Teaching Graduate Biology

A collection of pedagogical tools and experiences of biology educators

Government of India
Ministry of Human Resource Development

IndiaBioscience
ENGAGING COMMUNITIES. ENABLING CHANGE

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This project is funded by the Ministry of Human Resources and Development under the Pandit Madan Mohan Malaviya Teachers Training Scheme. All these articles have been featured on the website www.indiabioscience.org. The article design and order has been modified to fit the theme of the book.

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Preface

This book is a compendium of the articles pertaining to education that have been published by IndiaBioscience. We have been building a community of life science researchers and educators through our online content and discussion space. It is an outcome of our efforts of the past few years, and we hope that it would be a good resource for the teachers of life sciences. We hope that this book leads to discussions and the building of a subject based network. Peer learning, after all is one philosophy that we go by.

The book contains articles on pedagogy, enquiry based learning and tips to teach topics of college biology. We have also curated the personal journeys of college teachers and universities, their stories on how they keep their classrooms engaging and updated, and their expectations from the policymakers.

All of our efforts within the education vertical are supported by a grant under the Pandit Madan Mohan Malaviya Mission on Teachers and Teaching by the Ministry of Human Resources and Development. We are thankful to Shakila Shamsu, Sajjad Ahmad and Poornima Hazra for enabling the release of the grant.

We are thankful to the inspired teachers, that have become our close associates and have been guiding us, special thanks to Vidya Jonnalagadda, Smitha Hegde, Asim Auti, Urmi Bajpai and Charu Dogra. This book would also not have been possible without all the educators in our network who have been encouraging and engaging with us throughout.

A special thanks is due to LS Shashidhara, Apurva Barve and the team at Centre of Excellence in Science and Mathematics Education, IISER Pune for their guidance and support.

Happy reading!

Team IndiaBioscience

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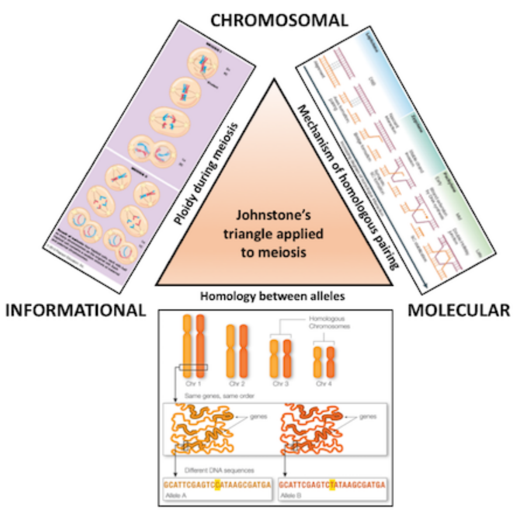
The triangle connect: the three levels to teaching meiosis

Anusha Krishnan

The concept of meiosis can be taught at multiple levels for a holistic understanding. Wright et al discuss three such levels, forming the vertices of the Johnstone's triangle.



Johnstone's Triangle (Photo: O'Connor, C. (2008) Meiosis, genetic recombination, and sexual reproduction. (c)Nature Education 1(1):174, http://learn.genetics.utah.edu/content/pigeons/geneticlinkage/, (c)Pearson Education Inc.)

Thirty-five years ago, Alex Johnstone, a professor and teacher of chemistry at the University of Glasgow, published a short paper on why students found chemistry hard to understand. He postulated that experts in chemistry viewed any subject topic at three levels, and "jumped freely from level to level in a series of mental gymnastics", whereas, students did not engage in such "multi-level thought". He used his knowledge of chemistry, and findings from information-processing studies to describe three 'levels' of chemical knowledge—the macroscopic or descriptive (embodying the physical characteristics of a substance such as density, color, etc.), the molecular or submicroscopic (explaining the chemical properties of the substance), and the symbolic or representational (formulae and equations). He devised a representational triangle known as the 'chemical knowledge triplet' which is highly influential in the field of chemistry education.

The utility of the Johnstone's triangle framework is not restricted to chemistry alone. A recent paper by Wright et al. from the Rochester Institute of Technology adapts Johnstone's triangle to address a question in biology education: why do students have trouble understanding the process of meiosis? Meiosis is a cell division process in which the daughter cells formed after division have one copy of the chromosomes carried by the parent cell. The process is essential for all eukaryotic organisms that undergo sexual reproduction and is central to the formation of gametes. The process of meiosis is undoubtedly complex; however, a thorough understanding and comprehension of meiosis is essential for the students of biology.

Unfortunately, despite repeated lessons on meiosis during the course of undergraduate study, Wright's team discovered that many students, even third-year biology majors, had a poor comprehension of the subject. Drawing from a large dataset of assessment responses, interviews, and classroom experiences, Wright's group postulated that students face trouble in connecting knowledge of DNA between three levels—chromosomal structure of DNA (sizes and shapes of chromosomes), molecular structure of DNA (relating to the sequence of nucleotide bases in DNA), and at the informational level (an abstract understanding that DNA sequences contain information in the form of genes). The study also found that the standard text books used in the classrooms also failed to connect the three levels in explaining these concepts.

The team has shown in a previous publication that although students possess the knowledge of chromosomal and molecular levels of DNA structure, they focus mainly on the former to explain the beginning and the end of meiosis. This inattention to the events occurring at the molecular structure of DNA (such as the process of complementary pairing and crossing over) leads to a lacuna in their understanding of chromosome behavior and the outcomes of meiosis on an informational level; for example, many lack the ability to articulate the phenomenon of allele segregation in the context of meiosis.

Wright and her team term the framework of these three levels 'the DNA triangle', and show that it is a generalizable model useful for teaching various concepts in meiosis, and for other processes involving DNA. In the course of gathering data to illustrate the usefulness of the triangle, the group identified three themes in meiosis that seemed to generate a lot of confusion among students—homology, homologous pairing, and ploidy. When questioned, experts and students had vastly different comprehensions of these three concepts.

Students thought of chromosome homology in purely physical terms—homologous chromosomes had “the same size and shape”. While experts defined homologous chromosomes on an informational level as well, carrying the same genes in the same order, but alleles differing from each other by as little as a single base. Homologous pairing and crossing over were defined by experts at both informational and molecular levels—that pairing occurs due to high sequence similarity between homologous chromosomes, and that crossing over occurs between complementary DNA strands to swap information through a physical connection. However, students believed that crossing over involved the exchange of chunks of sister chromatids exchanging places. Experts defined ploidy at informational and molecular levels as the presence of two sets of information for each ‘type’ of chromosome, one maternal and the other paternal, in a typical diploid cell. Students, though, defined ploidy simply on the basis of chromosome set—replicated two-DNA chromosomes were considered diploid, while unreplicated one-DNA chromosomes were haploid.

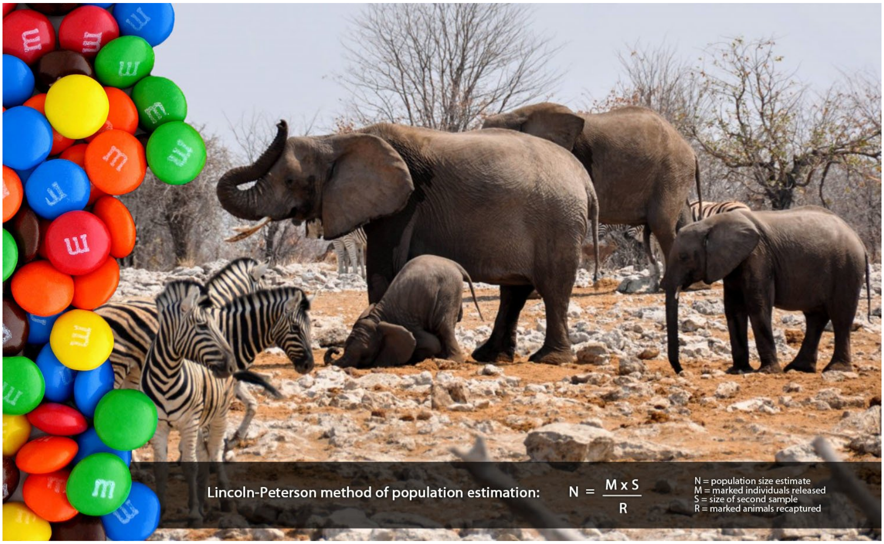
“Meiosis, was a confusing topic for my students when I was teaching it a few years ago, and I suspect it remains so. Some of the confusion comes from poor retention by students; sadly, most students do not internalize the learning and focus only on clearing the semester-end exams. But some of it is definitely due to poor understanding of the structure of a chromosome,” says Vidya Jonnalagadda, an undergraduate teacher from Hyderabad, India. Jonnalagadda, who was much enthused by the work, adds, “I cannot agree more that is it really important to explain meiosis in terms of all three aspects (chromosomal, informational, and molecular), and to clarify meiotic processes in this framework. I believe that designing a comprehensive "triangle" plan for any topic in biology will definitely help students and teachers.”

Based on their study, the authors suggest that effort needs to be made to introduce molecular-level details in explaining meiosis to undergraduate students. They put forward the idea to have interactive sessions where students become chromosomes by using long paper strips printed with DNA sequences as visual and physical aids. By comparing base sequences on their strips to find their homologous pair, physically aligning the strips and crossing over complementary bases on sister chromatids, students gain a better understanding of these concepts of homology.

Teaching statistical concepts to ecology students, the sweet way!

Lakshmi Supriya

What approach could a teacher take if her students are wary of numbers and statistical analyses? Could an ecologist replicate fieldwork within the confines of a classroom? A recent research paper discusses the use of sweet, colourful candies as a teacher's aid for imparting mathematical reasoning and introducing the strategies of fieldwork.



Mathematical reasoning for ecologists (Photo: Images: Wikimedia Commons and Pixabay. Image modified to its current form by Manoj Rangan.)

Mathematics evokes images of numbers and symbols – biology graduates see it (or are assumed to see it) as a dry, complicated, and abstract subject. However, the learning of biology (particularly the fields of ecology and evolutionary biology) has a strong component of mathematical reasoning to it. Biology teachers often struggle to make mathematics interesting. Studies have shown that relating statistical concepts to real-world problems or using physical objects to demonstrate concepts could be effective tools to increase student understanding. Recently, a group of ecology educators added colour to explaining applied statistical concepts using sweet candies!

Most ecological fieldwork involves estimation of **species population and species diversity**. These estimates tell how the population of species changes over time and area. Decreasing populations signal a species is not doing well, and may require interventions to help them thrive, allowing for planned conservation efforts. The population estimation exercise includes capturing a sample of animals, marking and releasing them back into the wild so that they mingle in the population. After a passage of time, another group of animals are captured. Some of these would already have been marked, and some not. This exercise leads to population estimation - based on the fact that the number of marked animals captured is proportional to the number of marked animals in the entire population. This method assumes that the size of the population does not change during the study period. A new study reports using M&Ms, similar to Cadbury Gems, to teach **population** and **diversity index** - key concepts in ecology.

Colourful candies can be used as a good substitute when field-based learning is not possible. Each pack of candies represents a closed community, that is, no candy enters or leaves the pack. The different colours can represent different species in a community. Students are divided into groups and each group is given a package of candy. Each group pours the candy into a container with a lid and counts the number of candies of each colour. The colour with the highest number of candies is noted. Closing their eyes, the students pick a few candies one by one. Candies of the colour with the most number are marked, either by scratching lightly or using a non-toxic marker. The candies are returned to the container and shaken well to redistribute them. The same number of candies as chosen the first time is again selected. The students then count the number of marked samples obtained during the second picking.

Using appropriate formulae (Lincoln-Petersen index) students can estimate the population index. Once this exercise is completed, they can join groups, combining their candies to mimic a larger population size and recalculating the population index. This would provide them an understanding of how population size affects estimates. By extending the exercise further, the diversity index, i.e. number of different species of animals in the community can be calculated (Shannon-Weaver index). The diversity index is based on the idea that in a very diverse community, if you pick one member, the probability that the next member will belong to the same species is low.

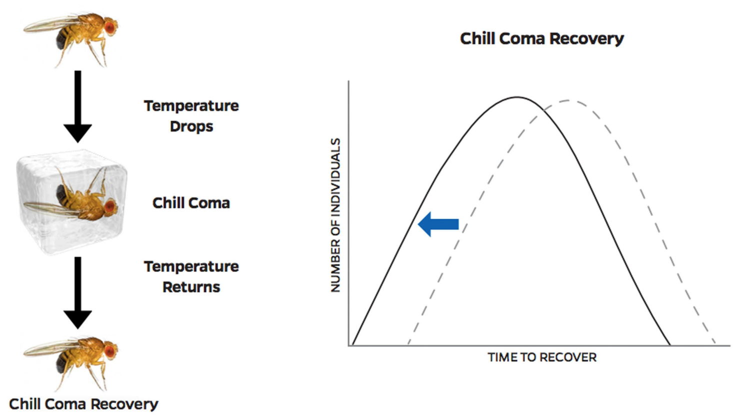
The authors reported that students found the candy exercise useful in understanding ecological concepts. Students were able to use the same techniques as on field researchers, giving them a sense of practical fieldwork. According to the authors, the idea can be also extended to help students learn other biological concepts, such as adaptation and basic genetics. Best of all, the students can eat the candies at the end of class! “The method is absolutely elegant and feasible (and delicious)," says Vidya Jonnalagadda, a biologist who teaches at the Bhavan's Vivekananda College in Hyderabad. This is something that she might try to use in her classroom to discuss probability, sampling, and confidence interval in biostatistics. In her decade-long experience of teaching biostatistics to post-graduate students, Vidya finds the main problem to be the inability of students to think numerically. She adds, "We do a great disservice to our students by bifurcating the math and biology streams at the +2 level."

Training of mathematical reasoning in biology is important, with specialized fields such as bioinformatics, theoretical biology, and mathematical modelling contributing to a rising proportion of biological research. In India, there has been a significant growth in curriculum in mathematical biology at the post-graduate level. However, the question remains - how to make mathematics less of the seemingly abstract stuff and more about the concepts that students can easily relate to. Innovative ideas are needed for biology students at the high school or undergraduate level, who at least in India, traditionally have had a less rigorous mathematical curriculum.

Teaching climate change and rapid evolution: the case of the comatose fruit flies

Anusha Krishnan

What happens when you expose fruit flies to low temperatures? Like many insects, they go into a chill coma - a sleepy state. Analysing the phenomena of coma recovery could help teach the concepts of rapid evolution, and the impact of climate change on it. How? A team of scientists and educators created a wholesome teaching module of fruit fly experiments using the phenomena of "chill coma recovery".



