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Foldscope Embedded Pedagogy in Stem Education: A Case Study of SDG4 Promotion in India

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Abstract: Most government schools and colleges run on low budgets in India, yet they cater to a large population of students. In government settings, biology labs lack basic equipment such as simple microscopes or compound microscopes or sometimes possess just one instrument. In the absence of compound or simple microscopes, the students lose interest in science. To solve this issue, the Department of Biotechnology, Ministry of Science and Technology, Government of India, introduced the origami microscope, the foldscope, into the Indian educational system. In this article, we describe the design of a sustainable, inclusive, and equitable curricula for teaching biological concepts using the foldscope. We describe the implementation of foldscope-adapted curricula in post-secondary settings to teach natural selection, developmental biology, parasitology, and economic Zoology via individual, small-group, and large-group field trips, and project-based learning that involves experiential learning. We found that these culturally sensitive pedagogies involving translingual instructions had the potential to retain students and make science education accessible for the linguistically and culturally diverse population of India. We could successfully implement our project as per the five priority action areas outlined by UNESCO. Therefore, we propose the adoption of the foldscope-adapted curricula under SDG4 to make STEM education accessible in budget-frugal settings.

Keywords: STEM education; education for sustainable development (ESD); foldscope; SDG4

1. Introduction

India is a country that contains one of the largest human resources in the world but most of them live below the poverty line [1]. Quality education is not accessible to the majority of the population. Costly private school education is a norm in India, but this option is neither inclusive nor equitable. The size of a class in undergraduate courses in Bachelor of Science programs comprises around thirty students in one class. Even at an undergraduate government college in India, it is a challenge to provide 30 compound microscopes in one class. At government colleges, students are usually asked to share microscopes or take turns on one microscope. Sometimes, students are unsatisfied due to the long wait for the microscope or just copy a friend's observations. This way, the country has been losing talent in higher education. Therefore, the government of India keeps introducing several programs to raise the quality of education at government schools and colleges. One such program was the Department of Biotechnology's Foldscope initiative, which was launched by the Ministry of Science and Technology, Government of India. The Department of Biotechnology (DBT), Ministry of Science and Technology anticipated the potential of the foldscope as a tool to inculcate scientific temper among students in frugal settings. The foldscope is an origami microscope that was invented by Dr. Manu Prakash and Dr. Jim Cybulski [2] at Stanford University. It is a paper microscope that comes as a water-resistant sheet of paper with modular parts that need to be torn off from the sheet and assembled. The parts of the microscope/origami sheet are color-coded for simple assembly. The microscope comes with circular magnetic couplers to keep the circular lens in place. Finally, the microscope folds as a 2-D structure which holds a slide just above the lens for visualization. The foldscope has a magnification of 140X and a resolution of 2 microns, which can be multiplied by coupling it with a mobile phone via magnetic couplers. It has been utilized to show entire classes on a screen by using the mirroring application of a mobile phone [3].

The foldscope initiative distributed foldscopes to Government schools and colleges. During this time, numerous workshops were organized to train teachers and students at the government schools and colleges. All the authors of this manuscript were the instructors in these workshops organized by the Department of Biotechnology, Government of India. Although the foldscope was available the curriculum, to teach using the foldscope was not. We conducted several workshops at government schools and colleges in underprivileged settings in Jharkhand, Bikaner, Pune, Mumbai, Ranchi, Vashim, Vishakhapatnam and Delhi. The foldscope also has an online community (React App (foldscope.com)) where the users share their exploration, but they do not align with school or college curriculum. Moreover, the instructional videos on this website are only in English; we used national and regional languages in our training sessions to make our lessons more inclusive (https://www.youtube.com/watch?v=27BVisjsiRk, accessed on 6 September 2022) because it is known that translanguaging can increase retention in STEM education [4–6], especially in countries where English is not the mother tongue.

The Department of Biotechnology (DBT), Ministry of Science and Technology anticipated the potential of the foldscope as a tool to inculcate scientific temper among students. DBT launched the nationwide DBT foldscope initiative through which we secured a grant to explore the uses of the foldscope in the post-secondary setting. We hypothesized that the foldscope could be the answer to bringing equity in science education to low-budget settings and the ever-increasing populations in the classrooms of government schools and colleges. We took up the syllabus of the Non-Chordata at BSc Honours program in Zoology taught in government colleges of India and analyzed several items that can be taught using the foldscope to undergraduate students of first year BSc. Zoology. We found that the foldscope was an excellent tool to study permanent, stained slides and live samples. The foldscope proved to be an excellent tool to study rotifers; arthropods such as crustaceans, cladocerans, acari, and aquatic insect larvae; and mouthparts of different arthropods. We conclude that the foldscope gives a view comparable to a compound microscope when coupled to a mobile phone. We could successfully determine the size of the ommatidium using the ImageMeter App with the foldscope. This study presents the data of multiple DBT-sponsored workshops conducted by the authors all over India in government schools and colleges.

