The Prakash Laboratory Foldscope Project Educational Initiative:

The "Ten Thousand Microscope Project"

Beta-testing the Foldscope through study groups involving professionals, amateur fossil collectors, and high school children

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Introduction

The "Ten Thousand Microscope Project" (http://www.foldscope.com/10ksignup/) is a large-scale, hands-on microscopy educational initiative involving the Foldscope developed by Manu Prakash and his laboratory team at Stanford University (Cybulski et al. 2014). The Foldscope is a low cost, origami-based foldable paper microscope that uses a spherical lens and external natural or artificial light to view materials as one would accomplish with a light microscope. The low power lens (furnishing approximately 140X) is useful to observe a wide range of materials. The ease in which the Foldscope can be made and used by anyone enables access to all people with an interest in the microscopic world.

The Microcosmos blog (https:/microcosmos.foldscope.com) is a forum where individuals can register their Foldscopes and write about their observations of microscopic phenomena. This enables the Prakash Laboratory team to receive direct contact from people about their experiences in making and using a Foldscope as well as disseminate the knowledge gained by all those participating in this world-wide project. As a person selected as a beta-tester, I wanted to assemble the input I received from those individuals participating in making and using Foldscopes that contributed substantially to my involvement in the Ten Thousand Microscope Project. As a result, I have compiled a report for the Prakash Laboratory that I hope will be a helpful contribution toward the next phase in promoting the Foldscope and microscopy world-wide.

In this document, I will report on the experiences people had with making and using a Foldscope. Suggestions and ideas on potential enhancements of the Foldscope are discussed. I will also reiterate the potential the Foldscope could have for influencing educational goals in science and microscopy education.

My Role as a Beta-tester

I applied to become and was chosen to be a beta-tester for the "Ten Thousand Microscope Project." In my proposal to the Prakash Laboratory, I stated that I wished to give a group of amateur fossil collectors the chance to make and use Foldscopes and to discover the wonders of the microscopic world. These individuals are used to hunting for fossils that can be seen with the naked eye, so they are not accustomed to delving into the microscopic world and are not collectors of microfossils. However, some of these people have had experience with using microscopes. As additional packages of Foldscope-making materials arrived, I decided to give some high school children a chance to discover the microscopic world as well. I anticipated that these individuals would have had exposure to microscopy and would be fascinated with the prospect of using a small foldable version in place of the more familiar compound light microscope. With the remainder of the Foldscope-making materials that I received, I decided to disperse these to professionals in the academic and research world. My thinking here was to allow professionals to see the benefits of easy accessibility to a microscope. If the resolution limits and types of specimens used are such that a Foldscope is sufficient for a given project, the availability of a low cost, portable microscope might influence the way in which research dollars are allocated.

Methods

I received a total of 36 Foldscope sheets, lenses, and the associated accessories for use by participants in the project. My mode of carrying out the beta-testing of Foldscopes was specifically devised as follows. First, an ensemble of academics and professionals (myself

included) were selected as participants, forming what could be described, loosely as a group. These individuals were to participate at will, making and using the Foldscope and providing observations and comments via the Microcosmos blog or directly to the Prakash Laboratory. Other than my observations, no further mention will be made in this report about observations made by the academics and professionals. The Foldscope 9-character identification labels (IDs) are listed in Appendix A for this group.

The second group of participants consisted of 14 amateur fossil collectors who are members of Friends of the University of Michigan Museum of Paleontology (hereafter known as the "Friends"). People in this group have a variety of backgrounds and vocations and/or professions. Some are retired, and some are very young and still in school. To facilitate successful usage of the Foldscope, I put together packets of slide making materials and instructions as well as the Foldscope sheet and accessories. The Friends were given approximately 6 months—from April to September, 2015—to make, use and report on the Foldscope to me. They could do this activity at their leisure and use whatever materials they wished to use for slide preparation. In their packets, suggestions were made on materials to use, how to prepare specimens and slide mounting techniques. With the Internet as a handy source of information, they were encouraged to research anything that would supplement their experience. Above all, they were encouraged to have fun using the Foldscope. The Foldscope IDs for members of the Friends are given in Appendix B.

The third group of participants consisted of 14 high school students enrolled in the Michigan Math and Science Scholars (MMSS) program in the biological oceanography course I taught in July, 2015. The students were from Michigan and other locations in the United States as well as from Japan and Puerto Rico. They had diverse backgrounds and interests and

exhibited different levels of knowledge and ability. Making and using the Foldscope was part of a whole day devoted to microscopy in the biological oceanography class. The Foldscope IDs for the high school students are given in Appendix C.

Results and Discussion

Below, I will describe my observations and the observations and comments by members of the Friends and MMSS high school children with regard to making and using the Foldscope. Their participation in this project is interesting and insightful, especially concerning the potential next steps that the Prakash Laboratory team anticipates taking to further the educational mission of making microscopy available and accessible to all.

Beta-test 1: My observations

For my testing of the Foldscope, I made slide preparations of Neogene diatomite. I had collected this material in August, 2000 from the Prassas Basin, Heraklion Crete, Greece. I used the paper slides and sticky tape provided with the Foldscope as well as glass slides and coverslips. I made dry and wet mount slides. In addition, I made observations of permanent mounts of phytoplankton from Lake Michigan and a diatom identification slide.

Using the low power lens, condenser and light module, I observed a variety of diatoms and other microfossils from multiple slide mounts that I prepared of the Neogene diatomite. The best finds were the diatom *Thalassiosira leptopus* and the silicoflagellate *Dictyocha fibula* (Figure 1). In addition, *Synedra*, *Achnanthidium*, *Nitzschia*, and other pennate diatoms were viewed. A lot of debris was present, and because of this, multiple slide preparations were

required to enable finding particular fragments or whole specimens of identifiable diatoms and other microfossils.

Data Sheet for Recording Foldscope Observations

Beta tester: Janice Pappas

First test group: Friends of the University of Michigan Museum of Paleontology

(I filled in the header information as an example; delete this and put your information here. Slide numbers 1 and 2 are only examples; delete or cross out this data and only include your own observations).

