Innovations

Foldscope™ as a Teaching and Learning Tool: An Indian Perspective

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Abstract

Science is all about how and why. India is a land of diversity and having an equally diverse education system. In a diverse classroom, it is important for the teacher to impart knowledge in such a way that it kindles curiosity in the learner. The best way to communicate science is 'learning by doing'. This requires great skill and apt teaching methodology especially in non-urban areas where the learning resources are scarce. In this regard there is a dire need for inexpensive, useful teaching and learning tools that can foster interest in science. This article is concerned with exploring the use and application of one such innovative tool—Foldscope™. Foldscope™ is a low cost, paper microscope that can help to magnify beyond the ability of unaided eye and explore our surroundings at the microscopic level. It is well suited to be used as a teaching and learning aide in Under-resourced regions. During the pandemic COVID-19 online and distance mode learning has come as a savior, this frugal tool can further facilitate practical learning because of its portability and unique features.

KeyWords: Foldscope, Teaching-Learning Process (TLP), Teaching tool, Portable microscope, Magnetic coupler, On-site foldscopy

Introduction

India, a country in South-Asia, is a myriad of geographical demographics with multitude of ethnic, linguistic and cultural diversity. Its unique diversity is the strength and basis of modern India. India was once a powerhouse of knowledge and wisdom. Despite a strong heritage of intellectuals and their pioneering contribution to the world in education and other fields, the present scenario of education needs innovative changes to foster creative and critical thinking skills.

Present Scenario of Education in India

The model curriculum formulated by Kothari Commission as per *Report of Ed. Comm, 1971*(Aggarwal, 2009) set up to maintain uniformity has not yet fulfilled its objective. The present educational system in India is more of an input/output kind of model. Due to an Examination-centric education system that promotes rote learning, students face a highly stressful environment with multifaceted competitions. A fierce battle is seen for grabbing grades focusing more on earning a degree and less on real skills.

The scenario of science education is even more complex, as it has failed to inculcate creativity and innovation among learners. It is a general perception that teaching science involves huge investment and that in a developing country where resources are limited, teaching modalities need to be limited (Kremer et al., 2013). Physical infrastructure in Indian institutions varies due to geographical and financial disparity. The conventional approach of knowledge dissemination using the chalk, talk, and walk method is practiced predominantly. Information and communications technology (ICT) teaching aides such as computers and LCD projectors are beyond the reach of many institutes and science laboratories, still a dream in remote areas.

In the era of globalization, Teaching-Learning Process (TLP) needs transformation (Mohapatra et al., 2012).The two crucial components–the teacher and learner both-- are continuously evolving with the changing educational needs. TLP is directed by quality of learning rather than teaching. For in-depth understanding of scientific concepts and phenomena, engaging students in practical activities is an important part of active learning in science education

(Nawani & Jain, 2010). Field-based study is critical to teaching and learning biology and can lead the students to discovery-based learning (Wieman & Gilbert, 2015; Fleischner et al., 2017).

The Digital India initiative aimed at empowering youth has led to increase in the use of laptops and tablets as a part of TLP. To meet the challenges thrown by learners, techno savvy gadgets that can be carried in pockets have conceived the recent 'anytime, anywhere' learning concept (Smith et al., 2011). One such tool that helps in 'active learning' is Foldscope™ (Cybulski et al., 2014). It is a cheap and portable paper microscope.

Though journey of microscope started around 300 years ago since the time discovered by Leeuwenhoek (Wollman et al., 2015), but is ever evolving in many ways. It is still out of the reach of many, and finds its place in laboratories only. Learning and understanding science is not a privilege of a few who can afford resources. The lesser privileged students from rural and tribal areas, where infrastructure is negligible and they have rarely been exposed to microscopes in their learning years, this affordable paper microscope-Foldscope™ is a hope for the less privileged to learn. The present article is based upon this innovative tool— Foldscope™ and its possible explorations in microscopic world within and beyond boundaries of class room. While there have been many publications over the past decade reporting on portable or mobile-phone microscopes, like Cellscope™ (Philips et al., 2015), comparably few studies have been reported of using it under field conditions. The COVID-19 pandemic has led to digital transformation of education even in most deprived regions of the nation and online teaching and distance education has come as a solution. This cheap tool can further facilitate practical learning of biology, as it has the potential to conform to curiosity of the learners due to its ease of use, low cost, and portability.