We designed the curricula to keep social justice in science education as a guiding principle. This article describes the research that the authors indulged in to create curricula that removed barriers to science education for marginalized communities in India. We also describe the implementation of the curricula in post-secondary settings. The study aimed to study the following important topics from the Zoology curriculum:

1. Study of pond fauna.
2. Evolution of mouthparts in arthropods.
3. Compound eyes in insects.

4. Field studies to identify pests in plants of economic importance.
5. Study of parasites.

2. Theory

The United Nations launched seventeen Sustainable Development Goals (SDGs) in 2015 to achieve "the 2030 Agenda for Sustainable Development," which was adopted by all UN member states. SDG4 targets to provide quality education for children, youth, and adults [7]. It has been recognized that this target can be achieved only by cooperation among individuals, educational institutions, and the government. SDG4 has ramifications on education policy [8], which depends on the willingness of the government to spend on fixing broken education systems [9]. SDG4 targets can be achieved at three levels, namely, the micro level, meso level, and macro level. The micro level corresponds to the individual level where parents and students recognize the importance of quality education. The meso level corresponds to educational institutions such as schools and colleges, trainers, educationists, and the learning environment. The macro level corresponds to government policies and investment in education [10].

Sociocultural theory argues that knowledge is not passively transmitted but actively constructed by the learner [11,12]. Social interactions and cultural tools play a central role in learning. Science is the result of sociocultural processes; therefore, learning science also means understanding the culture of science [13]. Microscopes are an integral part of the culture of science. Learning life sciences just by reading textbooks and listening to a teacher in a classroom may help students learn the facts and principles of science but will not help them understand how knowledge is constructed in science. They will not develop the skills needed in science [13] if they are not introduced to constructivist pedagogies. Production of scientific knowledge and therefore learning of science is situated in the context and culture of science. Experimentation is central to science because when students perform experiments, it helps in conceptual learning, and gives them an experience of science [14]. Experiments such as demonstrations, imitation, or open-ended inquiry require various cultural tools and a foldscope is one of them. A tool, such as the foldscope, that is easy to use and handy to carry is suited for all kinds of experiments. However, open-ended discovery is where the foldscope is most valuable, as students can perform experiments independently outside the educational institution. Open-ended experiments have the potential to not only help children learn science concepts but also develop science-specific skills. Developing science-specific skills is one of the aims of science education as they help solve day-to-day problems and have implications for democracy and social-justice issues [14,15]. Specifically, developing skills and knowledge so that the younger generation can act towards sustainability. UNESCO's Sustainable Development Goals (SDG) advocate for adopting pedagogies that promote active, collaborative, and self-directed learning oriented toward developing problem-solving skills and connecting both formal and informal learning [16]. The Indian Government acknowledges the SDG goals in the recent National Education Policy (2020) [17] and echoes the need for education for sustainable development. The DBT foldscope initiative was launched by the government of India to establish social justice in the field of science education. Our study describes the benefit of a macro-level endeavor by the government for achieving SDG4 and the efforts of the authors to achieve SDG4 at the meso level.

3. Materials and Methods

3.1. Foldscope

Foldscope was supplied to our college by the Department of Biotechnology, Ministry of Science and Technology, Government of India under the aegis of DBT Foldscope Initiative. Foldscope was assembled, and slides were prepared and visualized as described previously by Cybulsky et al. and available at Tutorials—Foldscope Instruments in the tutorial section of the Foldscope Community online (Microcosmos—Welcome to the Foldscope Community).

3.2. Source of the Fresh-Water Organisms

Freshwater was collected from a local pond to study the fauna such as crustaceans (water flea) and aquatic larvae (mayfly larva). The organisms were released with water in the same pond after the study. Source of the pest: the spider mite was collected from the tea leaves in the tea gardens of Darjeeling. Source of butterfly: the dead butterfly was collected from the college gardens to carry out the study. After the study, all the organisms were released into their natural habitat.

3.3. Estimation of the Size of the Ommatidium in Housefly's Compound Eyes

First, an empty slide was kept with grid (we used a slide with 0.5 mm grid) in a foldscope and a photo was taken of one square of the grid using a foldscope. Then, the picture was opened in an app called ImageMeter. The square of known size in the image was taken as a reference to measure the diameter of the field view (circle in which we see the objects through the microscope) via the app. Once the diameter of the field view for the given phone and foldscope pair was determined, this information was used to measure the size of an unknown object. Example of ommatidia: A dead housefly was mounted in the foldscope. The picture of ommatidia was taken by attaching a mobile phone with the foldscope. The image was opened in ImageMeter, and the diameter of the field view was taken as a reference to measure the size of a single ommatidium using the measure tool in the app. About 4–5 readings of different ommatidia were taken to calculate the average size of an ommatidium. The image of ommatidium size is uploaded as a supplemental file, Figure S1 (in Supplementary Materials). The size of the ommatidium was measured to be 13.18 μM.