Foldscope ID Label: 0001 4233 54E6 ←[Fill in the numbers/letters for your ID label here]			
Name: Janice L. Pappas ←[Fill in you name here] Contact Information: jlpappas@umich.edu ←[Fill in your e-mail address here]; [Optional: address and phone number]			
Slide Number	**Date**	**Specimen/Sample ID, locality, collector, date**	**Observations (@ low power = 140X)**
1	4-3-2015	Diatom – Thalassiosira leptopus; Neogene diatomite, Prassas Basin, Heraklion, Crete; J.L. Pappas (collector), 31 Aug 2000.	Whole specimen; round; can see central area and pores on surface; fairly clear view of this large specimen with other diatom fragments and pieces of debris in field of view.
2	4-4-2015	Silicoflagellate – Dictyocha fibula; same locality, collector and date as slide number 1	Looks like most of a Dictyocha fibula; edges of the roundish hexagonal cells are clear; debris in field of view, but does not obstruct the specimen.

Figure 1. Data sheet example and two entries of my observations of Neogene diatomite.

The permanent mounts of phytoplankton from Lake Michigan were prepared with a toluene-based mountant with high refractive index, and the slide strew mounts contained a large variety of microorganisms. With low power and short working distance between lens and eye when using the Foldscope, it was difficult to see fine detail. However, identifications could be made to the species level in some cases. Diatoms such as *Asterionella formosa*, *Tabellaria fenestrata*, *Fragilaria crotonensis*, *Aulacoseira granulata*, *Synedra delicatissima* var. *angustissima*, *Cymatopleura solea*, *Stephanodiscus tenuis*, and *Nitzschia acuta* were viewed. Other species of *Synedra* plus *Cylotella*, *Craticula* and other diatoms and as well as green algal cells of *Scenedesmus* were also found. Individual and colonial forms were present. By scanning over the entire coverslip of each permanent mount, the diversity of phytoplankton from Lake Michigan was readily apparent using the Foldscope.

The diatom identification slide consisted of many specimens of *Arachnoidiscus ehrenbergii*. I estimated that they are approximately 100 to 300 micrometers in diameter, which would fit in the range for the genus (Round et al. 1990). With the Foldscope, I could easily see the radial costae, between which poroids (Ross and Sims 1972) are visible. The central area could be seen even down to the slit-like openings arranged in a circular fashion. When very carefully focusing up and down on a given specimen, I could see both valves of the diatom. Construction of a diatom is like a Petri dish where the round faces are the valves (Round et al. 1990). The valves are where the details of each *A. ehrenbergii* can be seen, and distinct glints of changing light values reflected off the exquisite glass surface structure when focusing with the Foldscope. At the edge of the coverslip, I found a partial *Isthmia* sp., which was a pleasant surprise.

I tried using the high power lens (480X), but did not have success in viewing diatoms, phytoplankton or microfossils. The restricted light field and very short working distance made it impossible to resolve actual specimens. I could see changes in light values as I scanned slides, but I could not obtain a clear view of a specimen. Multiple attempts were made because I was especially interested to be able to view diatom microstructure with the Foldscope as well as diatom and green algal cells that were not easily identifiable to species level with low power.

Beta-test 2: Friends of the University of Michigan Museum of Paleontology

Members from the Friends who participated in the Foldscope project were asked to make a Foldscope, prepare slides with specimens, and comment on what they viewed with their Foldscope. They were also asked to comment on the how difficult they felt it was to put the Foldscope together. I put together a self-contained packet of everything each member would

need to carry out their microscopy studies. One of the items that each member received was a small capped vial of Neogene diatomite from the Prassas Basin, Heraklion, Crete, Greece. I wanted the Friends' members to prepare and view paleontological material. In addition to receiving the Foldscope sheet and accessories, a packet of information and instructions, and supplies for slide preparation, they were also given a data sheet (see Figure 1 as an example) to be filled out. On their data sheet, members were to describe and/or draw their observations from each slide they viewed. The information and instructions sheets are presented in Appendix D.

The Friends were encouraged to make slide preparations of whatever materials they had an interest in viewing. As a result, a diversity of materials were used. Although the Friends are an organization of amateur fossil collectors, individuals exhibited a flare for particular areas of expertise, possibly pertaining to their former occupations (some are retirees) or other endeavors in which they have engaged.

Organisms figured prominently in the selection of specimens viewed with the Foldscope. Yeast, bacteria, mold, animal and plant parts, and specifically insects comprised many of the items of interest. Pond scum, algae, cyanobacteria, moss, a chironomid larva, a protist, and brine shrimp nauplii and egg casings covered the gamut of aquatic-based materials that were viewed with the Foldscope. Foodstuffs and abiotic materials were other choices for slide preparation. All of their observations were done at low power, and I will highlight some of the Friends' observations from their usage of the Foldscope.

Members of the Friends gave detailed descriptions about their observations and/or drew detailed pictures of their findings. The "clear image of the pollen showing the straight sides" of pollen from a dandelion was stated by Bob Simmer. Graham Lewis remarked that when viewing a chironomid larva from Essex Co., Hudson River, Rt. 28 N, "…image quality is superb. I could

discern surface details on [the] cuticle; clear view of mouthparts and setae, despite being a poorly prepared slide." Among his choice of specimens for viewing, Graham made a slide preparation of cheek epithelial cells mounted in 0.9% saline and stained with methylene blue. His observations were compromised by contamination with paper fibers. Still, his interest and attention to advanced slide making techniques is very much appreciated.

A peel of a monarch butterfly wing was viewed to be "very cool" by Diane Baclawski. She went on to say that she "can see interlocking parts of wing pieces (Figure 2). Diane had her Foldscope for a short time but made good use of it.