Chill coma recovery test is used as a tool to study the genetics of fruit flies (Photo: Drowsy Drosophila. Modified to current form by Manoj Rangan)

European great tits (*Parus major*) which need caterpillars to feed their young, time their egg-laying schedules to coincide with maximum availability of this creepy-crawly food. However, earlier spring onset due to global warming, is causing caterpillars to mature earlier than the birds' eggs hatching, leaving parent birds with scarce food resources for chicks.

Are these birds able to cope with this change? The answer to this is as yet undecided, since the battle between climate change and the birds' adaptation is ongoing. A study on a Dutch population of these birds has found that a genetic subpopulation can vary the timing of their egg-laying. This population can lay eggs earlier, and so, feed their chicks with the early-emerging caterpillars. This has led to an intense selection for birds capable of varying their egg-laying timings, and the Dutch great tit population has shown distinct genetic changes over a span of just 32 years.

This case of the European great tit highlights two important processes – one, global warming can create immense selection pressure on living organisms; and two, certain populations can evolve rapidly to adapt to this pressure.

As evidenced by the example above, climate change is a key driver of evolution, and understanding this is of immense importance — yet most schools and colleges provide no linking study matter between these two processes. "Climate change and evolution are treated as separate topics in the biology pacing guides, scope and sequence, and Florida science standards", says Julie Bokor, from the outreach centre at the University of Florida. "Often, climate change is dealt with in environmental science classes, while evolution is in biology courses," she adds.

How then, can students in a classroom be taught about climate change, its effects on genetic variation, and consequent changes in populations and species survival?

Enter the fruit fly (*Drosophila melanogaster*), which can be used in classrooms to explore interactions between climate change and rapid evolution, thanks to a three-lesson module designed by a group of teachers and a scientist. The module (which includes Bokor as an author) includes an experiment on chilled comatose fruit flies, and is aimed at linking climate change to lessons on evolution; a detailed version of the module is freely available to instructors as a teaching resource.

At temperatures between 4–7°C, fruit flies go into an inactive state known as a "chill coma". For fruit flies, the chill coma recovery time (CCRT) is a known heritable trait that is dependent on several genes. Fruit flies from temperate regions are known to have shorter CCRTs than those from tropical regions. As flies in a chill coma cannot find food, mates, or avoid predators, CCRT is likely to be adaptive in seasonal temperate climates, where a sudden cool period may be followed by rapid warming.

First Lesson

A basic understanding of adaptation is required for students to be able to interpret data on how quickly comatose flies recover. Thus, the first lesson in the module introduces a fundamental

question—are all species affected equally by climate change? To stimulate their minds, students are assigned two articles as homework. One, that future climate change not only includes global warming, but also leads to extreme weather events such as heat waves and cold snaps; and two, an article that introduces the concept of phenotypic plasticity, where a single genotype can produce multiple phenotypes depending on the environment.
Following a discussion of these concepts, students must work in small groups to analyse eight climate-affected species to predict which species would be more populous ("winners") or less populous ("losers") in response to expected changes in climate. This analysis activity uses 'species cards' based on real data from a study that analysed species vulnerability to climate change, and aids in correcting two common misconceptions about evolution and climate change—(a) that evolution only occurs over very long periods of time, and (b) that climate change negatively impacts all species.

Second Lesson

The second lesson aims to help students explore the role of natural selection on the long-term survival of a species using an active laboratory setup. Students use a modified form of a widely used protocol to address the question — is there potential for natural selection to act on the fruit fly?

To assess the impact of temperature on the rapid evolution of fruit flies, small groups of students observe six vials containing ten flies each; the flies in each vial are from genetically distinct lines. Flies are chilled on ice for three hours to induce a chill coma, and the time taken for flies to recover (CCRT, defined as the fly's ability to walk) is noted by the students. Based on the pooled data collected, students must create and compare graphs of mean CCRTs for the six fruit fly lines.

In an instructor-mediated class discussion, students must identify CCRT as a genetic trait on which natural selection can occur. Following self-study sessions about classic mechanisms of evolution (mutation, gene flow, genetic drift, non-random mating, and natural selection), a post-lab question set is used to help students connect the lab-activity with the study material.

Third Lesson

Lesson three aims to help students synthesise their knowledge of climate change and evolution to tackle the question, "What patterns of natural selection might occur as a result of climate change?". In this one-day lesson, students learn about different types of selection (directional, disruptive, and stabilising), following which, they must complete an assessment in the form of a "natural selection in the face of climate change" activity. Based on a fact sheet with a species description and a problem that the it faces due to climate change, students will again work in small groups to identify how a population might respond to climate change.

This lesson must conclude with a discussion on the limits of evolution—namely,

1. Species do not evolve by choice;
2. Evolution is limited by existing genetic variation; and
3. The pace of evolution may sometimes not be able to keep up with environmental changes due to climate change.

The teaching module, which was implemented on high school students, has been reported by the authors to engage students at a higher level than previously used methods. “This curriculum unit provides opportunities for students to make their own connections between real world occurrences,” says Jessica Mahoney, an author in the publication, and a classroom teacher.

“Although this is an interesting setup, procuring six strains of *Drosophila* would be difficult for most Indian undergraduate classes”, points out Helen Roselene, Head, Department of Environmental Sciences, Mount Carmel college, Bengaluru. However, if experiments with live fruit flies are not possible in a class setting, the authors have provided a data set on CCRTs for use by teachers who can conduct the lesson as a purely analytical exercise.

In all, the module encourages cross-curriculum-based inquiry and may help students engage with climate change policies worldwide. “India is one of the countries likely to be highly affected by climate change,” says Nirmala Raghunandan, Head, Department of Biology, St. Joseph’s pre-university college, Bengaluru. “Introducing this module in Indian schools could be really useful as it can help sensitise students to the effects of climate change, and educate the next generation of leaders and decision makers on how climate change can affect evolution,” she adds.

Botanical Tree-Thinking: a card game to teach plant evolution

Bharti DK

What if playing or trading cards had information of the natural world? Educators suggest that it could induce "tree-thinking" - the understanding of evolution using phylogenetic trees. This article discusses the use of playing cards as teaching tools to piece together key events in plant evolution.

Botanical Phylo Cards (Photo: Requested with permission from Phil Gibson.
URL: http://jphilgibsonlab.oucreate.com/Tree_Thinking/Tree-Thinking_Modules_&_Lab_Exercises.html.
Modified to current form by Manoj Rangan)

Plants and trees are deeply embedded in our view of the world and define the landscapes around us. About 515 million years ago, plants first appeared on land and changed the course of history - they have pumped oxygen into the air, broken down rocks, controlled water flow, established nutrient cycles and paved the way for evolution of land animals. Evolution of plants from green algae to canopy forming trees is marked with physiological and morphological innovations. A keen observation of these morphological traits in the plant phylogenetic tree can help in better understanding the process of evolution.

Though the current college curriculum introduces milestones in animal evolution, the events in plant evolution are less discussed. Smitha Hegde (Professor, Science education and research, NITTE University) concurs “The UGC prescribed syllabus for Bachelor’s degree in Botany lacks guidelines on teaching the subject of evolution.” Recent efforts by educators had led to the development of card games for science education, through the help of open-access and crowd-funded initiatives. A card trading card game “Phylo” uses animal species cards to teach concepts in biodiversity and ecology. Recently, researchers at the University of Oklahoma have developed a Botanical Phylo-Cards game that aims to introduce students to major plant groups and evolutionary events using a card-sorting activity. Botanical Phylo-Cards was inspired from the earlier Phylo game and was created to improve the tree-thinking curriculum (understanding evolution using phylogenetic trees) and introduce concepts of inheritance and evolution using various activities and resources.

The game consists of two sets of cards – each card in Set A has a photograph of a plant species along with its common and scientific name, while a card in Set B additionally has coloured dots as a representation of genetic information on one side, and figures describing plant traits on the other. The coloured dots in Set B cards represent the sequence of the ribulose bisphosphate carboxy-oxygenase large subunit (*rbcL*) encoding gene, which is often used by researchers to understand evolutionary relationships between plants. Differences in the number and arrangement of coloured dots between species reflects variation in their gene sequences. Closely related species show greater similarity in their dot pattern compared to species that diverged earlier during plant evolution. The game covers 27 plant species representing a range of extant plant groups including bryophytes (liverworts and mosses), pteridophytes (club moss and ferns), gymnosperms (conifers such as pine and fir) and angiosperms (flowering plants including monocots and dicots).

The authors suggest two ways in which the card sorting game can be conducted. In the first method, the players first sort Set A cards into groups based on visual cues from plant photographs (morphology). They then sort the Set B cards using patterns of coloured dots (genetic data) provided for each plant species. The players compare these two independent groupings, where the hypothesis of plant groups obtained from morphology is tested against genetic data. The grouping based on morphology is expected to be crude - with errors coming from misleading morphological characters. For example, players might group plants with a grass-like appearance (e.g. horsetail, ephedra) with true grasses, based on their morphology - these species, however, belong to different taxonomic groups. Another example of crude grouping would be the separation of flowering plants based on flower colour, which would fail to separate monocots from dicots. This exercise can be used to introduce the idea of morphological convergence across distantly related species, and the need for gene sequences to understand evolutionary relationships.

The groups created by players using genetic data in Set B can also be used to explain the concept of a phylogenetic tree. Much like a family tree or a pedigree, species can be sequentially grouped based on similarity in their gene sequences to produce a phylogenetic tree. The groups obtained from Set B cards are organized and connections drawn between them to derive the phylogenetic tree. The branching patterns on this tree shows the evolutionary relationships between species. The cards in each of the groups are then turned over to reveal plant trait information. The appearance of vasculature, seeds, fruits and flowers are mapped to different nodes of the phylogenetic tree to understand their evolutionary significance.

The second method of conducting the game involves a head-to-head competition between two groups of players. First, the two groups independently sort Set A cards based on morphology. The differences in groupings from these teams are compared to highlight the subjectivity in morphological classification. Next, the teams are presented with Set B cards, where one team uses the genetic data coded in coloured dots for grouping, while the other uses plant trait information. These groupings are compared to look for congruence between plant genetics and morphology.

The game gives students a first-hand experience on how botanists use gene sequences to build phylogenetic trees, and reconstruct important events in the evolution of plant traits. The authors report success in meeting learning objectives across student age-groups with this game. It is a step in the right direction, feels Navendu Page – a faculty member at the Wildlife Institute of India, Dehradun who studies plant diversity. “Even books for young children are about animals and don’t really cover plants,” he says. “The most useful aspect of this game is that it introduces students to concepts in evolution which can be quite difficult to understand” he adds.

What is research?

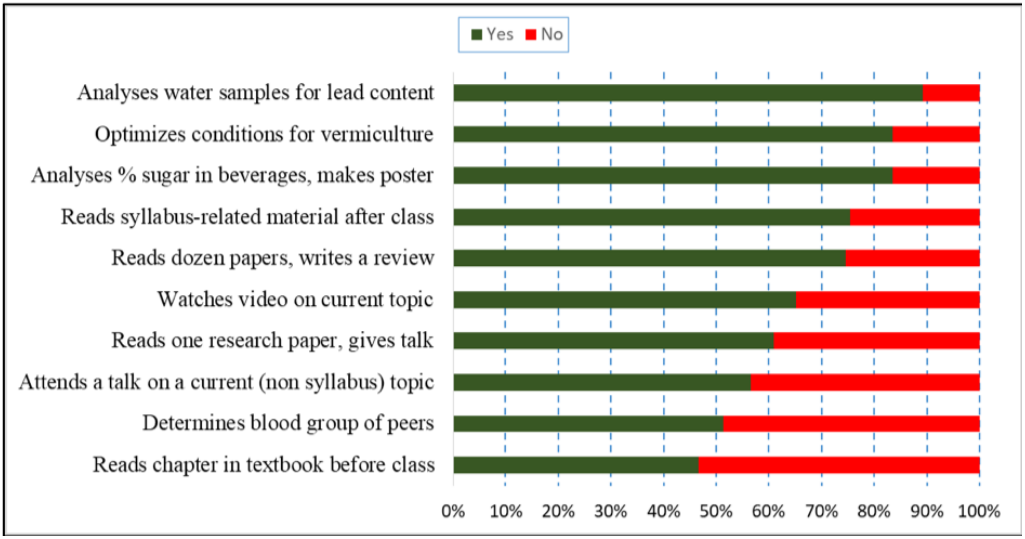
Vidya Jonnalagadda

Vidya, an educator at Bhavan's Vivekanand College, Hyderabad presents a fresh perspective on what activities constitute "research". She advocates that not all research requires lab work, expensive reagents and high end instruments.

Vidya - “Identifying student activities as genuine research”

Vidya Jonnalagadda from the Bhavan’s Vivekanand College, Hyderabad uses the concept of Research-Based Pedagogical Tools (RBPT) to answer the empirical question. Vidya conducted a survey-based study of 117 educators (UG/PG college lecturers) to find answers to key questions and raise a few more. She has been a part of the RBPT workshop at NISER Odisha and Bhavan's College Hyderabad. The participants of the workshops were geographically heterogeneous, representing the states of Andhra Pradesh, Karnataka, Maharashtra, Orissa, Telangana, Tamil Nadu, and Uttar Pradesh.

The goal of RBPT is to use the practices of research as a teaching technique. I was interested to know as to what student activities were considered research by college teachers. Can the activities by students be broken up into research components and rated? Moreover, is it possible to do research without adequate reagents and high-end instruments? Teachers were presented with fictional scenarios of students taking up voluntary activities and asked if they regarded them as research. The recorded responses were anonymous and binary.
Following were the scenarios:



The percentage of responses to the scenarios were recorded as yes or no
Three scenarios involved sample composition analysis (blood, beverage and water samples). Interestingly, a higher majority of educators (90%) recognized the analysis of water samples to be a research activity compared to that of sugary drinks (84%) or blood groups (51%). Is the impression of doing research an outcome of the model being studied? Noteworthy, only the study of beverages was associated with a poster presentation; suggesting another question – is communication of one's scientific study an essential component of research activity? Interestingly, the analysis of vermiculture with a potential entrepreneurial and environmental benefit was ranked lower to that of water and beverage samples. Does this mean that "applied" work is less "research" than "academic" work?