3.3.1. Field Exploration of Red Spider Mite

Darjeeling tea is famous for its peculiar flavour and taste and has been cultivated in the Darjeeling hills in India. During a visit to the tea gardens of Darjeeling, various tea plants exhibited signatures of red spider mite infestation. To confirm the infestation, microscopic observation of the pest is necessary. We collected the infected leaves from the tea gardens and the pests were transferred onto clean glass slides by gently brushing off the mites from the leaves. A glass coverslip was used to cover the freshly transferred mites. The slides with samples mounted on them were observed using a foldscope coupled with a smartphone.

3.3.2. Study of Parasites

A head louse was collected from an infested student and it was mounted on the slide by standard procedure and observed through a foldscope via smartphone. The video was recorded to observe the entire organism.

3.4. Selection of Items to Study with Foldscope

Different items were selected from the curriculum to create learning experiences with biological materials easily available around us. Topics selected included the evolution of mouthparts in arthropods, different types of scales in the animal kingdom, compound eyes in Arthropoda, the study of pests in fields (economic zoology), observation of pond fauna, observation of larval forms in pondwater, and study of parasites. The methodology to successfully use foldscope in handling different specimens was developed collaboratively by the exchange of insights among all the authors of this article over 70 workshops conducted all over India in different schools and colleges. Then, the items from the BSc. (H) Zoology curriculum prescribed by University of Delhi, India, were selected to be taught with foldscope.

3.5. Participants

The foldscope-adapted curriculum was tested in the teaching laboratories of the Zoology department of Shivaji College in Delhi, India. The college is 100% governmentfunded and follows the curriculum prescribed by the University of Delhi, India. Teaching with foldscope was carried out by the same person to maintain uniformity and to avoid bias. The only selection criterion for students was enrolment in the second semester of BSc. (H) Zoology. All the students in the class were part of the study. The students in the second semester were selected to conduct this study because they have the experience of the classes in semester 1 that provided only 3-6 working simple/compound microscopes for the entire strength of 38 students of Indian origin. The class in which the curriculum was tested had 60% girls and 40% boys in a class of 38 students. Each class in a government college of the University of Delhi has 15% Scheduled Caste, 7.5% Scheduled Tribe, 27% Other Backward Classes, and 50.5% students from the unreserved category. The class was held once a week for 14 weeks over one semester for one academic year.

3.6. Adapting Syllabus to Foldscope

The topics from the Zoology syllabus were tested with foldscope to see if foldscope can give results comparable to a compound microscope. The methodology to use foldscope for studying different specimens was developed collaboratively by the authors during several workshops held at schools and colleges in different parts of India, mentioned earlier. The items were then aligned with the syllabus prescribed by the University of Delhi for the BSc. (H) Zoology students.

3.7. Assessment of Adaptation

The assessment was based on the quality of pictures/videos recorded with foldscope. The teaching plan included providing a foldscope to students, providing the specimen to the students, and the students recording pictures with their mobiles coupled with the foldscope and submitting them to the teacher.

3.8. Feedback

The feedback was collected through an online questionnaire that had open-ended questions: 1. How did you feel about having a personal foldscope throughout the semester? 2. Do you think that a foldscope is a good replacement for a compound microscope? 3. What was the best part about using the foldscope? 4. What is your overall feedback? The students completed an electronic questionnaire via Google forms.

3.9. Analysis

The success of foldscope was analysed by the a. quality of images compared to the ones observed by compound microscopes by the researchers, b. analysis of the value that these pictures bring to the curriculum, and c. the student response.

4. Results

4.1. Introducing the Use of the Foldscope to the Students

Students were provided with a foldscope. Students assembled the foldscope as per the instruction manual. The user has to follow the instructions to assemble a two-dimensional, color-coded paper microscope. Figure 1a,b show the two sides of the foldscope. They were provided with the origami sheet with the instruction manual. Students were observed at each step of assembling. The students need to separate the parts of the microscope from the origami sheet. When they went wrong, they were only given a hint and asked to go back a few steps, read the instructions again and repeat the steps. This way, a constructivist ideology was followed by the researchers to let the students practice self-directed learning from the first step. It was found that all the students could assemble foldscopes and prepare slides by themselves. Therefore, it was concluded that the foldscope was a user-friendly tool. Once the assembly was over, they discovered a new way to make microslides of minute insects/leaves/pollens to visualize via the foldscope. The students then observed a number of scientific phenomena by themselves which no amount of description by the teacher would justify. Therefore, a class that focuses on assembling of a new-age microscope makes the learners experience the principles of microscopy along with several other scientific phenomena. The students were given space to commit mistakes while assembling the foldscope. Further, they were given full freedom to take this handy microscope to the field and collect different samples. Later, the students observed the samples collected by students and document different scientific phenomena observed. Many times, they were in awe to observe and validate a structure/phenomenon previously studied in a textbook. This also allowed them to top-up the knowledge that a text/diagram cannot describe, while a live observation via a microscope can.