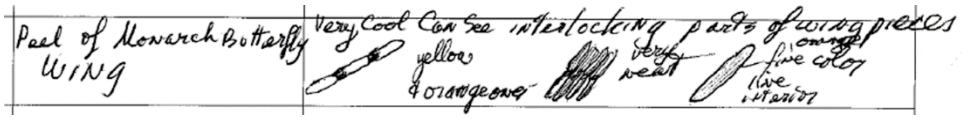

Figure 2. Diane Baclawski's drawings of Monarch Butterfly wing parts.

John Topor made an astute observation about the skin from a yellow Spanish onion, indicating that there are, "[m]any black-edged elongated cells packed parallel to each other" and "[c]ells appeared several times longer than wide," providing not only an observation on position of the cells, but also a relative measure of cell size.

Darlene McDonald made a great number of slides and was enamored with the ability to see such abundance in such a small field of view. Most of Darlene's observations are from plant materials, with a few exceptions from the animal world. Like Bob Simmer, Darlene looked at pollen and finely differentiates them as "small dark, thick, circular dots with 'prickly' protrusions covering surface" for basil pollen, and "…clumps of small circular dark bodies…" for goldenrod pollen. Darlene described a house fly wing as being "covered with thick hairs" and the "[i]nterior covered in small pores with individual hairs." She goes on to say that, "[i]ndividual fine hairs line inside [the] edge of [the] wing. Thick structures present as dark lines

to form shape." Of a human blood smear, Darlene says that the cells are "very minute" and "some [are] red, some [are] clear and that "[t]he quantity is amazing."

David Clark had some good observations of the Neogene diatomite material supplied to members of the Friends. He drew some good, general renditions of the diatom *Thalassiosira leptopus*. This diatom is probably around the same size as *Arachnoidiscus ehrenbergii*, and to be able to enough detail to distinguish the two centric diatoms using the Foldscope is truly amazing (Figure 3).

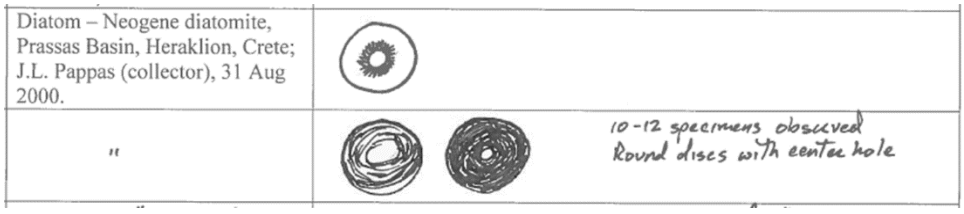

Figure 3. David Clark's drawings of Neogene diatoms.

Jim Craig also made some excellent observations from slide preparation of the diatomite. He drew pictures (left to right) of a silicoflagellate, potentially two different pennate diatoms, and a centric diatom that might be a *T. leptopus* (Figure 4).

Figure 4. Jim Craig's drawings of microfossils from Neogene material.

Some of the most detailed observations came from Alex Brown. He spent a great deal of time writing descriptions and making drawings of his observations (Figure 5). Alex identified his specimens with both their common and scientific name.

Like Graham Lewis, Alex used stains in slide preparation. He saw amyloplasts clearly within potato cells stained with iodine. This is the classic way to reveal unpigmented plant plastids that contain starch (e.g., Kuipers et al. 1994). Alex also viewed potato cells without stain for comparison. He prepared and viewed purchased diatomaceous earth, and entered his observations as entry number 8 on his data sheet. According to Alex, "The diatoms in this sample look like squares but upon closer inspection are cylindrical." This is a keen observation since this diatomite is composed of freshwater taxa that is cylindrical and almost entirely identifiable as *Aulacoseira granulata* (e.g., Harper and McKay 2010). Another observation by Alex is worth mentioning. From a stained mount of pear fruit cells Alex prepared, he saw "sclereids clearly visible in sample" with the lumen present. Alex's careful slide preparation and observations show the great utility of the Foldscope, even at low power.

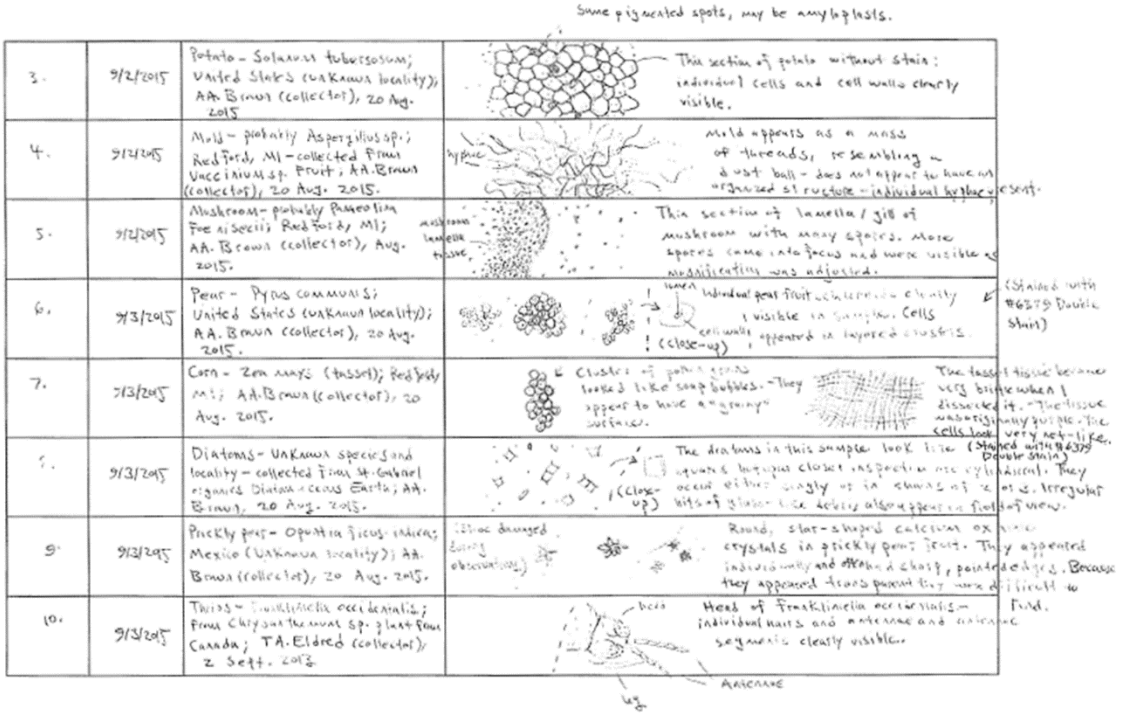

Figure 5. The second page of Alex Brown's data sheet.