The next activity that I assessed was that of reading. While writing a review and giving a talk on research papers was ranked high (75% and 61% respectively), reading about a topic before class was not counted as research by 55% of the participants. In contrast, further reading on a topic after it was taught in the class was considered as research by 75% of the participants. It is curious that voluntary enquiry to subject matter is not perceived as research until primed by a teacher. Yet, state of the art reading associated with an oral/written presentation is perceived as research. Also, the medium of the post class enquiry mattered - reading syllabus-related topics were ranked high compared to attending a seminar or watching a video lecture delivered by an expert.

One dimension of my thought experiment was to learn the responses of teachers to the activities constituting research. Among the population tested, over 50% of teachers thought that at least 7 of the 10 activities constituted research; and 19 teachers among the 117 tested considered all the 10 activities to be research. Whether this behavior has to do something with the training of teachers is unknown as the survey was anonymous.
Since the teachers had around a minute to answer each question, I consider the answers to be instinctive. I here suggest a rubric, based on which student activities can be ranked. I hope that this leads to a consensus on the idea of research. I suggest the following five parameters to be a part of the rubric:

- Involvement: Did the student do something actively (read, measure) or passively (listen, watch)?
- Manual Skill: Did the activity require skill in a laboratory technique?
- Reference Work: Did the student survey literature to locate a suitable reference material?
- Comprehension: Did the student analyze the result of the activity to gain a deeper understanding of the topic?
- Communication: Did the student generate new content in an oral, written or a graphic form?

When the “instinctive” responses were rated using this rubric, the activity that led to a holistic learning and effective communication was the one where the student set up and evaluated several conditions to arrive at the “best” condition (the vermiculture activity). Based on this rubric, reading a topic before a class rates higher than attending a talk or watching a video. I can conclude that, attending classroom lectures – even lectures describing research work or results – does not help the student develop any research ability. Moreover, activities that do not involve lab work: reading one or few papers, and giving an oral or written presentation score higher than a repetitive exercise of analyzing blood groups or water samples. When judged by this rubric, even in setups where lab space, reagents, and/or equipment is limited, a teacher can design and recognize library-based work as authentic research that provides a student the opportunity to develop transferrable skills and generate new, high quality content.

Activity	Involvement	Manual (Lab) skill	Reference work	Comprehension	Communication
Reads textbook chapter before class	Active	No	Yes	Maybe	No
Determines blood group of peers	Active	Yes	No	No (Not required)	No
Attends talk on student health	Passive	No	No	Maybe	No
Reads one research paper, gives talk	Active	No	Yes	Yes	Yes
Watches video on current topic	Passive	No	Yes*	Maybe	No
Reads a dozen papers, writes a review	Active	No	Yes	Yes	Yes
Reads syllabus-related material after class	Active	No	Yes	Maybe	No
Analyzes beverages, makes a poster	Active	Yes	No	Yes	Yes
Optimizes conditions for vermiculture	Active	Yes	Yes	Yes	Yes
Analyzes water samples	Active	Yes	No	No (Not required)	No

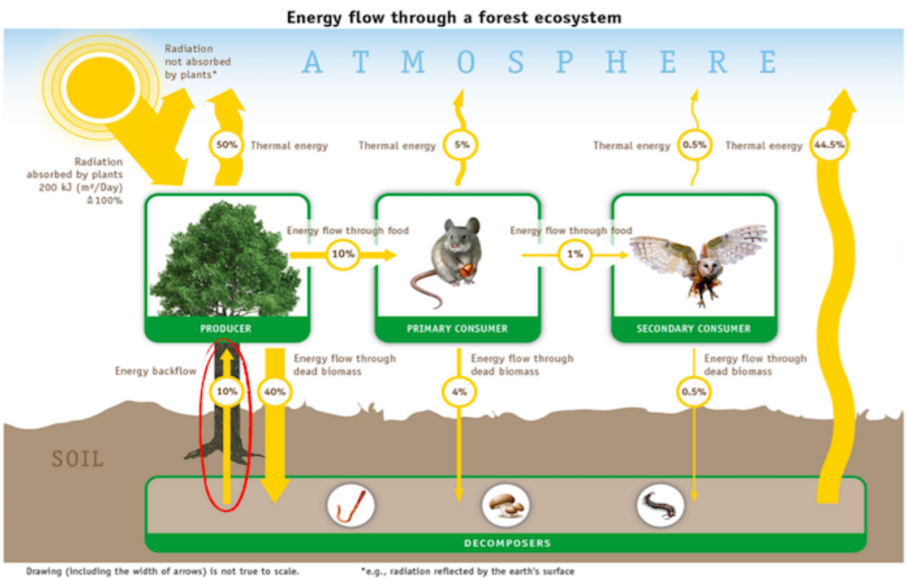
Rubric for qualifying student activities as research * - If the student has searched for the video lecture himself (not recommended by someone else).

Vidya stresses on using a standard criterion as a basis of judgement of research activity. She plans to use this rubric to further develop the idea of research. She says it might help a teacher appreciate genuine discovery and design projects not heavily dependent on laboratory facilities.

Deliberately introduced errors as a pedagogical tool: the teaching of energy flow

Anusha Krishnan

Would learning be enhanced if errors were introduced in scientific diagrams? Students who explore and explain these errors seem to achieve a better understanding of the subject matter, suggests a new study.



Incorrect diagram of energy flow through a forest ecosystem (Photo: Wernecke et al, doi: 10.1187/cbe.17-07-0133)

"Don't waste a good mistake; learn from it." - Robert Kiyosaki, Author- Rich Dad, Poor Dad
Making mistakes is part and parcel of learning. If used constructively, errors can be a wonderful tool in a teacher's stockpile of resources for instructing students. Another extensively used

resource is visual presentation—the art of conveying an idea or concept with a picture, a diagram, or flow chart. A recent study from the University of Kiel in Germany shows that these two teaching aids can be combined to help students gain a better understanding of abstract concepts such as energy flows in ecosystems.

The study demonstrates that when students are given a flawed diagram explaining a concept and asked to spot and explain errors in it, they attain a better grasp of that concept than those asked to learn with accurate diagrams. However, this approach requires three specific conditions—that the symbology in a diagram must be absolutely clear, that students must already have a good understanding of the subject, and finally, students must be willing to study such diagrams closely and thoroughly.

The idea of deliberately introducing errors, a concept known as 'negative knowledge' or the 'knowledge of *how something is not,* in contrast to *how it really is*' has been applied in teaching mathematics, its use in classrooms to tackle conceptual misunderstandings however, is not widespread.

Amongst students, most errors occur due to partial understanding or misunderstandings in abstract concepts such as that of energy. When learning about energy flow in biological systems, many students harbor two major misconceptions – one, that plants can obtain energy from soil, and two, that energy can be cycled within an ecosystem. Using these misconceptions, researchers introduced the error in the form of an additional arrow (circled in the image above) and tested the effectiveness of three teaching strategies. In group one, students given a flawed energy-flow diagram were asked to find the error and explain why it was an error. A second group was given the flawed diagram with the error highlighted and were tasked with explaining the error. While in the third group, students were simply handed the correct diagram, and asked to learn about energy flow in an ecosystem. Students were tested on energy-flow concepts before the given task (pre-test), and once again after they completed the task (post-test). The differences in scores between the pre-test and post-test were used as a measure of how much students had learnt from the tasks.

Overall, students from all groups scored more in the post-test than the pre-test, indicating that they had gained an improved understanding of energy flow after the tasks. Closer analysis of the data showed that students from group 1 and 2 who had correctly explained the error seemed to have learnt more than students in group 3, or the unsuccessful students in groups 1 and 2.

The most striking finding was that only 10% of group 1 students were able to correctly identify and explain the error in the diagram. Compared to their peers who could not complete the task, these students had spent more time focusing on studying the diagram to spot the error. In contrast to group 1, nearly 30% of the students in group 2 explained the error correctly, indicating that spotting an error requires much more cognitive focus than having the error pointed out and needing to explain it. The researchers also found that the successful students in this group had better knowledge of energy concepts than others in the same group.

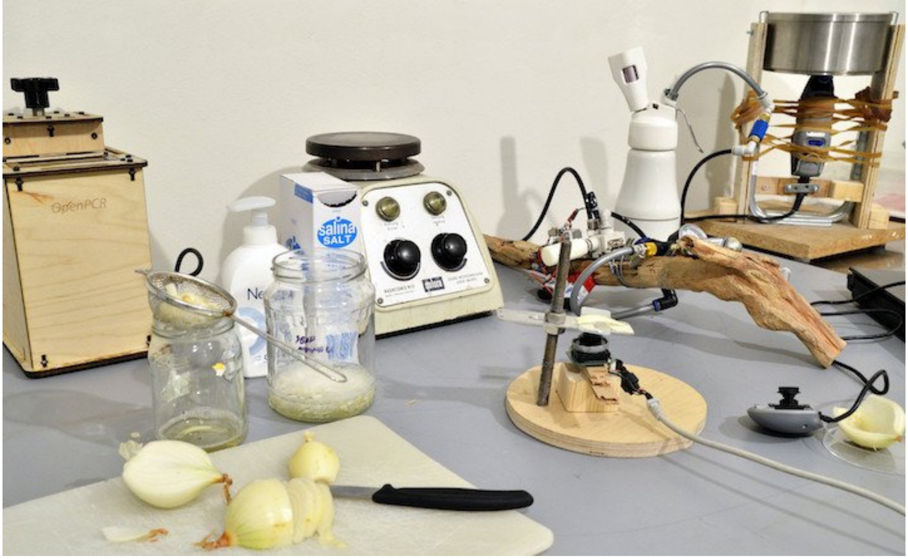
In essence, inserting errors in diagrams can help learning only if students successfully find and explain such errors. Furthermore, researchers found that students often misunderstood the symbology and labelling used in the diagrams. Therefore, for such a teaching strategy to succeed in helping students, three points must be ensured: 1. that students clearly understand the symbology and labelling in diagrams, 2. they have a good grasp of the subject, and 3. they must study the diagrams carefully, and in detail. It has been noted that when learning with visual aids like diagrams, many students tend to skim over the material without examining it in detail. Although not labelling the error in flawed diagrams may encourage students to put in more cognitive effort in studying the diagram and the concept, this does come with the danger of imparting wrong information. A student in a hurry may simply memorize the wrong facts without bothering to check the instructions accompanying the material.

In conclusion, deliberately introduced errors in visual aids can foster an error-tolerant classroom culture by showing that learning from errors is not only possible, but also desirable.

Jugaad in science: effective biology practicals on a shoe-string budget

Anusha Krishnan

Running a lab and conducting experiments can be expensive. Globally, ingenious students and teachers have developed hacks for cheap science (including a 15 Rupee centrifuge!). We Indians are masters of "jugaad" - can we make scientific experiments accessible to all?



Extracting DNA from onion - Biohack -A cast of homemade, donated, and open source instruments (Photo: Martin Malthe Borch, Source: flickr, License: CC BY-NC-SA)

My first academic thrill came from a ‘quick and dirty’ little protocol our undergraduate class used to extract DNA from an agarose gel slice. We used sterilized Eppendorf tubes, an aged and erratic centrifuge, a brand-new gel electrophoresis kit, and DNA samples scrounged from a nearby research laboratory.

To us, the experiment was a vicarious form of research.
Most educators will agree that good teaching must focus on helping students become independent learners—practical experience and training are crucial for this process. Though many educational institutions today have laboratories equipped with the necessary instruments (and reagents) for basic biology/molecular biology experiments, many do not. Furthermore, such ‘experiments’ are often no more than demonstrations carried out by teachers.

Scientific laboratories are expensive
Since molecular biology is one of the most widely utilized sub-fields in biology, let’s estimate the finances of a functional laboratory. A quick cost-estimation comes to a staggering total—at least 20 lakhs—for basic requirements such as a centrifuge (2–6 L), a PCR machine (5–6 L), electrophoresis chambers and power packs (0.5–1 L), a bacterial incubator (0.5 L), microscopes (0.5–1 L), and a spectrophotometer (4–5 L). In addition to one-time buys like hardware, the cost of chemicals, reagents, and maintenance for a laboratory with ten working students may exceed 1 L per year.

“When I began setting up a research lab for undergraduates roughly 10 years ago, just the cost of readying the space and buying instruments cost us 10–15 L,” says Urmi Bajpai, ateacher at Acharya Narendra Dev College, New Delhi, who has headed and still runs several research projects powered by undergraduate students. “The concept of involving students in undergraduate research projects has proven to be a great one! It definitely requires hard work and patience but is worth the effort,” she adds. In a previous article, Bajpai mentions the initial grants that got her laboratory going—these, unsurprisingly, run into lakhs of rupees.

Such expenses are not unique to the area of molecular biology; ecologists, neuroscientists, botanists, biochemists—whatever be the field of pursuit—there are incredibly useful commercial products that may not fit the expense budget.

The bottom line is, **experiments in biology can be expensive**.
Given such costs, can undergraduate students, amateur scientists, or science hobbyists undertake biology experiments without the support of a professional laboratory or an academic institution?

Surprisingly, the answer is yes! There are several ways in which an interested person can contribute to a research project or carry out biology experiments on a shoe-string budget.

Ultra-low-cost solutions to expensive equipment: frugal science
The first name that comes to mind when mulling over the concept of an inexpensive laboratory machine is Manu Prakash. A Professor of Bioengineering at the Stanford University, USA, Prakash runs a curiosity-driven lab, has created major cracks in the instrument-expense-barrier with his foldscope and paperfuge. Prakash describes his group’s innovations as ‘frugal science’

solutions to the problem of insufficient resources.

The foldscope is an ultra-low-cost microscope made of paper, which currently costs less than 2 USD (roughly 150 Rupees) and can provide magnification (up to 140X) and resolution (down to 2 microns) similar to those of conventional research microscopes. The paperfuge is a whirligig-based paper centrifuge which can be run by hand, costs roughly 20 cents (15 Rupees), weighs only 2 grams, and can achieve speed of up to 25,000 revolutions per minute.

Locally sourced, build-it-yourself systems
Scientists are slowly clambering out of their ivory towers to acknowledge the need for low-cost robust equipment not only for teaching purposes, but also for scientists on small budgets to help generate preliminary data for risky but promising projects. One laudable effort at equipment construction comes from a recent publication in the Journal of Undergraduate Neuroscience Education, which details the fabrication of a Morris water maze using locally sourced materials. This maze was used by undergraduates to study the effects of diet-induced obesity on cognitive function in rats. The total cost of maze construction, including the tracking system and analysis software cost the authors ~1500 USD, whereas, commercially available mazes from companies such as Ugo Basile or San Diego Instruments cost ~5000 USD.