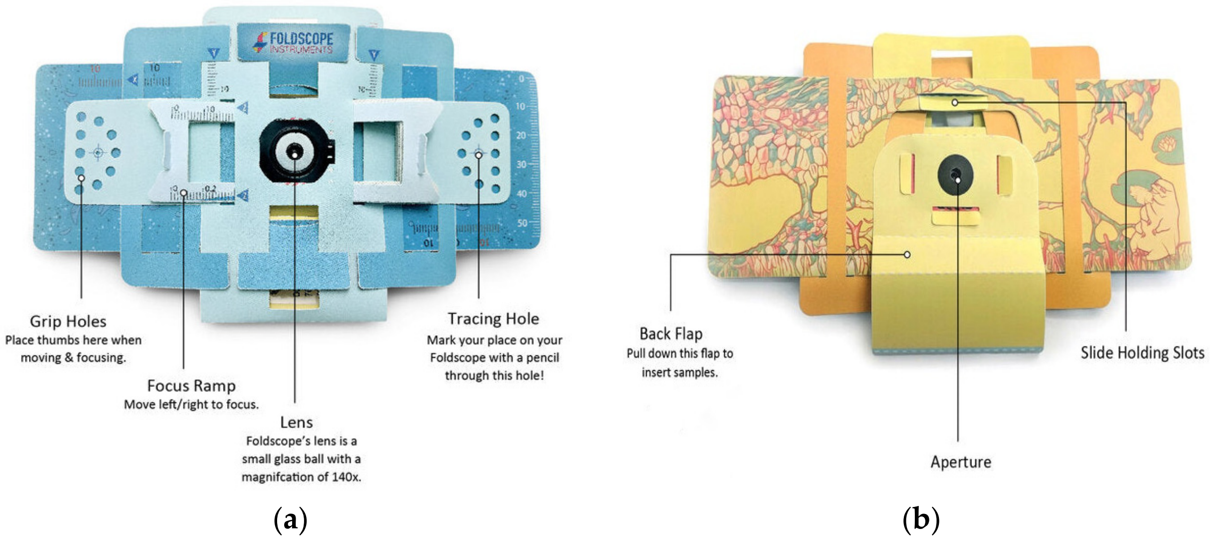


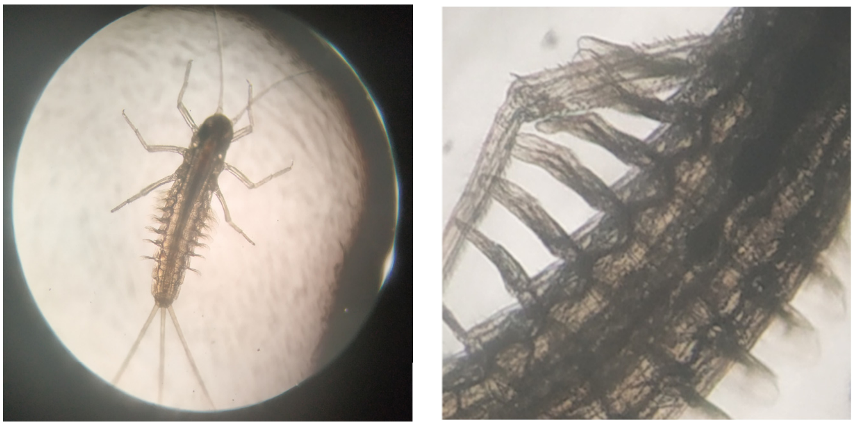
Figure 1. (**a**) The front side is blue with a black lens in the centre. This is the side from which one views the image and move to focus the specimen. (**b**) The back side is yellow with colourful art work. This is the side from which the slides are inserted and where there is light source LED.

4.2. Study of the Selected Items from the Curriculum

4.2.1. Study of Pond Fauna

The study of pond fauna is an important self-directed activity from the Ecology practical curriculum. The students observed cladocerans/water fleas in different stages of life via the foldscope (Figure 2), mayfly larva via compound microscope (Figure 3a), and tracheal gills of mayfly larva via the foldscope (Figure 3b). Students usually only see a diagram of tracheal gills in textbooks. The diagrams are usually simplified two-dimensional drawings that fail to inspire students.

Figure 2. Observation of water flea with foldscope.



(**a**) (**b**)

Figure 3. (**a**) Visualization of mayfly larva with a compound microscope. (**b**) Visualization of mayfly larva with foldscope. The tracheal gills have been zoomed in.