Foldscope as an inspiration for inventiveness in scientific inquiry and microscopy

At the Cranbrook Institute of Science in Bloomfield Hills, Michigan, Dexter and Elizabeth Snyder are docent volunteers with a passion for helping children discover the world of science. They are in charge of the Family Discovery Center at Cranbrook that provides members of the public with the opportunity to engage in various natural science related activities. Visitors soon find themselves immersed in botany, zoology, paleontology, and anthropology by engaging in hands-on experiences with the specimens and artifacts such as skeletons, rocks, fossils, insects, and cultural materials at the Family Discovery Center.

According to Dexter, "The Family Discovery Center was established in 2010, opens on Sundays, and is developed and staffed by volunteers. It provides our visitors [with] a learning opportunity that ignites curiosity and inspires a joy of inquiry through adult-child activities. We serve 2000 or more visitors a year." As Dexter says, "We foster an atmosphere of inspiration and creativity."

Dexter and Elizabeth obtained two Foldscope packets at a meeting of the Friends where they are fossil enthusiasts and members of the group. The Foldscopes were to be used by people that visit the Family Discover Center during the summer of 2015 to learn about all things microscopic. Microscopy is an important part of learning at the Family Discover Center (Figure 6). Microscopes and supplies are available for anyone with an interest in discovery of the smallest that nature provides. In fact, a regular presentation to visitors is that the magnification of the microscopic world happens by nature itself with the help of a pond water drop and laser pointer (Figure 7).

Figure 6. Children using a microscope with visualization through a computer.

(Photo credit: Dexter Snyder).

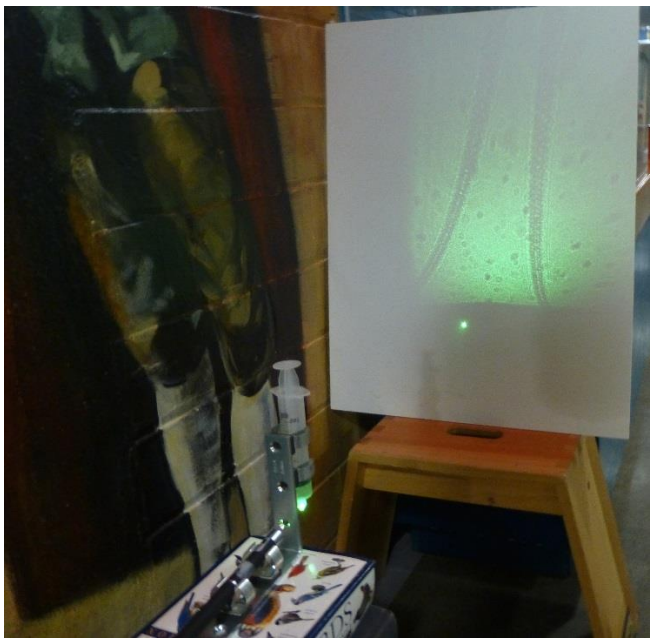

Figure 7. Using a pond water drop and laser pointer, nature's microscope projects an image.

(Photo credit: Dexter Snyder).

Family members readily made microscope slide preparations using sticky tape and plastic slide blanks. Tape was used as the cover slip on the mounted specimens. Commercially prepared slides were also available for viewing. To provide the transmitted light source, an incandescent light bulb was used. An adult docent made the Foldscopes using the on-line instructional video (http://www.foldscope.com/10kmicroscope-project-blog/2014/12/14/official-video-instructions-for-foldscope-assembly-and-collecting-data-on-cellphones) and helped people to view slides that were prepared from a number of natural materials. People were able to see: cell walls and nuclei of stained onion epidermis; cubic halite crystals; cells from a smear of dried human blood; distinct sharp sides of a stained pumpkin stem; pig motor neurons; stoma, phloem and xylem from pine needles; the central canal and ventral fissure from a rabbit spinal cord.

Dexter explains that he and other docents tried to get family members to use the Foldscopes, but younger children did not have the patience or motor control to find and resolve specimen images. Alternatively, Dexter, being a tinkerer with enthusiasm for inventions himself, made his own simple microscopes. Microscopy should "work for all levels of young learners," according to Dexter, echoing the intentions of the Prakash Laboratory team. "By late middle school, [and] certainly high school, kids can use the FoldScope. I work mostly with the younger set - shorter attention span, less experience futzing with delicate adjustments, greater payoff for modest magnification (25-to-50X)," says Dexter. He uses larger inexpensive ball lenses, providing a larger field at less magnification. Dexter's microscopes are constructed with clothes pins and a bit of wood along with the larger ball lens (Figure 8). His microscopes are reminiscent of the Van Leeuwenhoek design. Dexter credits the Prakash team for "inspiration, plus your great design for the serious magnification." He indicates that, "Family Discovery Center is now developing an activity where visiting families can make their own slides, use

either [a] FoldScope or [my] homemade versions – depending on the child's age and ability – and either take home a ball microscope or anticipate commercial availability of the FoldScope."