“Constructing your own equipment, provided you have the time for tinkering and standardization, can be most rewarding. Not only do you gain an in-depth understanding of the system, the fabrication costs using locally sourced material are generally a fraction of what you would spend on a commercial product,” says Urvashi Bhattacharyya, a neurobiologist who works as a technical manager at the Institute for Stem Cell Biology and Regenerative Medicine in Bangalore. Although Bhattacharyya (who worked on rat olfaction for her PhD) designed her own experimental arena because no commercial products met her exact specifications, points out why commercial systems are a big boon to some. “If you do not have the expertise (valuable for precision and accuracy) or time to do build your own system, I would advise using a commercial product,” she says.

“Behavior systems, especially tracking software, can be excruciatingly expensive,” says Bhattacharyya. “So, the work in this paper was pragmatic and commendable, especially since they were able to replicate the basic experimental results in the maze,” she adds.

Another area of research where innovations are rife is in ecology. “When I was studying hornbills in Dandeli, I needed a quick, inexpensive way to measure canopy density. That’s when I came across a publication from the 1970s, which explained how a simple densiometer could be constructed out of cardboard and string,” says Sneha Vijaykumar, who recently completed her PhD from the Indian Institute of Science. “I was an MSc student with no money to buy a fancy densiometer, but managed to construct one, and gathered some useful broad-range data with it. I think that instruments and innovations like these are such good resources for students. What’s even more amazing is that with the appropriate instructions, this construct can still be used by teachers to conduct canopy cover survey lessons for students,” she adds.

A whole new dimension to build-it-yourself instruments: The advent of open source hardware

In 2003, the Arduino project was started by the Interaction Design Institute Ivrea in Italy, to help provide supplies for creating low-cost devices that could interact with their environment—robots, thermostats, and motion detectors. Currently, Arduino is an open source hardware and software company, project, and user community that provides microcontrollers and kits for building digital devices and interactive objects. Arduino has spurred many advances including a do-it-yourself construction kit to build a PCR machine, which is currently available for 599 USD from the OpenPCR project.

Besides Arduino, a global community focused on biohacking can provide simplified step-by-step instructions for constructing molecular biology instruments such as agarose gel electrophoresis kits.

Community laboratories and citizen science projects

The biohacking or 'modern do-it-yourself biology laboratory' movement began to gain momentum in 2008 with groups such as Hacketeria, DIYbio, and GOSH (gathering for open science hardware). These groups are usually international communities of scientists, hackers, and artists, who believe in interdisciplinary cooperation, and practice DIY (do-it-yourself) or DIWO (do-it-with-others) biology. Biohacking hasresulted in the birth of community laboratories such as GaudiLabs and BioCurious. GaudiLabs organizes regular 'hack sprints', where people interested in a particular subject meet and work together for short and intense hacking sessions. One such session has produced an optical tweezer which can be constructed for <100 USD using harvested lasers from old DVD drives. Some of the current projects at BioCurious are the BioPrinter (to design an open source DIY cell printer) and the Open Insulin Project (aimed at finding newer, simpler, less-expensive ways to produce insulin).

In addition to community laboratories, an average citizen, student, or science hobbyist can contribute to low-budget scientific endeavors by participating in citizen science projects. These are crowd-sourced, community-based projects where volunteers gather information which is pooled and analyzed by a core team of organizers. In India, MigrantWatch is an excellent example of citizen science. Over its duration (from July 2007–August 2015) participants have uploaded over 30,000 migrant bird sightings; although the project has now stopped accepting uploads, it has partnered with the global birding platform eBird to continue listing and recording sightings in India. SeasonWatch is an ongoing project that aims at monitoring seasonal changes in trees; all the data collected is freely available to participants who can analyze the records to explore how seasonal leafing, flowering, and fruiting patterns of trees have been altered (or not?) by climate change.

Low-cost science in India: are we there yet?

Although we as a nation pride ourselves on our innovative hacks when faced with insufficiency, Indian science has not yet reached its peak in *JuGAaD (Justified Guideline to Achieve the*

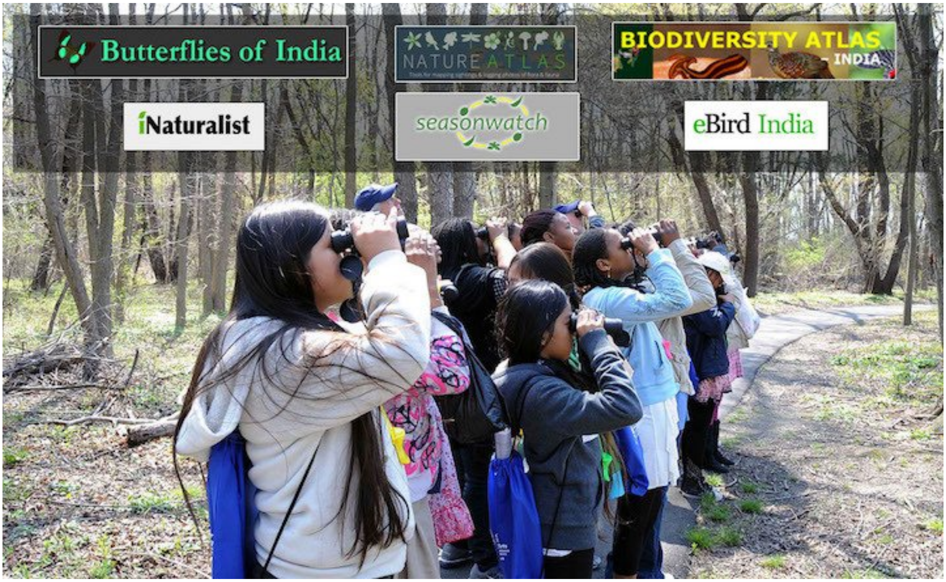
Desired State). It is highly probable that our laboratories have academic pasts littered with useful, practical, and low-cost alternatives to many scientific instruments and protocols. Many of these remain unrecorded, or may have been lost to the ever-looming spectre of 'professionalism'. After all, a result recorded with a commercially produced, well-tested product will be more believable than a locally constructed hack.

It is, however, important to note that such hacks should be recorded and preserved in the interests of frugal science. It is hoped that India's entry into the 'science hack days' forum since 2016 will encourage more minds to think of newer low-cost, innovative alternatives to expensive gadgets.

Bringing online citizen science to classrooms

Suchitra Sankaranarayan

To introduce the habit of observation and systematic recording, young citizens should be encouraged to participate in active science. One way is to inculcate field observation within the school and college curriculum. Citizen science initiatives combined with information technology are powerful tools in knowledge creation and collective learning.



Birdwatching trips could be inculcated within the curriculum (Photo: Wikimedia Commons. Modified to current form by Manoj Rangan)

Gathering data via citizen science, a movement where the community takes active participation in scientific research, attracts collaboration between scientists and the public, enabling the discovery of newer endemic flora and fauna, and cultivating interest in sciences that are not restricted to books and laboratories. Recent years have seen the advent of informatics, leading to the development of a number of scientific digital tools on the internet. In areas such as ecology where studies involve field observations, such tools can prove invaluable support in gathering vast quantities of data through online citizen science. Amateur naturalists and photography hobbyists have explored such tools - eBird, iNaturalist and the Encyclopedia of Life (EoL) are large scale initiatives that encourage animal watchers to submit data of species distributions. A bioinformatics platform called Biodiversity Atlas - India (BAI) aims to document population and migratory trend of various species groups such as butterflies, mammals and reptiles. “More than 90% of the data is from citizen science”, says Krushnamegh Kunte, who manages BAI. “In the last 1.5 to 2 years, we have generated about 70,000 records using image-based data.” He is working on expanding the platform to incorporate non-image based data, such as documenting animal calls and sightings.

One way of exposing younger generation to this method of data collection is to introduce these tools in the school and college curricula. A seven year long study published in *The American Biology Teacher* (ABT) studied the educational outcomes of integrating publicly available aids on the internet with natural history courses at the undergraduate level. The students used NatureAtlas, a website that helps contribute georeferenced material of organisms, generate and access interactive data visualizations, allowing a fresh look at biodiversity specimen information. This activity created new records of existing species in the local biota. Nature Conservation Foundation (NCF) scientist, Suhel Quader who actively encourages citizen science activities, explains how online citizen science can help both students and teachers. “Web-based tools can be used to show students some pre-defined result, but more interestingly, can open up the possibility of students asking their own questions and finding answers to them - and these can be questions and answers that have never been addressed before. Teachers would then focus less on the facts, and more on questions like what makes an interesting and/or important question, how can I find the answer, how can I assess the reliability of this answers and so on.”

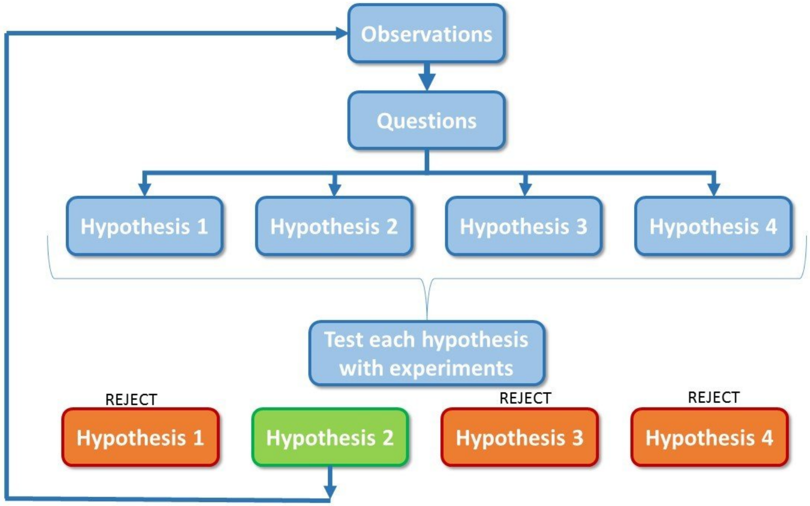
In India, engaging students through classroom and extra curricular activities is ongoing. NCF’s SeasonWatch project collaborates with schools to monitor trees on their campuses or nearby gardens for studying flowering seasons. BAI conducts “Biodiversity Marathons” in partnership with various NGOs where leading naturalists introduce students to these platforms and encourage them to upload information. Kunte thinks that exposing students early on to ventures like these and talking to them about population ecology can capture their attention, give them a sense of being personally involved in science and potentially attract them towards academia. Bangalore based EcoEdu that collaborates with schools and colleges to inculcate awareness and empathy towards biodiversity also introduces students to eBird, Early Bird and iNaturalist. Citizen science programs allow people to learn **data collection and analysis** - two powerful skills for scientific research. Hari Sridhar, an ecologist from the Indian Institute of Science who has taught a course on the lives of birds at the Azim Premji University to students from non-scientific background says, “I encourage students to try birdwatching and sign onto eBird to archive their records. It gives them a sense of what scientists do with respect to systematic data collection and use." Such informal practices however exist only in some schools. Curricula in schools and universities are often rigid and offer little space for teachers to explore newer methods of pedagogy.

An added challenge is maintaining a constant level of interest and enthusiasm for extended periods, such as after the completion of the course. "It is hard to get everyone excited and keep them motivated to continue contributing to internet platforms" Kunte observes, "We need the vision and discipline to ensure that these projects are carried through generations." Moreover, it requires skill and training to be able to trust the quality of data. Quader is of the opinion that while citizen science projects tend to adopt fairly simple protocols and generate high quality data that is comparable to that collected by trained professionals, there are several ways of improving it such as training reviewers and developing computational tools, automated or semi-automated for detecting unusual details. Web-based tools for studying ecology offer far reaching consequences. For scientifically inclined laypersons, such tools provide an opportunity to explore an interest while making a valuable contribution to basic science. For the community, citizen science helps raise awareness towards issues such as endangering of species. For naturalists, this is a quicker method of data collection that they can then cross reference and corroborate before publishing them in the database. The introduction of these online instruments in curricula for students in practical courses or field trips can inculcate an interest in observing and documenting regional flora and fauna, irrespective of their professional fields, which is highly beneficial. "We have plans to explore such possibilities with high school students and undergraduates in the coming years, using data from eBird and from SeasonWatch", says Quader.

Experiences in using the scientific method as a structure to teach biology

Swati Patankar

IIT Bombay faculty Swati Patankar realised imparting facts is not the way to teach biology. So she decided to teach science the way she does science.



Scientific Method (Photo: Swati Patankar)

When I first started teaching biology at IIT Bombay almost fourteen years ago, I quickly realised that if I taught facts my students and I would have an awful time in class. This was because my students had learned these facts very recently, were much better at memorizing information than me; and in terms of being a repository of facts, my real competition was the internet, which I did not have a hope of beating.

Interestingly, and very intuitively, my strategy to handle this was to use the scientific method to teach biology. Let us quickly remind ourselves what the scientific method involves (see the figure above for a visual representation).

The crux of the scientific method involves making observations and asking questions. To answer these questions, scientists come up with many hypotheses and then systematically test each hypothesis with experimental approaches. Some hypotheses do not stand the test of rigorous experimental validation and are therefore discarded. The valid hypotheses are further tested by more experiments and finally the one hypothesis that still stands is now used to make predictions. Yet more experiments based on these predictions will tell us whether the hypothesis is valid, needs to be modified or possibly discarded. When the hypothesis has not been falsified for a long time, it becomes a theory. This structure of doing science has been used for centuries.

So now let us get into how one might use the scientific method as a structure for teaching biology and its benefits.

1) Classroom teaching

I have been teaching Molecular Biology for over a decade now and structure many topics along the lines of the scientific method. For example, when we study the discovery of Okazaki fragments, the class is first introduced to the observations that led to the classic Okazaki experiments. These observations include the knowledge that DNA replication is semiconservative , starts at a bi-directional replication fork and occurs only from 5′ to 3′. These observations lead to a conceptual problem which is that both of the two strands of DNA cannot be replicated in the same direction as the movement of the replication fork. Indeed, one strand will have a direction of replication that is opposite to the direction of the replication fork (see the figure for a visual representation). The mugged up answer to this problem is “One strand (the lagging strand) is synthesized as short fragments called Okazaki fragments while the other (the leading strand) is synthesized as a continuous, long polymer”.