Democratization of Science: A Govt. of India initiative

Foldscopy is an initiative of DBT, GoI (Department of Biotechnology, Govt. of India) for augmenting science education. DBT aims at *Popularization and Democratization of Science* in India by taking science to the doorsteps of all, even in resource poor settings across the country. With this objective DBT has partnered with Prakash lab's on foldscopy to make the mission 'Science for all' possible. As a part of this endeavor the department has sanctioned projects grants to researchers and academicians in schools and colleges for exploring diverse habitats. Twining Programme is initiated by DBT (GoI) to booster the collaboration of North Eastern states with other parts of India for quality research, education and training in biosciences (Sharma and Mohan, 2016). Under its Foldscope™ Twining programme, collaborative research projects between North Eastern Region (NER) institutions and from other parts of country has culminated exchange of innovative ideas among different Foldscope users across the nation. (http://dbtindia.gov.in).

Foldscope™: The portable microscope

An Overview

Foldscope™ is a low-cost, thin, pocket microscope made of color-coded paper coated with water-proof polymer. Manu Prakash, the brain behind this tiny invention, an Indian-origin scientist at Stanford University, conceptualized the idea, keeping in mind the resource constraints of developing countries (https://foldscope.com).

Foldscope™ works on the same principle of magnification as a simple microscope. It is a transmissive light microscope. The low power lens supplied with the kit is a borosilicate glass ball embedded in a circular black plastic piece; it is capable of magnifying objects 140X. This magnification is highly effective if compared to a low power lens of a compound microscope used in laboratories which has a 4X objective lens and a 10X eyepiece, the magnification being only 40X (Cybulski et al., 2014).

Unique Features

Foldscope™-the origami-based mini-microscope has following features:

- It can be assembled from a waterproof flat sheet of paper containing its jigsaw pieces within 10-15 minutes.
- Its tiny size ensures safety against damage even if dropped from a multi-storied building or stepped on.
- It is portable - being small, it can easily fit in a pocket.
- It does not require an external power source for illumination.
- It can be used for direct viewing by eye or can be projected on a screen.
- It can be coupled to a mobile phone to capture images.
- It can be used for bright-field, fluorescence or projection microscopy.

Basic Foldscope™ kit and its variants

Components included in basic individual Foldscope kit are enough to observe microscopic specimens around us. It contains Foldscope™, prepared glass slides, standard paper slides, microwell paper slide, an extra magnetic coupler, ring stickers, cover slip stickers and a cotton swab. Another variant, "The deluxe individual kit" is supplied with versatile accessories, it includes an LED magnifier light, scissors, forceps, microwell plates, petridish, microfuge tubes, droppers, strainer, clear tape roll, microscope slide set, reusable slides and cover slips, ring stickers, sterilized sample bags, a notebook and a pencil. The Foldscope™ instrument is identical in all the variants.

How to use

Foldscope™ is ready to use in three easy steps (Fig.1).

- The first involves assembling the Foldscope™ unit by joining together different pieces from a flat sheet provided in the Foldscope™ kit
- The second focuses on collecting and working with the samples.
- The third captures images of the object using smart phone coupled to Foldscope™ with a magnetic coupler (http://www.foldscope.com).

Figure 1 *Steps to use a Foldscope™*

A) Color coded waterproof origami sheet. B-C) Jigsaw pieces taken out from sheet which are joined together by paper folding to assemble Foldscope. C) Various accessories and kit components of Foldscope kit which are used for sample collection, preparation and viewing. D) Front view of Foldscope instrument-blue in color. E) Rear view of Foldscope instrument- yellow in color having slide pocket where slide is inserted upside down. F) Foldscope attached to smart phone. *Courtesy: Foldscope instruments*

Sample Preparation and viewing

Specific directions to use are provided in detail with each Foldscope™ (http://www.foldscope.com). It allows any curious explorer to have microscopic observation of any sample within short time with just a simple glass slide, transparent tape or cover slip and Foldscope™ without requiring any costly material or equipment.