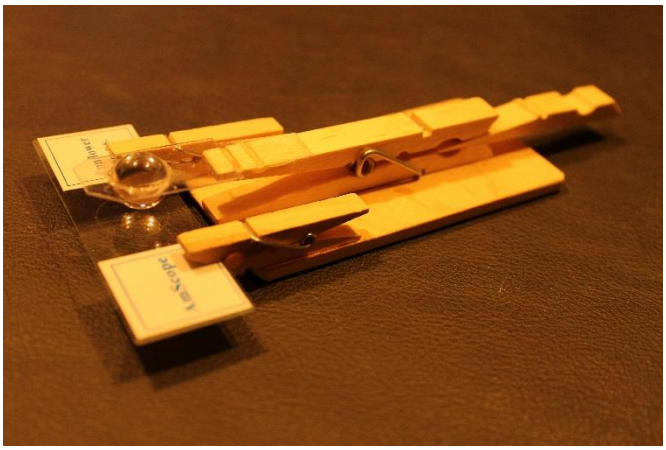

Figure 8. Dexter Snyder's ball microscope. (Photo credit: Dexter Snyder).

As they scan and view specimens with Dexter's microscope, the children are encouraged to draw what they see. As a couple of examples, flower parts and leaves were provided as the material to be examined and illustrated, and some of the children did just that (Figures 9 and 10). The microscope images are much like those that one would see using a Foldscope and reported on the Microcosmos blog.

Dexter and Elizabeth Snyder are dedicated to science education for children. Their enthusiasm for science extends to the parents and adults that visit Cranbrook who benefit from such dedicated individuals. As with the Prakash Laboratory team, they are in large measure instrumental in promoting microscopy for all.

Figure 9. a, flower parts viewed with ball lens; b, inner flower parts drawn by a child. (Photo credit: Dexter Snyder).

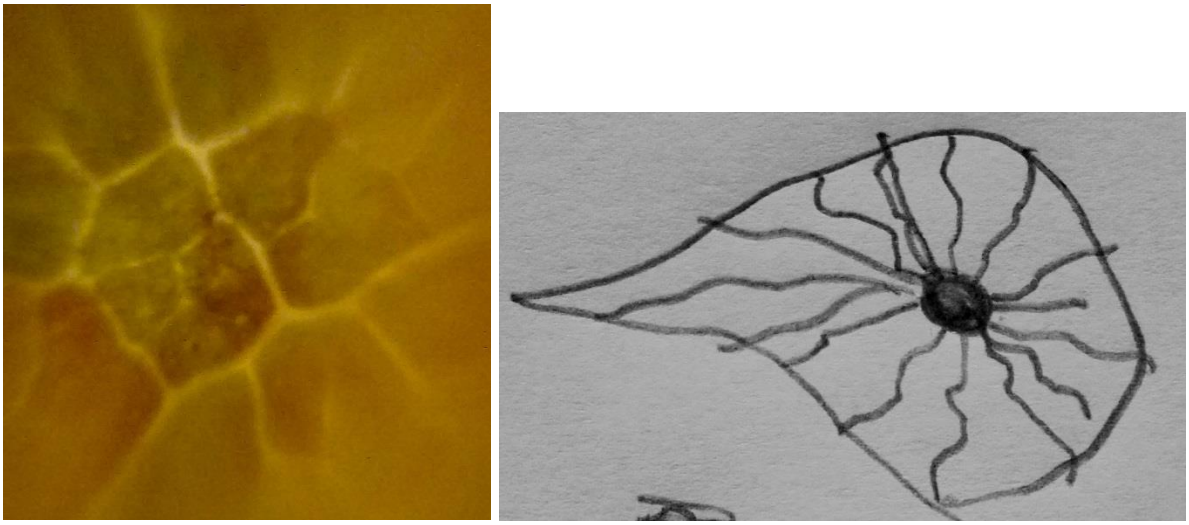

Figure 10. a, leaf veins viewed with ball lens; b, leaf veins and fungus drawn by a child. (Photo credit: Dexter Snyder).

Beta-test 3: Michigan Math and Science Scholars July, 2015—biological oceanography class

During July, 2015, high school students from all around the world attended my biological oceanography MMSS class entitled, "Deep Sea Monsters or Docile Dwellers? The Biology of the Oceans." They each received a Foldscope sheet and accessories to put together a Foldscope and use it to view prepared and student-made slide mounts. During the microscopy class, we used compound light and stereo microscopes as well. Students learned which materials were best viewed with a compound light microscope and the Foldscope vs. viewing with a stereomicroscope.

The prepared slides consisted of mounts of parts of sea stars, *Grantia* spicules, *Aurelia*, *Hydra*, marine diatoms, zooplankton, phytoplankton, and radiolarians. Every student also had the opportunity to look at a prepared slide of the diatom *Arachnoidiscus ehrenbergii* (the same slide which I mentioned earlier in the section on my observations). Students had access to a salt water tank with sea anemones and urchins in residence as well as aquatic plants in order to make slides of epizoans, epiphytes or free-living aquatic microorganisms.

All of the students found it very easy to put together the Foldscope. They were amazed that something so small and simple could produce an image so sharp and clear with the low power lens. Students commented on the amount of detail that was seen with the Foldscope and how the level of detail was comparable to low power with the student compound light microscopes. One student remarked, "When we used the FoldScopes, I was surprised to see how well they worked. I had expected them to look different as well." In general, the students were impressed with the level of clarity in viewing specimens using a Foldscope and liked the small size, making the microscope readily portable.

Usage of the Foldscope –additional remarks and recommendations from testers

Overall, users of the Foldscope were surprised by the quality of viewed specimens. People found it remarkable that the Foldscope could furnish the degree of sharpness and clarity in viewing specimens with such rudimentary construction materials. Some of the participants in the beta-testing of the Foldscope had specific comments about the Foldscope and weighed in on what they liked and what they thought could be changed.

One high school student remarked that the Foldscope took some getting used to in order to view slides. He said that Foldscopes were slightly hard to use until you got the hang of it. He said that, "Overall, while I did like the FoldScopes, if they were slightly easier to use it would help a lot."