I next ask the students to come up with at least 3 other mechanisms by which the problem can be solved. This forces them to think of new hypotheses beyond their mugged up facts. Then we look at the experiments and data from the Okazaki experiments and eliminate any of their hypotheses that do not fit the data. While looking at data, the students realise that the early results actually showed short fragments on both strands, not just the lagging strand! This is quite a shock to the students who have mugged up that DNA replication is semi-discontinuous. We further explore the data and the students go off and search the internet for why the data is not consistent with their expectations. I also show them a figure from a biochemistry textbook (Lehninger) from the 70s and 80s showing short fragments on both strands of the replicating DNA, illustrating that even textbooks evolve as more and more experiments are performed. By the way, if anyone is interested in the mystery behind the early observations that both strands appear discontinuous, do a Google search for discontinuous DNA replication and uracil-excision repair and have a look at papers from the 70s and 80s.

When taught through the scientific method, students realise that textbook information is based on data that can change with the next experiment. They are forced to question facts and so leave the class appreciating that biology is more than cramming 'facts'. This method can be applied to any professional setting: “look at the data and decide for yourself” is a good learning even at McKinsey consulting or a bank.

2) Setting exams

The scientific method works well for setting exams. For the first year B. Tech class (~450 students who just cracked the Joint Entrance Exam for IITs and dropped biology years ago), I set an exam paper based on a real case of food poisoning at the hostel mess that had been covered by InsIghT, the student magazine at IIT Bombay. The first question went like this:
You are now an expert in Biology and are called upon as one of the members of the committee that is examining the case. You find that the Chinese dinner contains bacteria called Salmonella that is known to cause food poisoning. You do some further tests on the bacteria.The first test you perform is Gram staining of these Salmonella bacteria. You find it is a rod shaped, Gram-negative bacteria. Draw a schematic of the plasma membrane and cell wall of Gram-positive and Gram-negative bacteria. (2 marks)

This way of framing the question gets the students to think about structure of the bacterial cell wall in the context of a scientific problem.

You treat the 16 hospitalized students with Penicillin (an antibiotic whose target is the peptidoglycan cell wall) and find to your surprise that they do not recover from the food poisoning because the Gram negative Salmonella bacteria are not killed efficiently by Penicillin. Based on your answer in Qs 1a, propose an explanation for why Penicillin is not effective for Gram negative bacteria. (2 marks)

Now, the students have to connect the diagrams of the bacterial cell wall from the previous answer with new information and interpret the new data.

You next treat the students with Erythromycin and they all recover except two. Unfortunately, one of these students seems to have a drug resistant Salmonella infection. Upon further study, the bacteria are seen to have acquired foreign DNA. As a Biology expert, you know drug resistance can be explained by evolution driven via natural selection. One of the 4 concepts in natural selection is variation. Give two ways by which the drug resistant bacteria can acquire genetic variation. (2 marks)

Now, the students are given a completely different topic (evolution) in the context of the same question. In fact, the food poisoning question had 7 sub-questions that covered the topics of bacterial cell structure, antibiotics, drug resistance, evolution, viruses, genome structure and they were all connected by the basic story of the hostel food poisoning.

3) Lab courses

Rather than simply learning techniques, the students try to answer a problem using the techniques that they learn. I have done this in two ways. First, for a lab course on Genetic Engineering, we were supposed to cover plasmid DNA isolation, PCR, cloning and bacterial transformation. In order to tie these techniques into a cohesive story, I made up a scenario where I told the students that we had isolated a bacterial strain from Powai lake that glows when we shine UV light on it. This strain seems to have a gene similar to Green Fluorescent Protein (GFP) and if we can clone the gene, we could start a biotech company and make lots of money! Now the same experiments had a purpose.

The second strategy was used during a Microbiology lab course where the students were asked to bring in samples from anywhere and these are typically water from the department purifier, their mess food (this is a recurring theme!), Powai lake, etc. I gave my colleague who was running the lab a suggestion that I would like to collect samples with a hypothesis in mind. For example, I would be interested to know whether the water supply in Mumbai gets more polluted as one moves away from the source (Vihar, Tansi and Vaitarna lakes). The way to answer the question would be to collect samples from the train stations starting closer to the lakes and moving further away. This strategy gave the students a hypothesis-driven lab course to isolate microorganisms as well as a small field trip on the local train. In the future, I would ask students to come up with their own hypotheses. This strategy has been used brilliantly by my classmate Carol Bascom-Slack and her colleagues at Yale (check out their paper).

Most importantly, when lab courses are taught using the scientific method, failure is also a learning experience. Often the experiments did not work, especially in the Genetic Engineering lab. Rather than wanting to just get results, we did a lot of troubleshooting to figure out why the experiment did not work. This gave the students the experience of learning from failure. The lab books were written as the work proceeded, similar to a scientific project (not after the lab was over, at the last minute before submission). Finally, the objectives of the class were to learn techniques, answer the main scientific question, learn time management, learn how to plan your experiments, etc.

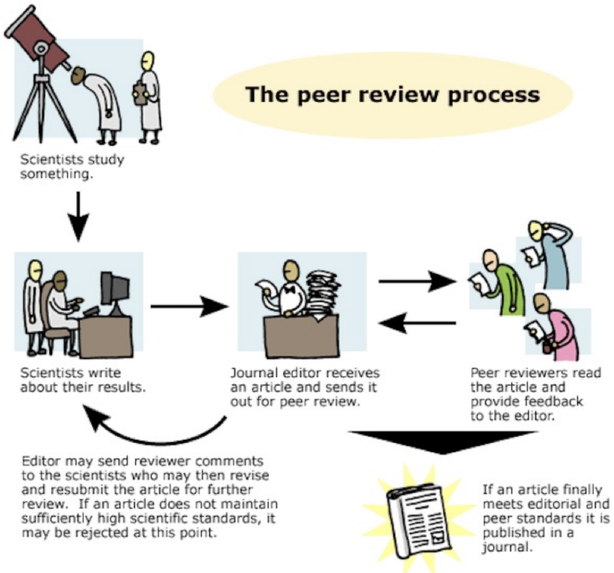
I have tried to illustrate the advantages of teaching science (especially the “muggu” aspects of biology) through the scientific method. Nevertheless, I am acutely aware that being at IIT Bombay allows me a lot of freedom in my teaching, which other teachers may not have. I teach B.Tech., M.Sc. and Ph.D. students; I set my own exams and grade them so that I can reinforce the concepts I am trying to get across. Teachers who read this piece might feel that I am in a privileged position while they have many challenges. I urge them to consider my challenge, which was to teach biology to IIT B.Techs - bright students who thought that the subject was utterly boring. We all have constraints, but as I am a scientist, I am always trying new strategies to do overcome them. I think this can be done by anyone.

Acknowledgement: This piece is based on a talk I gave during the 26th Biennial conference of the Asian Association for Biology Education (AABE) at Goa from September 20-23, 2016. Thank you to Dr. Narendra Deshmukh and the organizers for inviting me and giving me a chance to organize my thoughts on the strategies I have used for teaching biology.

Can we incorporate peer review in science classrooms?

Reeteka Sud

The strict criteria that apply to doing science, can they be made part of learning science? How can science students be taught the process of critical assessment and feedback?



Peer Review process (Photo: "Scrutinizing science: Peer review". Understanding Science. University of California Museum of Paleontology. 18 May 2017 <http://undsci.berkeley.edu/article/howscienceworks_16>)

Relegating decision-making responsibility is very easy to do, easier still when people don't have the tools to dissect the veracity of information for themselves. Within the scientific community, the answer for “should you believe any given report” generally includes “was it peer-reviewed”. The point of peer review being that we don’t believe something just because “a very senior scientist says so”— there are standards that have to be met -- a decision made by other scientists in the same field (peers of scientists doing the study). The strict criteria that apply to doing science, can they be made part of learning science? How can science students be taught the process of critical assessment and feedback? Peer Instruction offers one possibility to do that.

Sometimes clubbed with many ways of class discussion, there are multiple elements to peer instruction. As the name suggests, students “instruct” their peers; only, unlike the lecture setting, here the instruction is in the form of a discussion. It requires students to self-evaluate what they know, present their point of view to their peers (the instruction part) and try to understand their peers’ arguments in turn. Teachers use it either for formative assessment of student understanding in real-time, and/or for specific needs of a project/assignment. For many, it is also a preferred method to teach students how to read original scientific papers.

When done right, this mode of instruction involves arguments being judged for their merit, like it is in peer review. “Translating” principles of peer review to peer instruction in class would include asking students to summarise their peers point of view, assess whether the argument [they heard] is logical, put forth their own argument and give reasons for agreeing/disagreeing with their peer(s).

Though discussion is an integral part of peer instruction, teachers who use this method advise to carefully introduce the format and to ensure it is made clear to students what’s expected of them; lest it becomes another case of “fisheye teaching” where discussion becomes confined between the teacher and a few extroverted students, sidelining the rest of the class.

In any form of discussion, shy students do have their work cut out for them. Not sure whether to clarify a doubt they have, not confident in their own point of view, or lacking the surety to debate another student’s opinion, they either don’t speak up or easily get disheartened when they get shouted down by other students. Here again, it is up to the teacher — to set the ground rules for discussion participation.

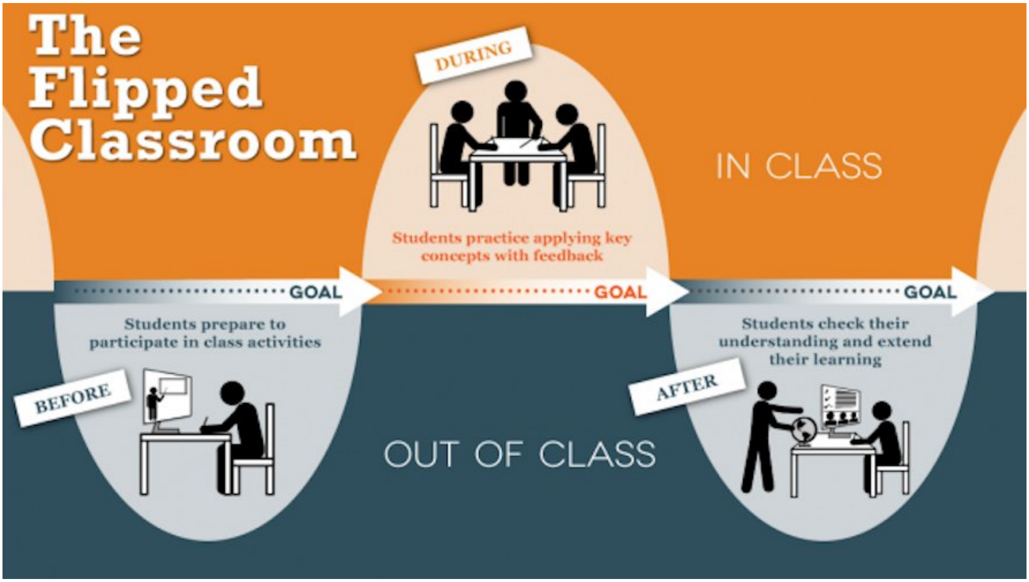
In the Indian context, several factors can make it a tricky business to adapt peer instruction. Culture plays a big role, always, in framing learners’ behaviours. Frequently, teachers report hesitation on parts of students to be direct, for worries it might be misconstrued and they’d end up alienating their friends. Not for nothing, but another reason discussions can be unsettling for students is that they are comfortable with “one-right-answer” evaluation system. Whereas with methods like peer instruction, having the right answer is not the end-of-story. Students have to be able to show how they got there. Swati Patankar, faculty at IIT Bombay, has been using peer instruction for 7-8 years. In one particular instance, her students, after learning ‘regulation of gene expression’ do a group exercise to “design your own genetic switch”. The class is divided in groups, and each group grades the presentations of the other groups, based on pre-set criteria. “I do need to nudge them to develop the criteria they must rely on to grade their peers. I make sure they understand it is not enough for any of them to give loose responses like ‘this was good’; ‘I liked it’. With some encouragement, students do come up with reliable benchmarks: ‘was the argument presented scientifically sound’; ‘was the presentation clear and easy to understand’; etc. For this to work, it is up to the instructor to set it up really well — to make it clear to students what it is that is being evaluated.”

For teachers using peer instruction, it is often rewarding to see students “get” the difference between what they know and what *they think* they know. “I do believe doing such peer activities gives students a holistic understanding of science process”, says Asim Auti of MES Garware college, Pune. “Students have to be trained to give critical feedback. I think this training is a long process, but totally worth the effort. In one of the courses I teach MSc Biotech students, their response was so overwhelmingly positive, it was incredible -- they asked “why is it we don’t learn science this way in school and undergrad too!”

Traditional lecturing, flipped

Reeteka Sud

What is a flipped classroom? How can a teacher flip their class? Is it effective?



Students at IISER Pune build a model of DNA Structure (Photo: Kundan Sengupta)

Inspired by one guiding question, “what is best for students in my classroom”, high school chemistry teacher Jon Bergmann, along with his colleague Aaron Sams, developed a teaching method now called flipped classroom or flipped learning. Jon defines it as “a pedagogical approach in which direct instruction moves from the group learning space (classroom) to the individual learning space (the student at home), and the resulting group space is transformed into a dynamic, interactive learning environment where the educator guides students as they apply concepts and engage creatively in the subject matter.” In other words, the learning environment in the class, as we know it, is flipped on its head.

Pedagogical tools like these can be particularly useful when the topic tends to be confusing for students—class time can be used for discussions directed at clearing their misconceptions. In fact, teachers who routinely flip their classes use this criterion in choosing whether or not to flip their classroom: which topics would be better covered if students are actively engaged in class? Flipped classrooms have been tried effectively in many countries; at every class level, from kindergarten to college; in classes of all sizes, from a dozen students to few hundred (the largest count of students was 350 students at a university in Ohio, US). In following such a method, teachers provide resources to students to review before they come to class, where this prior knowledge is made use of in way of either discussions or activities. Quite often, these are in the form of video lectures, either created by the teacher themselves or curated from one of the many popular lecture videos freely available online. Notable examples of such online portals include Ted Ed, Khan Academy, iBiology, etc. Interested teachers can also model their flipped classrooms after experienced peers, for example, Ms. M's Biology class or Biological Principles course at Georgia Tech University. A 'Quick Start Guide' from the Center for Teaching and Learning, University of Texas Austin, recommends instructors make available 3-5 videos each week, each lasting only 3-5 minutes. Short videos are crucial so neither teachers nor students feel overwhelmed. Examples of tools to help teachers make their own videos include TeacherTube, Windows Movie Maker, and ScreenCast, to name a few. A collection of videos showing instructors using this mode of teaching in their classrooms can be accessed at http://flippedclassroom.org/.