Sample

Sampling involves mounting a small piece of the specimen on a glass slide and covering it either with a glass cover-slip or fixed using a piece of clear transparent tape/adhesive. Enormous variety of samples, dry or wet, can be observed under Foldscope™. It can be tiny microorganisms like some filamentous bacteria, fungi, protozoa, various tissues and cells for histological studies, as well as large organisms like nematodes, insects and their larvae, pollen grains, feathers, etc. Any translucent sample that allows the light to pass through it can be viewed under Foldscope™. Very dense and thick samples can be spread in a suitable liquid and covered with the cover slip. Simple staining techniques are required for better visualization of certain samples, while some can be viewed directly. Dry mounts are ideal for observing hair, feathers, airborne particles such as pollens and dust, as well as dead matter such as insect legs or antennae. Opaque specimens require very fine slices for adequate illumination.

Slide insertion and focusing

The slide is inserted within the slide pocket upside down (towards yellow side). Focusing of the mounted object can be adjusted in a simple way by sliding the paper platform with the thumb and forefinger.

Viewing

There are three methods to view the samples. First, the sample can be viewed directly through the eyes (Fig. 1). Second, it can be viewed through the camera of mobile phones. To view a sample with a phone, attach a magnetic coupler (provided in kit) over the lens of your phone camera- by using either a double-sided ring sticker or with any other tape. Bring your phone's camera near blude side of the Foldscope's lens and it will automatically fit in place because of magnetic couplers. The magnified image of the sample is visible on the screen of the camera. Foldscope's lens has a magnification of 140x, and that magnification is multiplied by the zoom feature of the mobile phone. It is ideal for recording the movements of living specimens by using the video feature of the mobile phone. For a clear photo and video record, a sample can be illuminated by holding the yellow side of the Foldscope towards a light source (any natural or artificial source such as a clear sky, tube light or the LED magnifier light provided). In the third method, a sample can be projected on a white screen or surface in a dark room. Projection requires a strong light source. A phone's flashlight can also be used. For this, attach a magnetic coupler over the phone's flashlight, and then bring phone's flashlight up to the aperture on the yellow side of Foldscope. Turn on the flashlight and aim it at a flat white surface. An image of the specimen inserted in Foldscope™ will be visible on the screen.

Use of Social Media Networking with Foldscope™

An online community, MicrocosmosFoldscope, is a platform for sharing information gathered through Foldscope™ (https://microcosmos.foldscope.com). This platform has served as a scientific social networking site and location for sharing of ideas and explorations from remote areas of India and the entire world. Instructors and students can post their observations on this community by registering themselves using their email ID and a unique code provided with each Foldscope™.

