start the video recording.

11. Turn off auto focus and auto exposure to keep the video image from jumping around. A single finger press and hold on the image for a couple of seconds, after recording starts, will freeze focus and exposure on both Android and iOS systems. For Android at least, you need to repeat this for each shot.

12. Use touch to set focus and exposure for video, after auto focus is turned off.

Tips for better video photomicrography

1. As with still photography, CLEAN the lenses first.

2. Start with a focused image in the eyepiece. Focusing with the cell phone screen alone is difficult.

3. Don't forget to turn off auto focus and auto exposure for video to keep the image from jumping around.

4. Double check your camera settings. Take advantage of any manual control available for better results.

5. I use a couple of rubber bands to help hold the phone onto the adapter. Depending on the adapter orientation, they may not be necessary, but they do provide the peace of mind that the phone won't fall off onto the floor and be damaged. They do not interfere with camera operation.

6. Optical zoom - using a higher magnification objective - is always preferable to digital zoom. Individual microscope and eyepiece combinations need different levels of digital zoom to achieve the same thing.

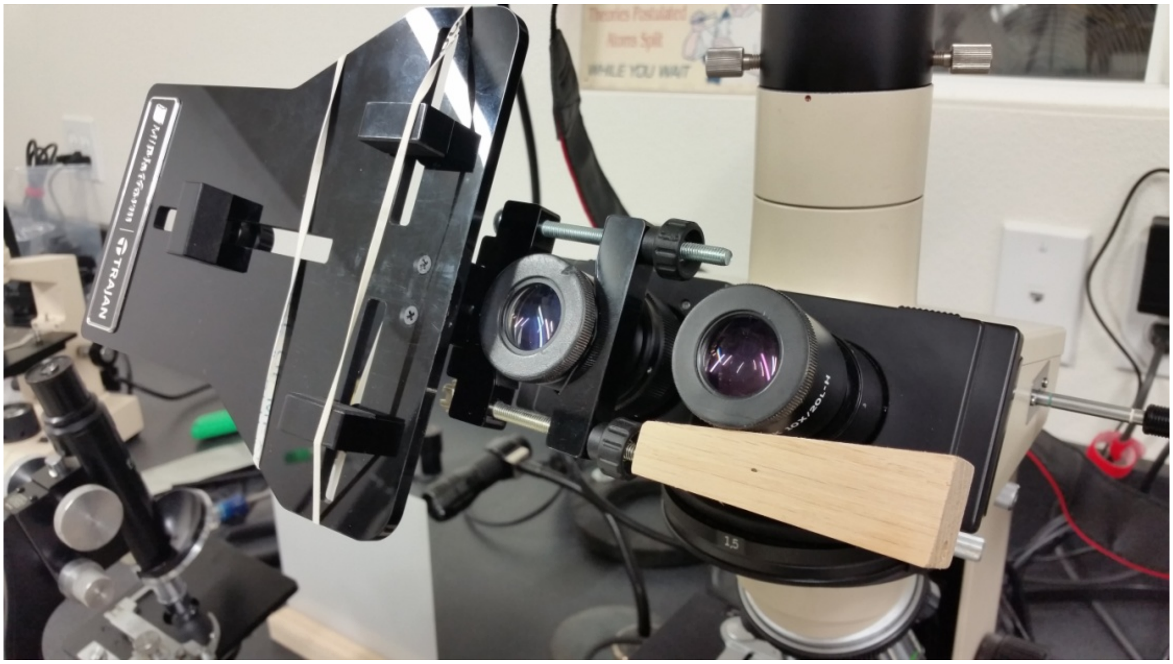
7. Please, please do not shoot "vertical video", with the phone held vertically, unless you are only going to show it on your phone. This is particularly true if shooting in 4K. Rotate the camera to horizontal so the orientation will be correctly tagged for horizontal viewing. However, at least with Android, if you turn off auto focus while recording horizontally, then change the orientation to vertical and continue to record, the video will be tagged, and play back, horizontally. That way you can record a specimen vertically if its orientation on the slide requires it, and still play it back without losing display resolution.

8. Video shot vertically, but shown horizontally, will be displayed at approximately one-third the size it would be if both shot and shown horizontally. It reduces displayed resolution on horizontal screens by two-thirds, since what is normally the wide dimension, is resized to equal the narrow vertical display dimension. The normally narrow one becomes proportionally smaller yet. In the case of full HD, 1920 x 1080 pixels, this converts the wide, 1920 dimension to 1080, and the 1080 dimension to 607 for display.