Multiple tools are available for teachers to make the most out it when they choose to flip their class. One option for teachers is to use “guide questions” during recorded lecture. These questions can be dispersed at different points in the lecture video in a “scavenger hunt” sort of format. They are generally open-ended questions, meant for students to know what they are expected to learn in a given topic. For instance, a lesson in Genetics might include a guiding question “are your genes your destiny?” A lesson in Ecology might include a question as “Should endangered species be allowed to go extinct?” — questions where both sides can be argued.

Although video lectures are commonly employed, they are by no means, an absolute necessity to flip a classroom. Textbook chapter readings or pertinent references can be employed just as well when making or watching videos is not a plausible option for teachers and/or students.
During class discussions that follow, teachers can get valuable insight into student understanding (and misunderstanding) of the material covered. In discussing with their peers, and getting feedback from teachers, students learn more deeply. And teachers can reach students at different levels of understanding, and different styles of learning. Teachers experienced in using flipped learning insist that the success of these measures, and in essence,

of flipped learning as a pedagogical tool depends on how closely the in-class discussion questions relate to the pre-class lecture material.
As a teacher, how do you know students are using the tools you make available? In one of the best examples of ensuring accountability than Bergmann shared with us, the teacher asked his students to complete an online quiz after watching video lectures. That made it clear to him which students had watched the videos, what they understood, and to what extent. Those who did not, or could not watch were set up in a separate group during class-time, and asked to watch it then. Those who scored 90% or higher in the online quiz were handed assignments, and those who had average or lower scores were given one-on-one time with the instructor. Jon Bergmann says the success of this approach hinges, to a large extent, on how a teacher uses class-time. “I would argue it (use of class-time) is not by lecturing. What exactly is done—activities, assignments or discussion—depends on the topic at hand. But it must be interactive”, says Bergmann.

Much like pre-class materials, low-tech options can also be availed to ensure students have completed the preparatory work. Examples include “entrance ticket” — assignments based on pre-class lectures, that students hand in at the time of coming to class. These can be tied to student attendance if need be—attendance is given to only those who turn in the assignment. Alternatively, the teacher can ask students to answer reflective, or thought-provoking questions at the beginning of the class.

What makes this form of teaching particularly appealing for classrooms in India is that it can make it possible for teachers to reach larger number of students in ways not possible following the traditional lecture format. For instance, a class of 150 students scheduled for three times a week, can be split three ways and each group meet only once for discussions on that week’s videos. Plus, teachers save on the time spent on grading student assignments, as what used to be homework assignments are done in presence of the instructor in a ‘flipped class’.

Pankaj Khanna, faculty at the Department of Chemistry at Acharya Narendra Dev College, New Delhi, actively uses recordings of his lectures. A big proponent of blended learning, he recalls how beneficial it was for him as a student to be able to watch recordings of his teachers’ lectures in his student days. Asim Auti, faculty at the Department of Biotechnology at MES Garware College (Pune) used flipped learning when his students along with students from Anna University (Chennai) and Osmania University (Hyderabad) participated in a short online course, “Frontiers course on Genomics, Proteomics and Ethics”. The lectures were conducted by faculty from Ohio State University, Columbus, Ohio (USA), available for streaming or download.

“The experience was quite new for our students, and they really enjoyed that! However, internet connectivity was an issue for some of them. The thing about flipped classroom is that apart from role of the teacher, the nature of student participation also changes: it requires planning on their part to write down questions as they are watching lecture videos, because it would be 2-3 days till in-class discussion.” On the subject of student evaluation, he says “all students had the opportunity to interact with the teaching faculty (at Ohio State). They were graded on the basis of individual interactions, and final presentation that each of them made.” Zainab Khan was one of the students in this course, pursuing her MSc in Garware college at the time. She recalls, “it was highly enriching experience—many new topics came out of discussions with other students, even ones that happened virtually [with students at other centres]. The faculty made sure we were actively involved throughout. I always looked forward to the class."

Thus, flipped classroom affords benefits of both extensive group discussion, and individual attention to students -- to the extent that’s usually not possible within the traditional [lecture] setting. Going through the traditional learning system for years on, students at any level become experts at “playing school” — they are used to getting specific directions. This is not to make a case against giving them directions. But if they can effectively repeat back definitions from textbook or regurgitate teacher’s words from a previous lecture, does that mean they have learned? Are the students “playing school”, or actually learning?

Model building as a pedagogy approach in biology

Kundan Sengupta

Kundan Sengupta from IISER Pune writes about how model building can be a useful approach in teaching concepts in introductory biology courses.

Students at IISER Pune build a model of DNA Structure (Photo: Kundan Sengupta)

It is a constant challenge for instructors to develop novel approaches of pedagogy, especially for introductory biology (Bio101) for the first year undergraduate students. Every year about 200 students are admitted into the five-year Integrated B.S/M.S program of IISER, out of which at least 60% of the students have not studied biology at their high school level, while the rest of the students have studied advanced biology. It is therefore a formidable task for the instructors to keep students engaged in class and interested in biology. Reasonably well-structured course content with periodic evaluation serve as useful indicators of the level of comprehension of biology by students from diverse backgrounds.

As a test case, we considered a novel approach for students to build models to represent any biological process or phenomenon as a part of their continuous evaluation instead of the usual quiz and exams for the first time at IISER Pune. There were no pre-conditions in terms of selecting topics. However, an important criterion was to ensure cost effectiveness and eco friendliness in terms of concept and design of the models. The class of 200 students was sub-divided into smaller groups of 10 students each. Each group sent in a title and abstract of the model that they intended to prepare.

Needless to mention, the momentum of building novel models built up closer to the deadline. A palpable sense of excitement prevailed on the morning of the exhibition. All students arrived early to set up their models. Amazingly, models ranged from demonstrating fundamental concepts of evolution from evolutionary bottlenecks to cell division, motor protein function, image formation on the retina, nerve impulse conduction and many more. What was particularly striking was the extent of innovation and simplicity that each model brought forth, using simple hand crafted material from paper and Styrofoam. Students also unleashed their artistic potential. This event underscored that even students not initiated or interested in biology were extremely motivated scientists to apply their skills across disciplines from math, physics and chemistry in devising novel approaches to demonstrate fundamental concepts in biology. A distinct advantage with first year students is their unbridled and unfettered thoughts that translated into action. Students were truly excited to discuss the science and the concept behind each of the models that they had created.

For instance, a group created a model demonstrating protein synthesis from a strand of mRNA as template. Remarkably, the model was fashioned out of a cardboard box, with a strip of paper representing mRNA with the codons indicated. Pushing the paper through one end of the box spewed out a chain of styrofoam balls from the other end depicting protein synthesis! A simple demonstration clarified a fundamental concept and any amount of lectures wouldn't help drive home this concept as well. Another elegant model demonstrated reflex action. A simple battery operated circuit with a live wire flinched instantly when brought closer to water.

All in all this event was truly a learning experience for the instructors as much it was for the students, since this highlighted the fact that students really do not need constant spoon-feeding and leaving them alone from time to time goes a long way in harnessing their latent talent, creativity, and curiosity.

When teachers talked

In-service training for young investigators in Indian universities

Mohammad Imtiyaj Khan

In this invited piece, Mohammad Imtiyaj Khan writes about the pressing need for more effective training systems in pedagogy and research for new lecturers in the Indian University system, drawn from his own experience as an Assistant Professor at the Department of Biotechnology, Gauhati University.

Mohammad Imtiyaj Khan

A young faculty member in a traditional university, however much he/she has excelled research-wise, is a greenhorn in teaching. To establish himself/herself as a personality to be looked up to, creating new knowledge and simultaneous effective dissemination of knowledge are a must. However, is there any effective training mechanism in place to help tackle the challenges that crop up in doing so?

The present human resource development centres (HRDC) under the UGC evolved from the past academic staff colleges, which, as per XI Plan guidelines, "*emphasizes teachers as agents of socio-economic change and national development and underlines the need to make them skill–oriented teachers*". Since the only teaching job in our country that does not require a professional degree/diploma or training in education/pedagogy is assistant professorship, the national policy on education (NPE, 1986) paved the way for in-service training for assistant professors.

It is mandatory for an assistant professor to undergo an orientation programme (OP) in the first two years and two refresher courses (RCs) in the subsequent four years. Many a time, the programme and course syllabi do not serve the purpose because of the following reasons.

- Insufficient funds to engage resource persons from across the country
- Lack of experts in and around the host institution
- Absence of lectures by industrialists/entrepreneurs/environmental warriors/politicians of repute and high academic quality and integrity,
- Heterogeneity of the candidates' backgrounds (e.g. on one hand, orientation programmes are open to one and all in their first two years of joining the job. On the other hand, refresher courses on life sciences, more often than not, turn out to have more of one particular subject, such as classical taxonomy/botany or zoology-oriented lectures/activities, while the participants are from botany, zoology, biochemistry, microbiology, molecular biology, and other backgrounds),
- Mixing of degree college and university teachers in the training, though the latter deal with only post-graduate and doctoral students,
- Questionable academic quality of the experts, some of whom are retired and not tech-savvy enough to deal with the Google-era participants, and some of whom themselves did not undergo such training.
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Because of these circumstances, orientation programmes end up disorienting the participants and refresher courses serve to normalise the levels of motivation and knowledge, instead of improving the same. Still, we are obligated to attend these 'trainings' out of learned helplessness.

Many serious participants expect to get some quick tips for balancing research, teaching and administrative work, in that order. However, that does not happen because for many of the resource persons, during their initial stage of teaching at a university some decades ago, eligibility criteria for the job were different, and, therefore, there was not much push for research. For example, they could become university teachers with just a Master's degree, and, hence, there was no expectation of research from them. Therefore, there was also no need for a proper funding mechanism for research.

Till date, there are a few instructors, for whom the research programmes are considered an academic formality for the respective degrees, while the postgraduate teaching programmes in universities top the priority list. This is so deeply ingrained in their mind that they have separated research into industrial and academic. Further, they believe that only the research institutes/laboratories under the DBT, the ICMR, the DST and others should do hard-core research, not the universities.

As a consequence of this mindset, research infrastructure is weak with erratic power and water supply, insufficient supporting staff, insensitively allocated budget for repairing equipment, non-existent auctioning mechanism for the junk materials, and so on. To compound the matter further, there are issues like the lack of environmental management systems and proper disposal of waste (chemicals, plasticware, glassware, metal scraps, solvents and biologicals). These issues could be addressed by installing an incinerator on the campus and by constructing a well-planned drainage system without involving much labour and hence, financial cost and time.

The absence of a dedicated section for research/project-related accounting leads to a step-motherly treatment and inappreciable status of research, even though these universities (including many central and state universities) award degrees like MPhil and PhD regularly. This situation is a consequence of irregularly-updated policies framed by people who were themselves never exposed to research labs of international repute, and some of whom are from non-experimental science backgrounds. In a traditional liberal arts university where the core strength is the social science or languages, it is impossible to exclude people from non-experimental science backgrounds while framing certain policies for the university as a whole, which may not take into account the needs of experimental scientists.

In the beginning, orientation programmes and refresher courses did not have any mention of helping in research-related matters as an integral part of the training. Subject-specific refresher courses were introduced much later. This means that batches of trained teachers have not attended subject-specific refresher courses, wherein research and development come into the picture.

The sorry state of research in universities is because of the missing emphasis on it. The problem with doing research in a traditional university largely arises out of misplaced priority of the administrators or the founding fathers. A separate research cell should be set up and adequate attention should be paid to the researchers in terms of supporting their needs. There is enough funding nowadays, even though its effective utilisation is an unrealised dream. Administrative checks alone cannot ensure the efficient and effective utilisation of funds if the policies governing the utilisation are not redesigned to be research-oriented from its current administration-friendly design. For example, under the overhead budget, there is limited flexibility to utilise the funds [1]. The solution to this could be brought about through both top-down and institutional interventions.

A young faculty member who has not managed to get his/her professional balancing act right even after attending the mandatory in-service training has to face non-technical problems as well, including financial and administrative hurdles. Among them, the problem of cramped space hits him/her hard in the very beginning as he/she fails to get himself/herself even a room to call 'office'. Ironically, the apparent reason for this is that these traditional universities were not built to create space, but to occupy space, as they are spread over a large area with less built-up floor area because of which there is limited space to utilise for research or to work in.

The next hurdle is the merry-go-round in the administrative offices that could be perfectly exemplified by the saying 'if the mountain will not come to Muhammad, then Muhammad must go to the mountain'. Left with no option, young faculty members learn financial and administrative matters on-the-job, though the orientation programme could be made more comprehensive by incorporating them in the syllabus.

Pedagogical/educational training (orientation programmes and refresher courses) for in-service faculty members could also be done more effectively. I have heard of the old practice of learning the art of teaching from senior teachers still being practised in a few universities wherein the new faculty members are allowed to attend the lectures of the senior professors in the first six months of their career without being assigned any class themselves. This practice can be quite effective in orienting new recruits towards teaching, but in conjunction with orientation programmes and refresher courses. Of course, it should be optional for those with prior teaching experience.

Considering that new recruits are usually motivated and prepared to take up the professional responsibilities, one can presume that they will not slide into the Scully effect [2], rather they will develop their own effective style of teaching. A robust real-time cross-feedback mechanism involving teaching, administration and finance should be introduced to assess the performance of young faculty members so that they get opportunities to improve on their weak points. The institutional quality assurance cell (IQAC) should be vibrant enough to provide the right guidance and recommendations to those who are in need of these.

A holistic approach to train assistant professors on pedagogy, administration and finance can minimise the time taken by them to fit into the role.

Notes

1. Overhead charges/budget is a part of the overall budget of a research project allocated for meeting the costs incurred by the project implementing institute on account of administrative and infrastructural supports. The infrastructural support is narrowly defined under this budget head as physical infrastructures, such as computers, ACs, furnitures, etc. Minor equipment and gas cylinders, for example, are excluded undermining the project's requirements.

2. Scully effect is the phenomenon of viewers getting unmindfully inspired by the fictional characters in TV shows or movies resulting in copying the choices and ideology of the characters.

In higher education, what relationship do teaching and research share?