4.2.2. Observation of Mouthparts and Compound Eyes in Arthropods

Students could observe the mouthparts of arthropods with a foldscope (Figure 4a–c). Mouthparts are usually taught as a theoretical concept which students usually cram and learn through diagrams. However, it is an important concept that teaches the evolution of mouth parts in arthropods on the basis of the natural selection of feeding habits. As shown in Figure 5, the ommatidia or compound eyes could be clearly seen with a foldscope.

(**a**) (**b**) (**c**)

Figure 4. Visualization of mouth parts of butterfly's proboscis (**a**); Piercing and sucking mouthparts of head louse (**b**); mandibles of a worker ant (**c**).

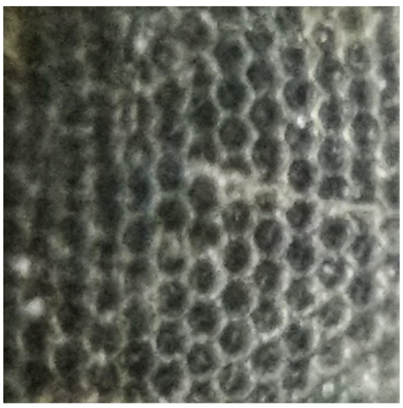


Figure 5. Compound eyes of a housefly.

4.2.3. Field Explorations to Study Red Spider Mite Infestations on Tea Leaves

Oligonychus coffeae Nietner, the red spider mite (RSM), is a major pest of tea (*Camellia sinensis*). It causes great economic losses to tea growers. Red spider mite infestations were observed on the tea leaves. Nymphs and adults of RSM lacerate cells produce minute, characteristic, reddish-brown marks on the upper surface of mature leaves, which turn red in severe cases of infestation (Figure 6a), resulting in severe crop loss. Clear images of mites and the features of red spider mites were captured (Figure 6b,c). On-field confirmation of red spider mites is critical to control infestation, and the foldscope seems to be a wonderful tool for the onsite identification of red spider mites. Infestation of red spider mites has been observed in tea plantation across the globe and especially in different tea-growing regions of India, including Kangra and Darjeeling [18–20]. The body did not have a division between the metapodosoma (thorax) and the opisthosoma (abdomen). The body looked rounded with four pairs of legs, so they belonged to Acari/spider mite. The characteristic features of acari such as the palp and the chelicerae were visible. The setae were visible, while wings and antennae were absent.

(**a**) (**b**) (**c**)

Figure 6. (**a**) The circled area shows infestation by red spider mites in tea gardens; (**b**) red spider mites dorsal surface observed via foldscope; (**c**) observation of the ventral surface with foldscope.

4.2.4. Observation of Headlouse with Foldscope

The Video S1 is a video of the head louse capturing the mouth part tube, eyes, the five-jointed antennae, setae, abdomen, and the blood-engorged alimentary canal. Thus, the video captured the louse's anatomy very well.

5. Analysis of Foldscope-Adapted Curriculum Items by Researchers

Analysis of the quality of images visualized with and recorded through android phones. As the images recorded in Figures 2–6 and Video S1 (in Supplementary Materials), the foldscope coupled with smartphones records images and videos comparable to the images recorded through a compound microscope. A reflective discourse was supported after every class in which a foldscope was used, wherein students discussed their ideas on observing the specimen. Their immediate reaction was recorded for acceptance and the quality of experience they had with foldscope.

5.1. Study of Pond Fauna

Students observed several species that thrive in pond water. In this manuscript, due to space constraints, all the pictures were not shared. However, students observed ciliates, waterflea (with or without eggs), larvae of disease-causing insects such as Aedes aegypti and *Culex* sp. We chose to share the picture of the mayfly larva because students were most excited to observe the tracheal gills of the mayfly larva, which looked distinctly different from the textbook diagrams. Tracheal gills are thin plates or filaments with an ample tracheal supply [20]. Arthropods also have a vast diversity in their respiratory mechanisms, which are studied in colleges. With the availability of the foldscope, students were able to observe these structures in detail. Therefore, we concluded that the foldscope was an appropriate tool to record fauna living in pond water. It is noted that the foldscope has the potential to support discovery-based learning. As this experiment was a self-directed activity, students carried their foldscope to the pond and observed different organisms.