Other comments came from members of the Friends. Graham Lewis said, "Constructing the foldscope was easy (I followed along w/ the video instructions), though I did experience the same problem as Dave C. (Friends member, David Clark) w/ the cut on one side of the "sliding stage" not being complete. The only difficulty I've had w/ using the foldscope is finding and positioning a specimen under the lens. I'm going to cut some more openings in the part of the stage that holds the lens, and hopefully improve visibility while maintaining the rigidity of the stage. I'll let you know how it goes... The paper slides are tougher to work with, specifically the adhesive labels (aka "cover slips"). It's easy to pick up dust or other contaminants from the surface you're working on. Also, the adhesive itself shows up when looking through the foldscope, obscuring specimens, especially if the specimen is not stained. I've picked up a basic selection of stains, so this shouldn't be as much of an issue in the future. Besides, the

image quality of the foldscope's lens is such that I'm not ashamed to look at the best-prepared glass slides with it :)"

Alex Brown had specific remarks as well concerning usage of the Foldscope. He said that, "The drawings I included with my observations are what I actually saw with the Foldscope, and even with low magnification I was able to see quite a bit of detail. At first I had trouble seeing objects through the lens but the more I practiced, i.e., adjusted the focus, moved the field of view around, etc. the more I was able to see. This was especially the case with the diatoms I observed (the freshwater *Aulacoseira granulata*). The top slit for fitting my slides into place was a bit too small; I had to jam them in to make them fit. Future models might have the slit a little bigger. In the course of observing a sample, one of my slides got damaged when it caught with the top flap as I was sliding it into place (thankfully I was still able to use it).
Future Foldscope instructions might warn people about this and tell them to pay attention and be careful when placing slides into the Foldscope. Since the Foldscope had to be held close to make observations, many of my slides became smudged from oils from my face and had to be cleaned. --Although this was a minor inconvenience for me, it might have been a concern if I was dealing with unique and/or permanent mounts. --I'm note (*sic*) sure what the solution to this might be. Overall I learned a lot from the Foldscope, namely, specimen preparation, silde (*sic*) mounting, and basic microscopy techniques. I also thought it was fun to be able to make microscopic observations at home, right in front of my computer, using a simple lamp! -- The possibilities for the Foldscope are endless."

While the Prakash Laboratory team has received voluminous feedback through the Microcosmos blog and from other sources, my involvement as a beta-tester with two different groups of individuals helped me to reflect on Foldscope usage and durability, offshoot ideas with

regard to the Foldscope, and the potential for additional dissemination of Foldscopes as educational tools for microscopy.

Like those testers already mentioned, I had problems with inserting slides into the second opening. This is a minor design fix that should not be a problem to remedy. Overall, the design of the Foldscope is really quite good. It is easily made, used and produces exceptional results for all its simplicity. It is fairly rugged in withstanding usage. I have let dozens of people view a slide using my already-made Foldscope, and it is still in good condition. I am not especially careful in how I transport the Foldscope, yet it has been robust to such nonchalant treatment. Some improvement is needed with regard to the high power lens. I tried mounting the high power lens as instructed (https://www.youtube.com/watch?v=x5yG2iP7cwQ) with two pairs of high power and holder pieces at two different times, and using these, was not able to focus on specimens in the phytoplankton or diatom identification permanent mount slides. I tried many times on different days. I tried reassembling the high power lenses and using them. Nothing worked for me.

There are a couple of items worth suggesting with regard to Foldscope usage. For educational and research purposes, it would be handy to be able to find a specimen with the Foldscope, put the Foldscope with the inserted slide down on a table, consult a book for identification of the specimen, pick up the Foldscope and inserted slide, and see that same specimen which was of interest. This would be useful if one wanted to show the same specimen to multiple people as well. Currently, it is difficult to perform this maneuver as there is no way to keep a specimen of interest stationary while using the Foldscope. Perhaps numbered tick marks (horizontally and vertically) on the static lower base and upper moving stage of the Foldscope could be used as references to indicate specimen position. Alternatively, perhaps

some sort of lock down mechanism on the upper moving stage could be added for use when a particular specimen is to be viewed. I will let the Prakash team see what they can do here.

To help conduct educational or research studies in the field, it would be useful to have an origami-based holder for storage of an already-made Foldscope and prepared slides. When in the field, slides are made on-site, and for example, if one needed to have a permanent record of specimens collected (as is the case for museum specimens), then it is necessary to keep rather than discard prepared slides. For students on an aquatic biology excursion, having a Foldscope handy with a small set of prepared slides would be very helpful in identifying microorganisms and for comparison purposes with the slides one would make on-site from a pond, lake or river.

One item worth mentioning is the utility of the light module. The ease in attaching the module to the Foldscope, the relatively long-lasting LED source, and the inexpensive replacement capability, makes the Foldscope even more self-contained and dependable over a long period of time. Using this module was quite helpful so that one was not reliant only on the available light source, which sometimes may be inadequate for using the Foldscope. Making the light module and condenser more widely available would be a great enhancement in using the Foldscope. However, the elevated cost per Foldscope may negate the addition of the light module and condenser in every Foldscope package versus availability of the Foldscope as it stands in the beta-testing project.

As an educational tool, the Foldscope has clearly been shown to be quite valuable. To disseminate this instrument to full capacity usage is perhaps one of the best ways to advance science education. With access for all, the Foldscope can transform classroom education into a non-formal activity that can be done at any time and any day. This is true not only because of the instrument itself, but also for the inspiration it provides to those with a passion for education,

like Dexter and Elizabeth Snyder at Cranbrook. A program to disseminate Foldscopes on a group-wide basis to non-formal educational centers such as Cranbrook or outreach groups, such as Michigan Technological University's Great Lakes investigations for grades 4-12 (http://wupcenter.mtu.edu/news/2015/RTW2015.html) would be one way to educate children via non-traditional institutions and extracurricular programs. In turn, many institutes and organizations could be used as vehicles in promoting non-traditional educational initiatives such as the Ten Thousand Microscope Project. We as a society must find ways to embrace ideas and concepts of non-traditional education to advance the betterment of people and sustain availability of remarkable instruments such as the Foldscope, which broadly promotes and contributes to science education for all.