Bidisha Ghosh

To teach or to explore? Can good teaching and ingenious research co-exist? How does faculty perceive the two tasks at hand? With the help of existing literature and expert opinions we attempt to delve into the problem.

Balancing teaching and research (Photo: Images from Unsplash. Modified to current form by Manoj Rangan)

Global environment demands universities and colleges to be centres of innovation. Faculty have to balance the expectations of good teaching as well as creation of knowledge through active research. Additionally, our early education system hardly offers enquiry-based learning, limiting the ability of graduates to serve the needs of technology industry and academia. The onus for filling this gap in education falls on the overburdened Indian faculty. In such a scenario, how does conducting active research fare against classroom teaching?

Several studies have explored the relationship between a teacher's research activity and teaching performance. A study conducted at the International University of Catalonia Spain explored this relationship using a large dataset of students enrolled in 229 courses (spread across the disciplines of architecture, health and social sciences). The authors explored the relationship to be - positive (mutually reinforcing), negative (conflicting) or neutral (no effect). One of the major conclusions of the study was that for a teacher conducting active research, teaching commitments could be challenging. We here explore this relationship in the Indian context through discussions with senior educators.

One hypothesis suggests good quality teaching to be an outcome of cutting edge knowledge gained during research – a reinforcing, positive relationship. Research training of educators, "Increases the chance of their students' exposure to emerging ideas, facilities and methodologies" says Subhas C. Lakhotia, Distinguished Professor, Banaras Hindu University. He further emphasizes "An active researcher is open to questions and encourages students to develop an enquiring mind." Bimalendu B. Nath, Professor, S.P. Pune University adds "A teacher with a training in research helps develop a methodology of curiosity based learning process in the classroom."
For improving the pedagogy of teachers through active research we need to assess if quality research is indeed practised. Unfortunately, a large proportion of faculty in our universities and colleges suffer from the lack of adequate infrastructure. Addressing this, Lakhotia says "An educator could discover knowledge through reading, discussions and discourses. This is the simplest way for an educator not involved in active research to deliver up-to-date knowledge." Bimal Nath adds "When students gain knowledge by questioning 'how' 'when' and 'why'- then the pedagogy becomes meaningful. In case of a dearth of resources, an ideal teacher can motivate students to think". Such inspiring stories of teachers' efforts can be found here.
Other thinkers of the field - like Parker and Serow consider teaching and research to be conflicting engagements. They attribute the conflict to the evaluation process for faculty promotion and appraisal that clearly favour research activities over teaching. Young academicians who need to carve out a career might not be motivated to invest time in teaching. Senior academicians attribute this outcome to 'university rankings' that are biased towards innovative research.

It is important here to delineate the goal of universities and colleges. *Universities are more focussed on research, while colleges thrust on the learning process.* MHRD has relaxed the criteria of API (Annual Performance Index) allowing college teachers to focus on teaching – hitting two birds with one stone – the move might also curb the rise of predatory journals. The evaluation of college teachers will be based on teaching performance, whereas, university teachers would be graded on research output. Research shall no longer be mandatory for the promotion of college teachers. Interestingly, grades can be also earned via other meaningful engagements like social work, adoption of a village, aiding students in extra-curricular activities and uploading subject course on Swayam.

Lakhotia suggests another criteria for assessment - “Every teacher should be assessed by students.” Taking students’ feedback for every class is, in principle, necessarily required (as per the UGC and NAAC guidelines). To this Lakhotia says “ This rarely happens and thus teaching is not objectively rewarded.” Student feedback taken anonymously can be shared with teachers for self-review. This can also be used as a metric for promotion, much like the modern school management practices followed around the globe.

The third scenario indicates that teaching and the knowledge production process are independent tasks – and require separate sets of preparation and personality traits. Lakhotia does not concur – “Teaching and research are mutually reinforcing. I learned from my students; our discussions provided a previously unthought of direction to my research. Moreover, a researcher’s questioning mind is an inspiration for students.” He suggests that emphasis should be placed on aligning the curriculum with the research interests of lecturers.

India is home to one of the world’s largest education systems – considering the number of institutes for higher education and the number of students. With the long overdue education policy being drafted, steps towards improving the higher education should include teacher skill development. A well-informed teacher can create a well-equipped student, ready to face the real world.

Talk with teachers: Going the extra mile

Urvashi Bhattacharya

We got three educators talking on their teaching methodology and the changes they would like to see. In a two part interview we bring forth the views of Charu Dogra Rawat (Assistant Professor, Ramjas College, Delhi University), Smitha Hegde (Professor, Nitte University of Science Education and Research), and Vidya Jonnalagadda (Educator, Bhavan's Vivekanand College of Science, Humanities and Commerce, Hyderabad). Here they state their efforts to keep the classroom up-to-date and bring in career awareness.

Charu Dogra Rawat (left), Smitha Hegde (middle, in the black and red jacket) and Vidya Jonnalagadda (right)

What kind of research do you bring into your teaching? How do you address the gap in knowledge between curriculum books and the latest in the field?

Charu: Before introducing a new topic, I ask students to collect updated information relevant to that area. I occasionally bring new research papers, or ask the class to read into its background information. This is to give them an idea of scientific reading and self-initiated exploration of a topic. While giving questions related to the content, I often suggest resources for exploration. Discussions related to the topic are held in the next session.

I also stress on the evolution of methodology and experimental protocols. I encourage them to refine experimental results by educating themselves with the advancements in techniques.

Smitha: I try to update students on the latest theories and events regarding my core subject. I continually attempt to translate the curriculum into meaningful hands on experience.

Vidya: For teaching tips (or research into teaching methodology), I follow Edutopia. The site provides excellent insights into student behaviour and motivation. I also follow the blog, Cult of Pedagogy. Each month, I generally read 2-5 articles from these blogs.

For subject-specific research, I look for review articles on the topic I am assigned each semester. I also write a "class textbook" for each course that I teach which includes the latest findings (printed notes covering the syllabus material well as related historical and/or recent findings). Each textbook has 25-30 pages of material for each "unit" of the syllabus; a course can have 2 to 4 units.

In our class discussion, I often ask students to look up some interesting topics related to the syllabus, but I do not include it in the grading system. I also run a facebook page for our college science club (voluntary activity open to all students) where I briefly describe recent or interesting findings related to biology (However, this page has been dormant this year due to various other activities. I hope to revive it when the college reopens).

How do you and your institute help students reach decisions about their future careers?
Charu: We do have institutional placements and invited seminars, but not much counselling is available to students. My own approach is to encourage them to choose what they are happy to learn and to explore resources in their subject. Within the DBT star college project, I ask them to choose their own topics, do a feasibility check based on the resources available in the lab, and then explore the topic in depth. I also call alumni from different fields so that students can connect or relate to them.

Smitha: We have a very active career guidance cell. We also have student- mentor groups (each faculty has 10 students to mentor). We conduct sessions on how to face interview, how to write CV and take sessions on how to face life, married life etc. I am also the student welfare officer. I counsel and mentor them on an issue to issue basis. The cells are constituted as per NAAC requirements by the institution, however the level of efforts may vary from teacher to teacher.

Vidya: There is a strong institutional-level effort to mentor our students for science-related careers. The institute conducts several visits to local industries/labs and national research centres, guest lectures from scientists, and an annual lecture series where they present their own project work in an inter-college competition.

In contrast, preparation for non-science careers is mostly left to the student based on their individual interests. There are outreach activities in the college in collaboration with local and national NGOs. Since our college became autonomous a few years ago, students can also opt for courses in other departments such as mass communication, languages, and commerce. However, we need to put in more effort in this direction by liaisons with people in other fields who can explain the opportunities in their areas and expectations of prospective employers.

“One teaching technique that made a difference in my class…”

Ranjana Agarwal and Aashutosh Mule

Ranjana Agrawal (Jaipur) and Aashutosh Mule (Mumbai) share teaching techniques they have found helpful.

Students playing Charades to review key concepts (left) ;Rangoli illustrating DNA replication (right) (Photo: Ranjana Agrawal)

Learning by playing

Ranjana Agrawal, HOD Biotechnology and Assistant Professor in Zoology, Kanoria PG Mahila Mahavidyalaya, Jaipur; supplements classroom teaching with games to engage students as she assesses their learning.

To break the monotony of traditional lectures, sometimes I supplement classroom pedagogy with games. Usually, I will select a topic that has been recently taught and design diverse games around that, ranging from painting to acting.

Students are divided in two teams for Charades, which I have used to review syllabus items; such as terms pertaining to instruments or biological processes. Once it is answered correctly, we quickly revise the corresponding topics. I regularly organise Rangoli and painting competitions where students draw phenomena like replication, cloning, bacterial gene transfer, etc. Drawing helps students in understanding the concepts and adding vivid colours from their imagination gives them a creative high.

Many times, I try to give daily life examples, to help students understand complex concepts. For instance, while teaching Immunology, I connect body's defence system with our country's defence system. Our army, navy and air wings have different functions and work together to fight foreign invaders trying to invade Line of Control. Similarly, our body's defence [immune] system has different cells with specialised functions to fight the pathogenic microbes that invade the body. The signaling molecules or ligands specifically interact with receptors, akin to a postman bringing messages to specific addresses. Examples such as these are intended to make biological concepts more concrete and relatable to students.

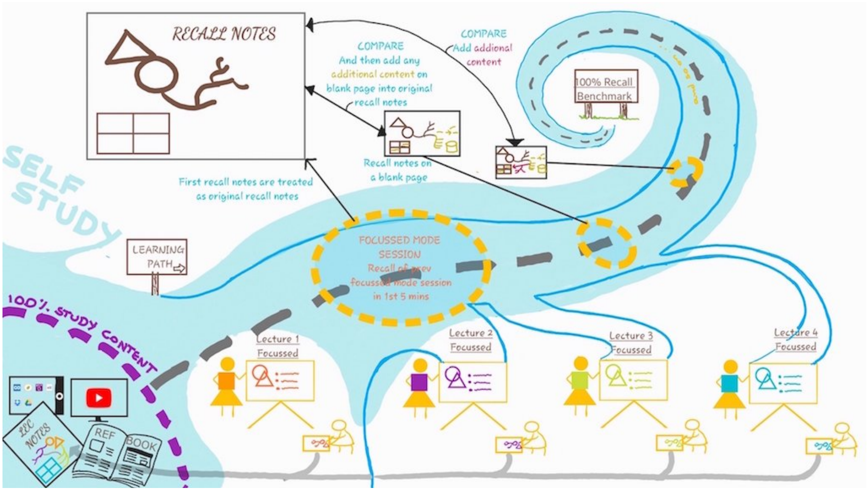
On occasion, I also ask students to give extempore speeches, to gauge their knowledge about a concept. This also helps them develop their public speaking skills. One class a week, I divide the whole class in 3 or 4 teams for quizzes. These can include combinations of visual rounds, buzzer rounds, and rapid-fire rounds on specific themes like immunology, biochemistry, haematology etc. Quizzes help them quickly review what they have studied in previous classes. Together with the ease of design and execution during regular lectures, games such as these make teaching and learning enjoyable. This serves many purposes– students have fun learning, develop healthy competitive spirit towards their peers; and as their instructor, I can analyse their understanding of the topic.

Recall technique based on the concept maps

Aashutosh Mule teaches BSc (Biotechnology) at Vivekanand Education Society's College of Arts Science & Commerce, Mumbai. He shares his 'recall technique' based on concept maps.

Concept mapping is a well known instructional technique. However, for all its benefits; understanding how to draw concept maps does not come naturally to students. Here I describe how I help my students develop this skill.

When a student studies a topic, whether during a lecture or during self-study, I call it a focussed mode session. As depicted in the figure, the first focussed mode session on the path of learning a topic is the first lecture attended by the students. At this point, they use keywords from the textbook, lecture notes or blackboard, to start on their concept maps.



(Image credit: Aashutosh Mule)

In the next class, I start by asking them to recall content covered in the previous class on a blank sheet. I emphasize the amount of recall as the yardstick by which I assess their level of understanding — my goal is to get them to 100% through successive attempts. In subsequent lectures, more of the content on the same topic is taught, and after each class, students add new information to the same concept map they developed at the beginning of each class.

Through implementing this technique, I have witnessed increased excitement in students for the revision sessions, which otherwise can seem monotonous and boring. Not just that, they also seem excited to put their understanding to test. The process infuses confidence in students to willingly come forward to test themselves.

Talk, blend and perform: my adventures in the classroom to engage students

Asim Auti

Here, Asim shares some manageable approaches, tried and tested in his classes, that also taught him substantially as a teacher.

With MSc students on a field trip (Photo: Asim Auti)

To teach well, in my opinion, requires deep knowledge of the content as well as the ability to communicate that knowledge effectively to students. At Pune's Abasaheb Garware College where I have been since 2008, I currently teach Biodiversity and Systematics course to undergraduates and Environmental Biotechnology, Bioinformatics and Genomics-Proteomics courses to MSc students.

Initially it was hard for me to break the stereotype of a teacher that students have in their minds. The process started when I realized that first I have to break the stereotype of a teacher that I had in my mind. Evidently residual from their high school days, students would expect readymade materials from me. It became clear that my goal of inculcating understanding of subject matter in students would not be met, by a long shot, if my students are focused on regurgitating answers in examinations without processing. It took me a while to reach where I am engaging students and fulfilling the learning objectives I set for my classes.

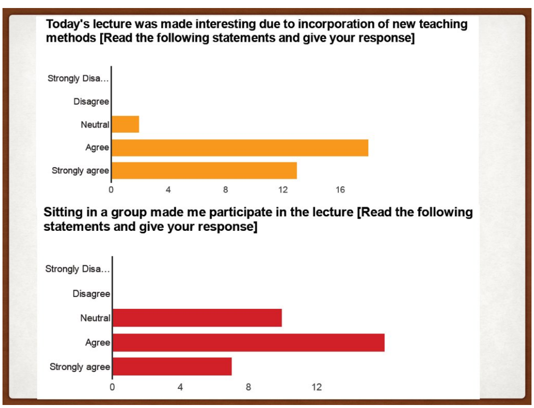
Over the years I have developed student-centric approaches of active learning, helping them adapt to understanding by engaging them, and aligning my teaching outcomes with assessments. I wish to share some such manageable approaches, tried and tested in my classes, that also taught me substantially as a teacher.