5.2. Study of the Mouthparts of Arthropods

The biggest group of animals in the animal kingdom—arthropods—show great diversity in their mouthparts. The mouth in an arthropod is generally made up of a mandible, maxilla, labrum, and labium. There are various modifications of these mouthparts vary according to the type of food the arthropod intakes. The evolutionary significance of the modification of mouthparts in arthropods is an important part of post-secondary Zoology syllabi. The structural configurations of mouthparts are related to feeding habits and natural selection. However, in Biology classes, they are taught with the help of diagrams. The mouthparts of arthropods are still under investigation and scientists are unravelling newer information to date [21–23]. The proboscis of a butterfly is regarded as a microfluidic probe to enter narrow corollas of flowers and collect nutrients. The lepidopteran proboscis is composed of two elongated c-shaped maxillary galea that come together at their medial sides by dorsal and ventral linking structures, the legulae, to form a circular food canal [21–24]. The shape of the drinking region of a proboscis varies in morphology: they can be either smooth or brushy bearing sensilla styloconica. The study by Lehnert et al. elaborates on the adaptive importance of these morphological characteristics of butterfly proboscis [25]. They utilized a confocal microscope to study the morphology of the lepidopteran proboscis. In the pictures captured by us, the sensilla styloconica was visible as projections from the proboscis. The piercing–sucking mouth parts of lice [26] and mouthparts of ants [27] were also visible with clarity. Therefore, we concluded that the mouthparts can be taught efficiently with the foldscope if the correct literature is related to the pictures and the pictures are analysed in the context of scientific topics of interest to biology classes.

5.3. Field Explorations Using the Foldscope

We began this field experience with the reiteration of precautions to be observed in the field. During this exercise, students are given a chance to be mindful but commit mistakes at the same time. The researchers stayed around them as passive members and let them collect some samples from the field. At the end of the field trip, a lot is taken home by the students such as confidence in the field [28–32], hands-on experience of the organism collection techniques, saving the organisms in the field and the significant skill of identifying the organisms. In the field, students recall and make sense of the knowledge gained during the previous theoretical sessions they attended. Participation in this activity also allows for reflective discourse. As foldscopes are small, light and portable, it was concluded that they can support meaningful learning experiences in the field.

5.4. The Study of Parasites

Arthropods have been recognized as a threat worldwide because of their ability to act as vectors for several microbes. Humans have been affected by Head louse *Pediculus humanus capitis De Geer* (family *Pediculidae*), Body louse (*Pediculus humanus humanus* L. (family *Pediculidae*) and Crab louse, *Pthirus pubis* (L.) (family *Pthiridae*) [33,34]. The acarologists are still refining staining techniques to identify lice in the laboratory [35]. Here, the video in the Supplemental file shows the observation of the head louse via the foldscope. We observed the head louse being collected from a student in the class. Head lice and body lice are considered subspecies rather than separate species. Body louse and head louse have comparable size, abdominal features, and legs. Due to the similarity between head and body lice, only the location of the host can confirm their identity. In our study, the louse was collected from the head of a human; therefore, it was concluded that it was a head louse. The morphological features of the parasite—including the thoracic sternal plate, abdominal spiracle, genital lope, and setal characteristics—could be precisely observed in real-time and because the video can be saved on mobile phones, it is safe to conclude that the evidence of these studies with the foldscope can be saved for future reference. We, therefore, concluded that the foldscope is a handy tool to teach parasitology in teaching laboratories of biology courses. In regions of high infestations such as in North, Central, and East Africa; Asia; and Central and South America [36,37], the foldscope can be used as a surveillance tool by public health officers to collect data on the prevalence of lice so that medical assistance could be provided. We concluded that the foldscope has the capacity of supporting situated learning.

5.5. Student Response

Student responses were collected via open-ended questionnaires. All students answered the questionnaire. We received 38 complete responses to the open-ended questions. A few of the responses have been shared here. "I saw the actual colors of the specimen for the first time because usually, we use fixed slides to study"; "It was a thrilling experience to observe a beating heart of live water flea"; "Foldscope helped me to step out of the books and have a hands-on experience to actually examine the invertebrates on my own"; "We were given a Foldscope for our personal use which helped me nurture my curiosity and learn more about the subject"; "I learned how to capture pictures and videos of moving microorganisms, maintaining the required magnification and focus"; "Now I don't need to wait for the microscope to be free and sit idle in the lab"; "First I used to think how these microorganisms look in real life as we only used to see them in the textbooks or fixed slides and the foldscope classes gave me the opportunity to see them live with foldscope".

The trends that emerged in their answers will be discussed here. Students appreciated obtaining a personal microscope throughout the semester because now they did not need to wait for their turn to use a compound microscope in class. They appreciated that they could save their results on their phone and study them any time they like. They appreciated that the videos and pictures taken with the foldscope could be shared with their classmates. Feedback from many students stressed that observing different parts of a live animal in the field was more inspiring than the conventional method of looking at the dead, fixed, and stained specimens in the lab. They pinpointed that the foldscope was not bulky; therefore, it could be used to perform field explorations at ponds and tea gardens. They appreciated that they could study parasites in real time with foldscope. Overall, the students wanted to use the foldscope in their ecology and non-Chordata classes to study items on the BSc. Zoology with the honours program. As active learning increases student retention [38–40], it was concluded that the foldscope had the potential to support self-directed, active learning in a constructivism-driven classroom [41,42]. The online community of practices of the foldscope is available for the exchange of knowledge. However, we found that reflective discourse in class caused better learning among students.