9. Video playback software chokes when trying to rotate and display 4k video on the fly, due to the relatively massive file sizes. Some phone software includes a method of rotating videos previously shot vertically, and there are some apps available that can correct it. Beyond that, rotating 4K will require video editing software, not just a viewer. Some players, such as VLC, can rotate HD or lower resolution video on the fly with no problem. It doesn't work with 4K. It may not be a problem with a 4K display.

10. When recording video, the audio recorder is also running, thus adding a concurrent sound track to the video file. It can be quite helpful to narrate the video with a running commentary as you shoot it, even if you have no intention of publishing the audio with the video. It will give you a contemporaneous record of what you did, and is much simpler to accomplish than writing down notes at the time. The original sound track can later be transcribed to notes, and then easily be stripped off the video. If you wish, prior to publishing, you may also replace the original sound track in post processing with a more carefully crafted and formal narration.

11. If you have a spare eyepiece, it is possible to leave the MiPlatform attached to it, and simply swap them out to quickly change between visual use and photomicrography. This is the approach I now use at my outreach demonstrations.



I have modified my own MiPlatform to allow horizontal still and video photomicrography by replacing one of the #10-32 screws with a piece of #10-32 all thread rod from a hardware store and adding a drilled wooden wedge (because I already had it) as a brace on the other eyepiece. The wedge looks a bit strange, but slides back and forth so is adjustable for level, and works quite well. I've added a large area washer under the focus locking screw on the back too, to allow more vertical travel for focus. A couple of rubber bands help prevent the phone from falling off.

Here is a link to the source video for the *Polycystina* frame grab image shown earlier. For best resolution, view at 1080p if at all possible:

https://youtu.be/YAc1HLGoFhk

This little sequence nicely demonstrates the resolution problem involved when shooting vertical video and displaying it horizontally. The rotated *Polycystina* part of the video is exactly the same as the initial part, but once rotated to horizontal it displays about three times larger and in the correct aspect ratio. The last part of the clip is of fresh-water plankton, also shot in 4K with the Samsung S5, through a BH-2, and down sampled to full HD. It also demonstrates what can happen if you fail to turn off auto focus. You can see the camera refocus on several occasions. Turning auto focus off will eliminate that jumping around effect, and any exposure changes.

Real-time viewing with screen mirroring to a large HDMI monitor

Mobile High-Definition Link (MHL) technology is a wired interface standard for transferring High-Definition video from a mobile device to a compatible television or monitor with an HDMI input (14). Using an MHL adapter and HDMI cable you can mirror the screen from your compatible Android smart phone to a larger, high definition monitor. Apple iPhones and iPads do not support MHL or regular Wi-Fi. Instead, the newer iOS devices use Apple Air Play wirelessly to Apple devices, or the Apple Lightning Digital AV adapter to connect to the HDMI cable and then to the monitor. Both the MHL and Lightning adapters also provide a USB power input socket so that you do not drain your device battery.

In the context of cell phone photomicrography, these methods provides at least a couple of distinct benefits. First, with mirroring you should be able to use the larger monitor to see whatever your cell phone camera is seeing. In this case that would be the view through the microscope, live, in real time. It would be useful for focusing, review, or direct projection to a classroom or other gathering, via an HDMI compatible projector or large screen. Second, any previously created content located on the smart phone or tablet, be it stills or video, can easily be shown on the larger display.

The bad thing is that, at least with the Android phones, auto shutoff will kill the app pretty quickly if you stop interacting with it. As long as you're doing something, or showing a video or slide show, it will keep mirroring. The iPad does not seem to have the auto shutoff problem. I haven't tested any of the iPhones.

Some of the newest Android smart phones, in particular the Galaxy S6 and S7 series from Samsung, will mirror wirelessly using Wi-Fi, given compatible hardware. I haven't tested anything Android beyond the Galaxy S5 which I own, and wired MHL. With the S5, wired MHL works nicely. I have tested the Apple iPad Mini Retina with the Lightning Digital AV adapter and it, too, works very well.

Conclusions

How many of us carry a microscope still camera around all of the time? How about a microscope video camera? Almost all of us do now.

I have shown how cell phone cameras can be very useful in microscopy. Imaging any place, using any microscope, anytime, is now relatively easy. If you have your cell phone, you have your portable microscope camera. From use with student and vintage microscopes, to even very high quality clinical and research microscopes, cell phone cameras are a valuable tool for the student, amateur or professional microscopist's kit. They can capture still images or video otherwise unavailable, provide excellent image quality, and an immediacy and transferability to social media and the web not available with other imaging methods.

And as cell phone cameras get better and better, our portable microscope cameras will get better and better, too.

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