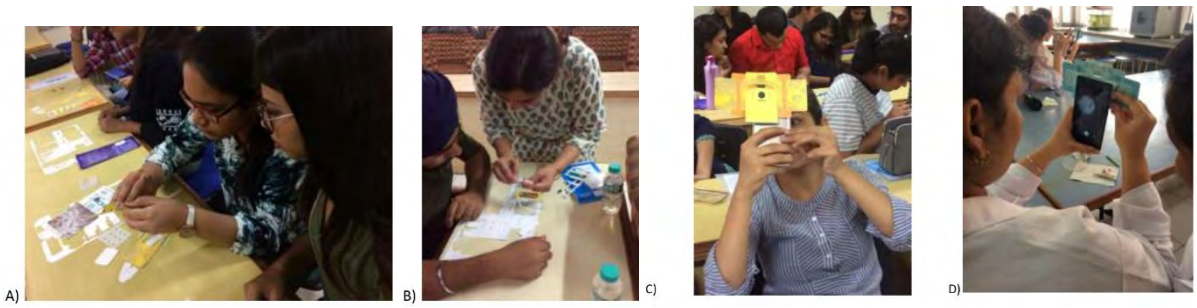
Methodology/the Process

The present article is an outcome of the observations revealing Foldscope™ usage. To use it as a teaching-learning tool, hands-on training sessions were conducted for undergraduate students during the 2018-2019 session. For this, a series of workshops and vacation camps (during summer and winter breaks) were organized by the Team Foldscope.IRB approval and student consent were obtained before conducting the workshop series. The instructors of all the workshops/ field visits conducted were the same so as to maintain uniformity. . In these workshops each participant was provided with a Foldscope™ sheet. After training to assemble and use these, students were encouraged to collect samples and explore on their own (Fig. 2).

The observations done by the team using Foldscope were posted on MicrocosmosFoldscope community with tags, # sd@foldscopechandigarh, and #Immuno@sdhawanchandigarh under # Indiafoldscopephase1.Students were able to perform on-site foldscopy with variety of samples collected during field visits and observe stained/permanent slides. A few of the explorations by the students during the field visits/workshops on Foldscope™ and captured with their smart phones as in Figure 3.

Figure 2

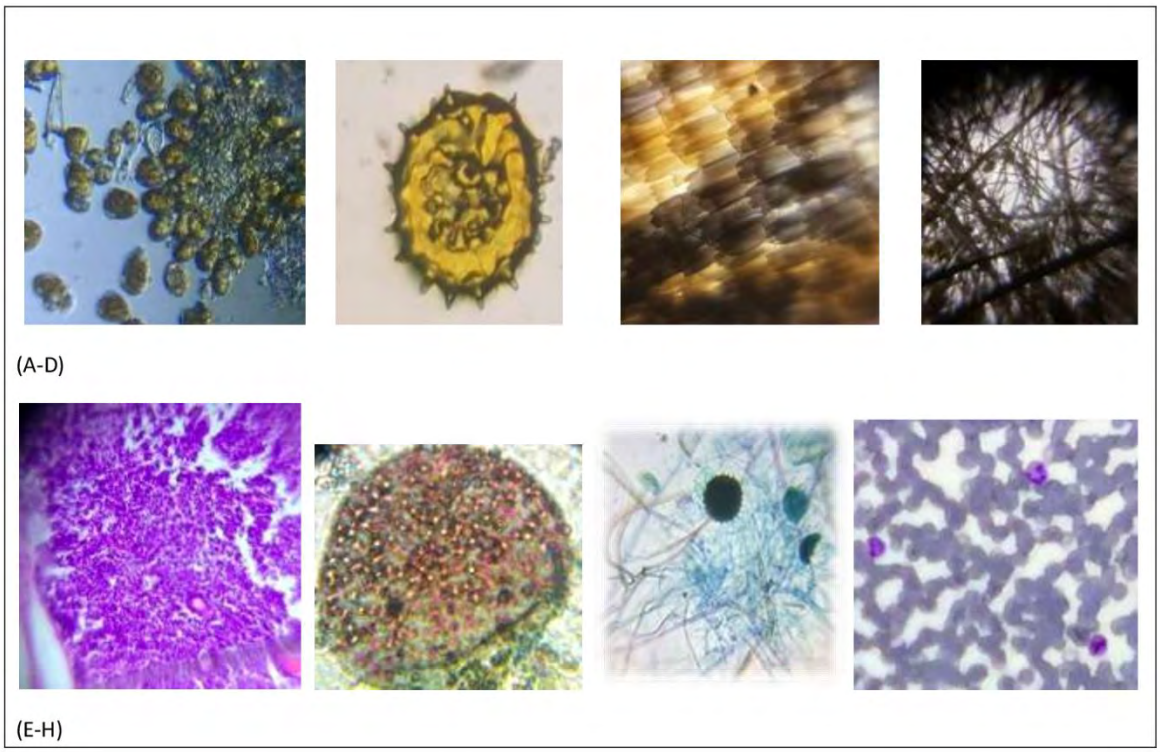
Foldscope workshop in progress at GGDSD College, Chandigarh, India



A) Undergraduate students attending workshop and assembling Foldscope™ from Foldscope kit components. B) An instructor helping to fold focus ramp for assembling Foldscope™. C) Another undergraduate student observing a *Volvox* colony while facing yellow side of Foldscope towards natural light. D) An undergraduate student excited to capture an image of focused slide on her smart phone.