Final Thoughts

The microscopic world is so important in our everyday lives, yet we know so little about or are unaware of this basic influence. The Foldscope enables us to access the microscopic world and see what we have been missing. We marvel at the macroscopic diversity and complexity of life on Earth, and now with a low cost, easily used option, we can open our eyes to a microscopic world that is every bit as diverse and complex. All we have to do is make and use a Foldscope, make a quick slide preparation, and we have found this whole new place to see, explore and appreciate.

The Foldscope is a game-changer for educational purposes. No longer do we have to have high monetary resources in order to do microscopy. In the long run, sustaining the production of and accessibility to the Foldscope is of the utmost importance. Open-licensing or other open-source means may be a way to address large-scale accessibility. A consistent,

reliable source of input funding for production and manufacturing of Foldscope materials may be achieved through crowdfunding, individual investment, charitable trusts, or other financial instruments. With the use of social media, various inventive avenues and instruments of funding are potentially in the offing, and we will all be beneficiaries of the world that the Foldscope has opened up for us.

Acknowledgments

I would like to thank Manu Prakash and the Prakash Laboratory team at Stanford University for selecting me to participate in the beta-testing of Foldscopes. I wish to thank everyone who participated in testing the Foldscope. My gratitude goes to my colleagues for their interest in the Foldscope as a realization of the concept that microscopy can be accessible to everyone. I am grateful to Friends members David Clark, Graham Lewis, John Topor, Jim Craig, Bob Simmer, Darlene McDonald, Alex Brown, and Diane Baclawski for their participation. I am especially grateful to Friends members Dexter and Elizabeth Snyder for their contribution and dedication to education. Finally, I wish to thank my biological oceanography high school students from the MMSS program for their participation. They now have Foldscopes with which to mark their educational progress with microscopy in a unique way.

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Ross R., Sims P.A. 1972. The fine structure of the frustule in centric diatoms: a suggested terminology. British phycological Journal 7: 139-163.

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Appendix A. Foldscope IDs for academics and professionals.

0001	4233	54E6
0001	4234	5042
0001	04F3	14B2
0001	04E3	CO33
0001	04E9	980F
0001	04E6	0C86
0001	04E4	559E
0001	04E4	90EB

Appendix B. Foldscope IDs for members of the Friends of the University of Michigan Museum of Paleontology. Four members kept their Foldscope and materials but did not report findings.*

0001	423A	3301
0001	4237	29AF
0001	4235	3311
0001	4237	A05F
0001	4236	CFAE
0001	4234	DAEF
0001	04F2	8456
0001	04E2	DBD3
0001	04E0	1126
0001	4234	78BB
0001	4239	E478*
0001	4237	5386*
0001	04F2	7487*
0001	04DF	E3E8*

Appendix C. Foldscope IDs for high school students in Michigan Math and Science Scholars 2015 class in biological oceanography.

0001	2A3A	AD86
0001	2A39	6A39
0001	2A2A	FD64
0001	2A2B	768E
0001	2A2C	2C38
0001	2A30	1794
0001	2A2C	C895
0001	04EC	CAF1
0001	04EE	FFF4
0001	2A2A	FB8B
0001	2A34	2522
0001	2A38	39F9
0001	2A38	F3D1
0001	2A35	8D9C

Appendix D. Instructions for members of the Friends of the University of Michigan Museum of Paleontology with regard to the Foldscope.

April 3, 2015

Beta tester for Prakash foldscope project: Janice Pappas, jlpappas@umich.edu

First test group:

Volunteers from the Friends of the University of Michigan Museum of Paleontology

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Congratulations! You are a participant in the Prakash laboratory foldscope project. A goal of the project is to make microscopy available to everyone with the Prakash foldscope because of its ease in assembly and low cost to produce.

To participate in the project, you will be required to assemble a foldscope, view microscopic entities, and record your observations.

You will find the following foldscope materials in your packet:

1 sheet with the Prakash foldscope and 6 paper slides (glass slides and coverslips can be used as well)

1 sheet with 25 adhesive backing strips for making slides (Scotch tape can be used as well)

1 low power lens (small black plastic piece with a "bump" (140X lens) on one side)

1 strip of double sided tape (other double sided tape can be used as well)

1 foldscope identification label imprinted with 3 rows of 4 numbers/letters and "foldscope.com."

Be sure to attach the adhesive identification label to the back of your foldscope. Record this identifier with every observation for each slide you view with your foldscope.

Instructions on foldscope assembly are found at:

http://www.foldscope.com/10kmicroscope-project-blog/2014/12/14/official-video-instructions-for-foldscope-assembly-and-collecting-data-on-cellphones

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Specimens for slide making:

You are also provided with a small amount of Neogene diatomite from the Prassas Basin, Heraklion, Crete, Greece, collected by Janice L. Pappas on August 31, 2000. More information on the deposits and diatom identifications can be found at

http://www.geo.fu-berlin.de/geol/fachrichtungen/pal/eigenproduktion/Band_10/07_Frydas_Bellas.pdf

and

http://www.geo.fu-berlin.de/geol/fachrichtungen/pal/eigenproduktion/Band_10/08_Frydas_Stephanopoulos.pdf

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Other specimens:

You are welcome to make slide mounts of anything that might be of interest to you. Some suggestions are:

Non-diatom microfossils (and their fragments) such as forams, ostracods, silicoflagellates, sponge spicules, radiolarians, dinoflagellate cysts, testate amoebae, pollen

Fragments of acritarchs, phytoliths, graptolites, conodonts

Fragments of mollusks, echinoderms, brachiopods, trilobites, or other fossil invertebrates

Fragments of vegetative matter including onion skin, leaves, pine needles

Cells of blood, protozoa, bacteria, phytoplankton from ponds

Other materials provided for you to make microscope slide mounts:

Glass microscope slides

Glass coverslips

A plastic pipette

Some lens paper (for cleaning glass slides, glass coverslips, surface of the low power lens)

Suggested additional tools:

It will be very helpful to you if you have a clean, fine tipped tweezers or forceps (for example, from a dissecting kit) or a clean dissecting needle to maneuver your samples for mounting. Other potentially helpful tools include a microspatula, additional pipettes, an X-acto knife blade/thin razor blade, 000 sable (or equivalent) brush (for picking up forams and similar

specimens). See: http://deepblue.lib.umich.edu/bitstream/handle/2027.42/106589/JLP-Friends%20Apr%202014%20talk%205-8-14-Annotated.pdf?sequence=1) for additional information.