The videos of organisms submitted by students recorded student's reactions as audio. The meaning-making exercise was elaborated at the end of each class by reflective discourse and student discussions. The five curricular items discussed in this article helped students to construct knowledge using the foldscope. The students' 'aha moments' for each topic were recorded by the teachers during the discussions and are shared below as per the topic:

A. "Observing the pond fauna helped me see unstained protists, and their movement"; "The book gives 2-D diagram of the larval gills, I observed that it is really a complex mesh and not straight lines given in the diagram."
B. "Evolution of mouthparts was more interesting to study with the samples collected by me. I got so intrigued that I collected them at home also to create my own picture gallery of mouthparts. This was more exciting than drawing diagrams. I now understand how arthropods are the most diverse phylum in the invertebrate animal kingdom".

C. “Compound eyes of butterfly and moth are taught in the curriculum with the same diagram, but I actually found that there were subtle differences in the appearance of the two in real life. I will collect more samples at home and observe them on my own.”
D. “Collection of pests in the field was an eye-opening experience, how a simple innovation can be useful in agriculture. I even observed the leaves and other plant structures of the infested plant”.
E. “Parasitology is a complete subject in which we use stains to observe different parasites. But with foldscope, I observed worms from the soil, water, and the headlouse. The details recorded with videos helped me to correlate better with the morphological structures described in textbooks”.

All these responses were proof that the foldscope could support meaning making and helped students to construct knowledge that was beyond the scope of the textbooks. Thus, it can be concluded that a foldscope is a tool that is embedded in constructivist ideology.

6. Discussion

The foldscope has been utilized for the visualization of several materials which have been catalogued on the online foldscope usage database (Microcosmos–Welcome to the Foldscope Community). However, most of the reports on the foldscope online database are casual observations of plant materials such as leaves and flowers, or non-living things such as fibers, etc. The foldscope has been utilized as a diagnostic tool for oral and urinary tract infections [43]. It has been utilized to monitor superoxide and cell death during pathogen infection in *Arabidopsis* [44,45], and fungal keratitis [46]. A fluorescent variant of the foldscope is available that can be utilized to study biofilm formation in stool to detect infection [47]. In South India, the foldscope has been further utilized to detect parasitic infections of the intestine. The foldscope is a good tool to study worms also, as it has been utilized to study the infections by *Schistosoma haematobium* in Ghana, South Africa [48]. Furthermore, the foldscope has been utilized as a tool to carry out developmental studies in zebra fish to analyse the effect of toxic substances on embryos [49]. Another group has studied the role of clitellum in the regeneration events of earthworms [50]. Cervical cytology has been elaborated using the foldscope to make decisions about women health [51]. The foldscope has been coupled with the geographic information system to report parasitic infections in children [52].

The pedagogical benefits of the foldscope have not been studied before. The researchers of this article report the adaptation of syllabus items to the foldscope for the first time. The foldscope is a tool deep-rooted in constructivism because students assemble the microscope themselves, prepare slides and visualize the specimen themselves. The foldscope enhanced students’ interest in studying Zoology or natural sciences. Students could develop a sense of belonging to the subject by owning their own microscope. The foldscope has proven to be an efficient tool to study permanent slides, pond-water fauna, the life cycle of microscopic organisms, and pests in the field. The foldscope can be efficiently used with the app ImageMeter to estimate the size of the object under the study; therefore, it is a cheap upgrade to the conventional microscope. As mobiles are common in rural and urban backgrounds, the foldscope can be a good tool to revive the interest of students in science in economical settings.

The chromatic and spherical aberrations are absent in the foldscope as it is a monocular microscope with just one lens; as a result, it does not require any special correction like compound microscopes need [53]. The foldscope has the structural disadvantage of having a very short working distance that makes the user tired over time. This disadvantage is usually overcome by coupling the foldscope with a mobile camera. We found that filming the video is easier with the foldscope and, later, the screenshots can be saved as pictures.

6.1. SDG4 Goals Served by Our Work

Our work aligns the research with the foldscope with the curriculum of higher education. Therefore, we have successfully tried to satisfy the SDG4 which aims to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all. We provide a foldscope-adapted curriculum, the implementation of this curriculum, and student validation in our study. This foldscope-adapted curriculum can be followed in any part of the world with easily available specimens and the one-dollar microscope. Therefore, it has the potential to eliminate discrimination and ensure equal access (Target 4.5). We provide proof that this curriculum can foster problem-solving skills, critical thinking, and teamwork across biological fields such as parasitology, infection biology, and natural science (Target 4.4).