Figure 3

Different explorations by undergraduate students using Foldscope™ and captured on smart phone



(A-D) On site observation of samples students collected during field visits. A) infected leaf of corn showing Rust of corn; B) Pollen grain of *Hibiscus*; C) Butterfly wing showing scales of butterfly. D) Entangled silk fibers of moth cocoon.(E-H) Observation of stained/ Permanent slides. E) Thymus-transverse section F) A *Volvox* colony G) *Rhizopus* Spores H) Human Blood smear.

General Observations and the Outcome of the Foldscope sensitization

Multifarious applications of Foldscope™

Foldscope™ was observed to be a multipurpose teaching and learning tool that may be useful for any educational institution. It can ignite young minds to come up with creative ideas.

An open school of learning

Age is no bar in usage of Foldscope™. It can be used by children, researchers, teachers or anybody

who has the quest to learn. The students trained at the workshop were allowed to take the Foldscope home to explore on their own. It was commendable that they shared the idea and had involved their parents and grandparents in this activity.

The preliminary observations on use of Foldscope™ as an active learning tool in science classrooms of both undergraduate and post graduate students revealed that it is a practical tool that students can use individually in bigger classes where access to microscopes is limited and generally the student: microscope ratio is ≥ 50:1It can be used in cell biology, microbiology, parasitological, immunology, and histochemical studies of various plant and animal tissues. Foldscope™ use is feasible in a course with medical focus or in a forensic science course, where students could look at prepared slides independently, can perform preliminary screening of hair, blood samples and can use it for human blood histopathological examinations like cell counting and morphology analysis. (Waliullah, 2018).

Multi-faceted all-purpose tool

Reports shared on a social networking community from different groups using Foldscope™ working in India revealed its potential for various applications, suggesting that it might be useful in all these fields (https://microcosmos.foldscope.com):

Biodiversity and environment - It can be used for exploring floral and faunal biodiversity of different habitats.

-Monitoring soil and water quality-Foldscope™ can be used for detecting microbial contamination in potable water and microbial load of soil samples. It can significantly contribute to pollution abatement and can find its place in soil and water testing kits.

-Sanitation and Hygiene- This tool can be used to identify eggs or larvae of disease spreading mosquitoes in stagnant water and destroy them at source. It can also be used for maintenance of oral hygiene by suggested use in diagnosing infections in dental plaque.

-In checking adulteration of food items-Foldscope™ can be used to check adulterants in various food items. It is reported to check adulterants and contaminants in various feed and food ingredients in field conditions using Foldscope™ (https://krishikosh.egranth.ac.in/handle/1/5810139727).

-In minimizing post-harvest losses-The fungal and microbial growth can lead to post-harvest losses. The quality check of perishable foods and microbial spoilage can be easily detected using this waterproof, light weight tool.

-As a medical diagnostic tool-It can be used to detect hemoparasites like *Plasmodium*, *Trypanosomes*, *Schistosoma* (Ephraim et al., 2015) and other dangerous blood-borne infectious diseases and disorders of blood; for analysis of crystals in urine. It can be incinerated along with infectious biological samples for safe disposal. In the less-developed countries where price soaring health check-ups fail to diagnose the disease in time for treatment, Foldscope™ can serve as a low cost, high performance tool for rapid on-site analysis. Without any expensive lab equipment, its usage takes as little as 5 minutes. Being affordable, user-friendly, rapid, robust tool it held great potential to deliver point-of-care diagnostics even in the absence of any power source and internet facility (Ephraim et al., 2015; Hu et al., 2014).