Information on how to make microscope slide mounts

Wet mounts: Use clean water (preferably distilled water). Use the pipette to deposit a droplet of water on your cleaned glass slide. If using a paper slide, mount a piece of adhesive backing to the underside of the slide—do not get you fingerprints on the tape. Deposit a droplet of water on this and try to distribute the droplet over the adhesive surface. Do not contaminate the water with instruments or your fingers! On either the glass or paper slide containing a water droplet, use a tweezers or dissecting needle to retrieve a very small bit of dry sample to deposit on the water droplet. You may have to do this a few times to get an even distribution of material on your slide. If using the glass slide, and your mount is not as good as you would like, you can clean the slide and repeat the process. If using the paper slide, you can try to change the amount of material/water by shaking off the excess. The adhesive should retain some of the material. If this does not work, you will have to use a new paper slide and repeat the above process. Your technique will improve as you make more and more slides!

After depositing the dry sample bit on the water droplet, you can now add a glass coverslip to your glass slide. To do this, use your fingers to grab the very tips of the corners of one edge of the coverslip. Do not put your fingerprints on the coverslip—they are not readily removed with water. Place the free edge of the coverslip at the left edge of the water droplet (if you are right-handed; the opposite for lefties). Slowly let the coverslip touch the rest of the water droplet gradually from left to right to prevent the creation of air bubbles in the water. Use a small piece of facial tissue to wick up any excess water that exudes from the edges of the coverslip on the slide. Do not wick up too much water that would make your mount dry out.

For paper slides, take another piece of adhesive backing and try to place it on top of the wet mount in a left to right fashion (or vice versa as necessary) as stated above in the glass slide-coverslip method to prevent the formation of air bubbles.

For wet substances, mount as above minus the addition of dry sample. For stains, search the Internet for particular stains and their protocols for use and applicability to particular types of samples/tissues/cells. Many stains are used with non-living (fixed) tissues; others are used with

live organisms such as protozoa. Some common stains to consider using include iodine, eosin red and methylene blue. Some stains are more permanent when combined with acidic or other media. Many other stains are available, depending on the kind of sample you are interested in viewing with your foldscope. Staining samples can be used in wet and permanent mounts.

Permanent mounts: A similar protocol to wet mounts is used, except the fluid used is a mounting medium that hardens and preserves the specimen over time. Permanent mounts can be done only on glass slides and coverslips. The medium used should have a refractive index that is most similar to glass to maximize viewing clarity of the specimen. Many permanent mountants are solvent-based (non-aqueous) and might be difficult to obtain. Naphrax for diatoms is available through Steve Nagy (http://montanadiatoms.tripod.com/). Presumably, Naphrax could be used with other types of specimens, provided that specimens do not react to the media, change the refractive index, or fade or change over time. General alternatives to Naphrax include Permount, Meltmount, Canada Balsam, and Taft's medium. All permanent mounting media should be handled with care, with proper protective clothing, and in a well ventilated room. Sometimes, heating is necessary to facilitate curing the mountant to the desired state of hardness. Alternatively, air drying can usually accomplish the same result (unless high humidity conditions exist), but a longer period of time will ensue until the slide is ready for viewing.

Semi-permanent mounts on glass slides can be done when the mounting medium is a non-hardening, non-aqueous substance with a high refractive index such as clove oil or glycerin. The coverslip edges of semi-permanent mounts can be sealed with clear nail polish or paraffin to reduce the evaporation of mountant over time.

Dry mounts can be done as well. Air drying sample on a glass slide with a coverslip may work for some wet specimens/wet mounts. In this way, such mounts are permanent, provided the coverslip does not become dislodged. Sealing the coverslip edges (as specified above) might hold the coverslip in place.

Always number and identify each slide you have made. This information will be transferred to your data sheet of observations.

Collecting data:

A data sheet has been constructed for you to record observations. [See the separate data sheet with example entries. An electronic version will be provided for you to use]. Be sure to transfer

the slide number/identifier for each slide you have made onto the data sheet. For each observation on the same slide, you should use a separate line for each entry. Be sure the slide number/identifier is clearly associated with each specimen observed on that slide. Write down all of your detailed observations—this information will be very important as empirical scientific data and in assessing the utility of the foldscope. You are welcome to expand the data sheet and add additional observations on separate sheets as necessary.

If you make permanent (or semi-permanent) slides, be sure to archive these in appropriate housing (slide box or other appropriate container) for safe keeping. Keep a copy of your completed data sheet with your archived slides.

Reporting data:

With any observations you make, you are welcome to join any of the blogs listed on the foldscope website (www.foldscope.com) and let others know what you found. In addition, I need to have you send me an electronic copy of all of your data sheets as a hard copy or as an e-mail attachment. Hard copies can be sent to me at: Museum of Paleontology, 1109 Geddes Avenue, University of Michigan, Ann Arbor, MI, 48109-1079.

As a beta tester for the foldscope, I will be writing a report on the utility and accomplishments of members of the Friends using the foldscope. You will be given full credit for your work!

Most importantly in this endeavor, have fun!!

Other references you may find helpful and interesting:

Mounting microfossils

1) http://www.microscopy-uk.org.uk/mag/artaug11/Micropaleo-Slides.pdf
2) http://www.modernmicroscopy.com/main.asp?article=102&print=true&pix=true
3) http://www.geotop.ca/upload/files/publications/cahiers-de-laboratoire/Micropal_Methods_2010.pdf
4) http://www.microscopy-uk.org.uk/mag/indexmag.html?http://www.microscopy-uk.org.uk/mag/artfeb99/kamast1.html
5) http://lrc.geo.umn.edu/laccore/assets/pdf/sops/smearslides.pdf