6.2. UN ESD Goals

Table 1 elaborates the analysis of our project as per the five priority action areas outlined by the UNESCO Education for sustainable development | UNESCO. The DBT foldscope initiative issued grants to the teacher educators to train teachers and students for sustainable learning in STEM. With the support of the Government of India, and the Ministry of Science and Technology, the authors of this research article mobilized local communities to strengthen learning opportunities for marginalized communities by promoting collaboration between innovators/the inventor of the foldscope and educators/curriculum developers/teacher trainers such as the authors of this article. The authors then went into their local society to promote ESD via the foldscope. Therefore, the DBT foldscope initiative promoted collaborations among the stakeholders. All the authors of this article can be regarded as critical agents of change because of their efforts in enhancing the capacity of civil society. To promote ESD, the authors were involved in communication with the local communities, teachers, and students in the local language, often falling back upon translanguaging The benefits of translanguaging are well-known in STEM education By facilitating the teacher's education, we generated ideas to shape a sustainable curriculum. In this article, we shared our experiences and a good example of ESD with local educators. This article provides an in-depth methodology, theoretical literature, and student validation of the activities to enhance interest in STEM education. In this article, we share the activities that support the national curriculum of Zoology/biology to support sustainable education in budget-frugal situations. Our project promoted ESD by building the facilitator capacity because we trained teachers in different schools and colleges of India ESD was promoted by providing a personal foldscope to each student; therefore, youth were actively mobilized via the DBT foldscope initiative. The authors of this article provided sustainable solutions at a local level by adapting items of the national curriculum for Zoology to be studied with foldscope. Through the activities described in this article, we implemented the ESD at post-secondary institutions and government schools.

Table 1. Education for Sustainable Development via DBT foldscope initiative in five priority action areas outlined by UNESCO.

Action Area	Alignment
Advancing Policy	Department of Biotechnology, Ministry of Science and Technology, Government of India, launched the foldscope initiative and invited project proposals to promote STEM education on a variety of topics using the foldscope.
Transforming Learning	We applied for the project and received the grant. We procured foldscopes from DBT, Ministry of Science Technology, Government of India. As we worked at the department of Zoology, we analysed the curriculum and explored the items with the foldscope to teach microscopy and natural science concepts underlined by the syllabus in the BSc. Zoology of the University of Delhi. We developed activities, and standardized protocols; and supported them with authentic literature. Authentic learning activities with the foldscope were tested in classrooms with students.

Table 1. *Cont.*

Action Area	Alignment
Building facilitator capacity	We conducted DBT-funded workshops at other schools and colleges in different districts of India to train other lecturers/teachers on using foldscopes.
Empower and mobilize youth	A foldscope was provided to each student as a personal microscope to carry out their own exploration.
Accelerate local actions	We accelerated local action by conducting workshops in schools, colleges, neighbourhoods, and communities in aspirational districts of India.

7. Conclusions

This research article elaborates on the benefits of the foldscope-adapted curriculum in post-secondary settings. As per SDG4, we were able to make STEM education accessible to the diverse population in India. We amalgamated multilingualism in our approach to retain talent in science. This study elaborates on the research conducted on the pan-India level to test these pedagogies in different languages, yet it does not compare the benefit of translanguaging with the absence of translanguaging while using the foldscope. This study provides proof of concept with validation by post-secondary students that the foldscope can be utilized to create authentic learning experiences compared with those created by a compound microscope. Our study describes the development of a methodology by the authors during more than 70 workshops conducted all over India with school and college students. However, the foldscope-adapted curriculum was tested formally on only 38 students for just one academic cycle. The curriculum was tested in a co-educational setting, but the analysis was not performed as per the gender of students. This leaves scope for the study to be repeated with a bigger cohort for more than one academic year and for other streams of Life Science as well. The study focuses on the Zoology curriculum of the second semester BSc (Honours program) only. The study can be extended to other semesters as well. Yet another limitation of the study could be its qualitative nature. We wanted to know the students' opinions about the adapted curriculum in their own words; therefore, we did not collect data on students' interests to be organized on a Likert scale. We wanted to be guided by a holistic experience of students rather than fragmenting their experience into quantitative parameters. We were primarily guided by students' reactions to the quality of images studied by the foldscope as compared to simple and compound microscopes. One may also carry out a future study to gauge the effect of the foldscope-adapted curriculum on the students' motivation and attitudes. Our study is proof of the concept that other curricula can also be adapted to be studied via the foldscope. There are some amazing Botanists who have performed extensive studies on plant parts with the foldscope. Those studies could be aligned for the Botany syllabi Foldscope Microcosmos web app. If a combined effort is made, then a school curriculum can be identified for teaching Life Science with the foldscope. This way, social justice could be established in the poorest conditions. Therefore, we conclude that foldscope-adapted STEM education can reduce economic disparity in education.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su142013427/s1, Figure S1: observation and measurement of a single ommatidium of a housefly's eye; Video S1: Morphology of a head louse recorded via foldscope.

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