As an In-field identification/learning tool

Field study is a vital component in addition to class-room sessions in effective Biology learning. Foldscope can shift the paradigm of research from laboratories to fields, experimental plots and even homes. It can be used by researchers in field as a tool for Plant Systematic, Palynological studies. For Plant pathology, it can be used to study symptoms of various diseases and microbial pathogens. It can be of great help to farmers in early identification of disease causing agents and communicate with regional agriculture officers in order to follow suitable control measures. The Foldscope Team explained the use and application of Foldscope for microscopic examination of leaves and plant parts to farmers and gardeners of Punjab and Sikkim to identify pests on plants (Fig. 2).

Role in online and distance education

The COVID-19 pandemic has led to digital transformation of education and online teaching. This immense shift from physical to digital education may persist to meet changing needs. Anticipating the future course of science education, a pedagogical change is expected in the teaching-learning environment in the post-COVID era. Physical distancing and social isolation measures, such as temporary closure of educational institutions and workplaces, have created an altogether different challenge. This cheap tool can facilitate practical

learning of biology because of its portability. The omnipresence of mobile phones and the growing access to internet across the country can make mobile phone foldscopy a promising technology. It is leading to easy information sharing, making it a perfect tool for innovative Teaching Learning Practice both in offline and online mode.

General Observations and the Outcome of the Foldscope sensitization

Besides publishing diverse and dynamic posts on MicrocosmosFoldscope community, our team at GGDSD College, Chandigarh was able to discern three salient aspects of Foldscope™.

- Foldscope™ can be used as a learning tool both by students and teachers in conducting hands-on sessions within and beyond boundaries of classroom.
- Foldscope™ can be used as a basic research tool, thus laying a foundation for critical thinking. The students undertook short-term projects using Foldscope during their summer and autumn breaks, exploring and learning on their own by designing independent projects.
- Foldscope™ can be used as an in-field identification tool. Outreach programs conducted for people of diverse age groups and spectra of the society such as farmers and gardeners have demonstrated its potential as in-field identification tool for pests and pathogens.

Advantages and Disadvantages of Foldscope™

Structurally, its unique features allow an edge over the compound microscopes in terms of its portability, low cost, easy usage, easy availability, lack of energy and power requirements, and zero maintenance cost. Its portability allows on-site analysis anywhere. Foldscope™ is simple to assemble and can be operated by anyone with minimal training. It can be used for direct viewing with the unaided eye or coupled to mobile phone for viewing and for digital record keeping for future use.

Despite its several advantages, Foldscope™ has certain limitations

Although a Foldscope™ is ideal for viewing sub cellular structures, its resolution is still relatively low as compared to the high power of compound microscopes. It has a very small focus range so image analysis is difficult. It can be coupled only to smart phones. Foldscope cannot be used under dark conditions. A light source is required. The LED magnifiers provided in the kit can be attached to Foldscope™ to mitigate this problem.

It requires regular cleaning and maintenance and must be stored in dry conditions.

Safety issues for novice workers handling unknown microbial biological samples is another major concern. It must be used under the supervision of a competent person who understands the risks associated of working with unknown microorganisms.

For on-site biological fluid sampling, staining, and sample preparation can be major limiting factors, as can taxonomical identification and characterization of flora and fauna.

Conclusion

There is dire need to switch from the traditional chalk and talk approach of knowledge sharing to a learner-centric, agile, and self-learning approach in a developing country like India. Looking out for possible ways and means of imparting continuous learning are the objectives of the teachers and institutions in particular. For teaching and learning biology, the microscope is one of the most basic and powerful tools. But it is still inaccessible in under-resourced regions. The Foldscope™, a microscope that each student can own to learn biology easily is seen as a fitting substitute. Technology based tools that are easy to use and handle individually to avoid the community sharing to preclude contagious spread are being explored to meet the changed educational scenario in the Post COVID era. Though virtual labs can be the answer in the emerging scenario, wet lab simulation is a problem. Our explorations demonstrated Foldscope™ as an economical, ready to use, student-centric learning tool with potential to overcome the obstacles in disseminating science/biology education anywhere, anytime.

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Declaration of Interest

The authors declare no conflict of interest.

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