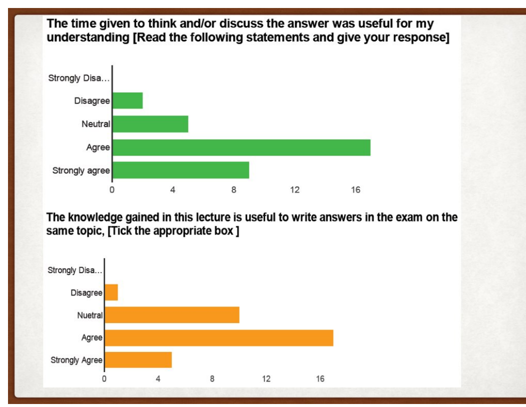
'Teacher/blackboard-centric' classrooms, I think, are counter to a conducive learning environment. There are, of course, genuine practical constraints to changing every classroom. But lack of resources cannot be an excuse if I want to really improve this scenario, I told myself. I started working on how to create a student-centric classroom. Meanwhile, I was aware of Robin Wright, at the University of Minnesota, has changed the way classrooms are designed in many US universities. Scientific studies done on redesigning learning spaces in classrooms have only confirmed their efficacy in improving learning and understanding in students. Meeting Robin Wright during the organisation of 'National Workshop for Undergraduate Biology Teachers', profoundly changed the way in which I used to think of a UG/PG classrooms. For starters, I changed the sitting arrangement for students in my class. They sit facing each other rather than me or the backboard. I chose modules from the course that would be appropriate to generate peer discussions and they could perform activities such as generating explanations for key terms, generating hypothesis on a given query, building models to explain given predictions, solving short quizzes and critically evaluating a given conclusion etc. For example, while teaching central ecological concepts such as 'Habitat' or 'Niche', I ask students to first discuss their own understanding of relevant terms (Habit, Habitat and Niche) and draw few examples from their surroundings to evaluate whether they see the distinction between these.

In general, the teaching strategies I opt for depends on what I expect students to take away from that specific topic. For the modules where conceptual understanding is important, I use active learning methods in the classroom; for information based modules (like Biogeography or study of biomolecular databases) I assign small problems that require students to survey original scientific literature for answers. There are modules where visual stimulus is important (such as protein structure prediction or study of an ecosystem), I teach with live demos or online tools or on-field trips which are supplemented with open discussions. I also use few (powerpoint) slides to reiterate fundamental concepts that students discuss.

The first discussions usually take a fair bit of time as students are not normally encouraged to 'talk among themselves'. Once they start apprehending the importance of such discussions for their own understanding, they become more open and responsive. Peer discussions followed by peer evaluations can then be used to teach various modules from the curriculum. But here one has to take care of the diversity of students that are there in each group, making sure each one of them participates and updates her understanding of the concepts. During class sessions, Formative Assessment tasks are helpful in assessing the levels of understanding, such as Think-pair-share, using Wikipedia or online worksheets where student do things actively which are relevant in the understanding current scientific scenario. I also mentor them via Piazza 24x7 classroom. Such mentoring is especially important when I expect them to come across difficulties in assignments/ tasks but at the same time want them to try to acquaint themselves with the knowledge of current research issues. Using Piazza also helps me manage my time and non academic activities to be performed in my college. In Biodiversity course I take students out on the field trips to help them 'see' what they have learnt. All these activities beyond a classroom also help me get in sync with students.

Initially, it was difficult for me to control students who tend to deviate from the main discussion or group assignments but I learnt to identify potential drifters and started giving duties as a group representative or a summary writer that made them focus. I assessed the effectiveness of this method by surveying the responses of students in comparison with regular classes engaged by me. Below are some of the questions I asked in an anonymous survey (using Google Forms) and students' responses.





To validate the effectiveness of my methods, I correlate their positive responses in the surveys to student scores in the final exams. The data points from such surveys are important feedback, but perhaps more important are non-quantifiable observations made during rearranged classrooms, that gives an idea of where a class is heading. Students otherwise non-responsive start to discuss in class. I was able to identify students that struggle with writing answers but are otherwise good in conceptual understanding. At times, ideas generated during discussions got converted to small exercises or mini-projects. For example, in one of the classes, while discussing factors affecting growth of seedlings, we devised experiments to monitor growth of roots and shoots with respect to direction of gravity. On their own accord, the students designed and executed small experiments at their homes to see what happens if seeds are sown in inverted or in slanting pots etc. Further they included other parameters such as direction of sunlight or type of seed. I also used a soft board for putting up student assignments, sharing co-curricular reading I thought they'd find interesting, and even stress-busting cartoons; which, I found, helps create an environment for students to feel comfortable and focus on their performance.

Teachers weigh in…

Reeteka Sud

In an education landscape where syllabus reigns supreme, some teachers/educators go the extra mile for their students, and constantly strive to improve teaching and learning in their classrooms.

Asim Auti (left), Urmi Bajpai (right) (Photo: Asim Auti, Urmi Bajpai)

Komal Kamra is an Associate Professor in Zoology at SGTB Khalsa College, New Delhi. She has been teaching for over 40 years.

Sangeeta Shetty is an Asst. Professor at the Dept. of Life Sciences & Biochemistry in St. Xavier's college. She is currently teaching courses in Microbiology, Biotechnology, Immunology and Bioinformatics, at both UG & PG levels.

Q. How did you come to choose teaching as your profession?

KK: As long as I can remember, I always needed to teach. Even the games I played were always related to teaching somehow. When I got a little older I would get the maids' children together and teach during vacation time. It was but natural for me to opt for teaching as a career.

SS: I never really thought about teaching as a career choice. It was rather serendipitous! I taught a course as a substitute for a friend for one semester. I was amazed at the response I got from students. I have grown and gained so much from all these wonderful lives I have been able to touch. I am so glad teaching "happened" to me.

Q. How would you describe your teaching philosophy?

KK: To impart knowledge in the best possible way. I believe in taking a holistic approach; I don't want to limit to curriculum only. A wholesome education is what the students should be getting when they come to college, otherwise they could have just done a correspondence course.

SS: Every batch of students is different, so I don't believe in a "one size fits all" teaching philosophy. Mine is a very student-centered approach to teaching; the specifics of techniques I use in class varies depending on the batch of students, what their needs are.

Q. How do you see your role in the classroom?

KK: My classes have, over a period of time, become more interactive. Often, it's the students who bring more information and enrich me. So I become a part of them and am enjoying this role.

SS: I tell my students I am not here to "cover the syllabus"; rather, my job is to "uncover the syllabus" — to make them curious about things. I don't give "notes", only references and lecture outlines. Our college uses the online learning platform Moodle. There's additional e-resources we make available to students, as and when needed.

Q. What are main teaching methods you rely on?

KK: Chalk-and-board remains the mainstay. Of late, I have started giving typed material ahead of the teaching schedule and asking students to read before class. That allows for in-class discussions. These discussions give an opportunity to throw the floor open for lateral discussions too; which often prove to be far more interesting and exciting than traditional methods. I do use power point presentations but rarely.

SS: Visuals are a far better way of teaching. Plus, the present generation of students are highly tech-savvy. So I rely on copious use of technology— animation is my preferred method, also YouTube videos, PowerPoints, games etc.

Q. How do you assess your students?

KK: I like to assess students not by comparison among them but by measuring how a particular student was before a course began and at the end of it. This makes them compete with themselves not with each other.

SS: Our college requires two internal and one final exam each semester. For one of these exams, teachers have a free hand at how they want to assess students. For instance, in the literature department, students had to watch a video, and discuss questions based on that. Some of my colleagues use the clicker system but I haven't tried it yet. I have asked my students' practical exams, to develop research proposals with all relevant parts-- research plan, budget, proposed experiments. This was followed by research work done, presentation and finally ability to write a research paper of their work done. On another occasion, students had to propose business development plans for Biotech Entrepreneurship.

Q. Do you agree or disagree with the statement — "today's students are lazier, or less prepared, or less motivated than my generation."

KK: I have found motivating students is not an issue — whether it is staying late on a weekday or getting together to work on a sunday, they are generally willing. When they can't, it is because of practical concerns -- as in they live far away so commuting is an issue, especially for girls. Higher education centres should be residential. That can make a big difference.

SS: I don't believe they are lazy or unmotivated. They do seem to be confusing "information" for "knowledge". There is no question that students today are different. And this difference does create friction at times. For instance, we depend on them to do background reading before class. That is needed for classrooms to be more interactive but more frequently, students fail to follow-up. That is very problematic. So, what we do is- we send that student to the library- their task is to read given topic for 40 minutes, come back to class and present to the class. And we've had success with that.

Q. What are some myths you think are around regarding teaching profession?

KK: The teaching profession is looked down upon as compared to the more lucrative administrative services or jobs at MNCs. Myth. I have never felt I am lesser. The teachers are paid less. Myth. I think we get good salaries and what we get from children as love and respect are far beyond any compensation.

SS: That teaching is a part-time job, and teachers don't have much work to do. The problem with this line of thinking is that it assumes that you are a teacher only when you are in front of the class; when in reality that's just the tip of the iceberg.

Q. What are your views on research experience as being part of students' undergraduate training?

KK: College curriculum is rather restrictive, for both teachers and students. There is no room for students to question, to explore. This is true even for science labs. Students have so much energy. And all we are offering is book knowledge. Education is much, much more than just exams. Frequently, I'll offer students, who are willing, a chance to do projects over their semester breaks. This may or may not be related to Zoology. But mainly, it is a chance for students to explore on their own. And it can yield big returns!

Three years ago, we did an 'innovation project' in collaboration with one of the faculty in Forensics department in our college, and we got a patent out of it! Last year, we participated in a NASA-led worldwide challenge. From India, there are several schools that participate but in the 18-21 age category, there has never been any representation from our country. So, we took that up as a challenge. The students set up a group, and they would come to my house every sunday, 9am. We did make it to the international challenge, but unfortunately were not able to secure funds to go to America for the finals.

On another occasion, out of discussion with students came the idea of a mobile app for spine injury— a community-based rehabilitation project. I was able to bring my own experience with spine injury to the project. This project culminated in the development of an app called "SpineVeda" (trademarked in our name), being translated now in 16 Indian languages. Out of 250 projects funded by University of Delhi that year, SpineVeda bagged the best innovation award.

Presently, we are also wrapping up a project on epilepsy, EpiReach, also funded by the University of Delhi. For this project, students go to jhuggi clusters to reach out to individuals with epilepsy who remain stigmatized. One Sunday a month, we hold epilepsy camps where a team of AIIMS doctors give free prescriptions and we give medicines free of cost. Recently, we met the Union Minister of Health and Family Welfare to launch a National Epilepsy Control Programme with very positive output.

SS: Research experience provides students with different kind of training, and they start to think very analytically. It of course puts departmental infrastructure and finance in stress, specifically at undergraduate level where class sizes are larger. It is also quite challenging for the teachers, but it has been a rewarding experience. Few months ago, I attended a workshop on research-based pedagogical tools, at IISER Pune, which gave more structure to my teaching. So, incorporating elements of research benefits not only students, but teachers stand to gain too.

Research with undergraduate students

Sravanti Uppaluri and Divya Uma

Sravanti Uppaluri and Divya Uma are faculty members at Azim Premji University, Bengaluru. In this invited article, they write about their experience of working with undergraduates, and how how using research as a pedagogical tool enriches undergraduate education.

Sravanti Uppaluru (left) and Divya Uma (right)

After many years of research training, we all start to think of how we can contribute to the scientific community. How can we best utilize our training? Which environment will allow us to thrive?

The path to finding a suitable niche wasn't immediately clear for either of us. Research and teaching are deeply intertwined, and have been artificially separated in some institutions – this is especially the case in undergraduate institutions. Yet the skills that are required to do research are precisely what students should be developing at all stages of their education – observation, critical engagement with data, suggesting alternative interpretations – to name a few. These are skill sets that are useful not just to scientists but all citizens.

Joining as faculty members at Azim Premji University (APU) within the undergraduate programme has given us the opportunity to continue pursuing a research career, albeit one in which progress has to be measured in unique and perhaps unorthodox ways. It is also a career that is deeply rewarding.

Using research as a pedagogical tool, students have the opportunity to learn by questioning, rather than passively receiving knowledge, and are better prepared for any kind of career. Undergraduate research projects can be run through more formal avenues such as honour projects with a fixed duration and expectations, or informal ones in which outcomes do not have to be clearly planned and may serve as exploratory pilot studies.

Working with undergraduates in the discovery process is uncharted territory for most young investigators. At best we may have been teaching assistants, or mentored undergraduate thesis projects during our postdocs. But these teaching experiences are rarely seen as paths to actually doing research in the sense of knowledge production, and rarely contribute to our own research careers. Yet, undergraduates don't come with as many preconceived notions and serve as a truly creative pool for scientific inquiry. Combined with the intellectual freedom we have at our institution, these two factors allow us to ask some rather unconventional questions.
Sravanti Uppaluri, extreme left, and Divya Uma, extreme right with undergrad students in the Biology lab at Azim Premji University, Bangalore

At APU, we have leveraged the diverse student body as well as the eclectic set of interests of the faculty (we are integrated in a liberal studies programme with colleagues from all disciplines – from psychology to physics to economics to humanities) to develop an equally eclectic set of research questions. Recently one of our students wanted to understand how "identical" progeny arising from asexual reproduction in multicellular organisms are. We worked together to hone the question and choose one specific characteristic that could be tested within our infrastructural constraints and ended up asking whether associative conditioning and memory is passed on to progeny. Since *Planaria* have incredible regenerative potential, we used amputations to produce progeny rather asexual reproduction.

The challenge, of course, is that a lot of foundational work has to be done when working with undergraduates when compared to graduate students. They require a lot more mentoring in reading and interpreting literature, they do not come with any experimental expertise (lab or field), and they often have difficulty evaluating the feasibility of a project. An additional challenge is of time scales--a conventional three year undergraduate degree where students are predominantly taking coursework leaves little time for a rigorous research project. Research has to be done primarily in the summer and winter breaks when both students and faculty are free. Moreover, by the time a student has developed some research skill, and the ability to work independently, it's time for them to graduate!

Students entering our undergraduate program only have a faint idea about how science is done, and don't think they themselves can be scientists! But after they have spent a year working on a research project, they begin to understand various processes that go into research such as, identifying a problem, developing different ways to tackle the problem, and collaborating with people with different expertise. Students also realize that science need not always be complicated and expensive, and often the elegance of an experiment lies in its simplicity. The liberal studies setting enables students to interact and learn from their peers, as well as faculty from other disciplines. For example, two students working on the biology of social spiders talked to an economist on campus, and are now learning to use agent-based modelling to visualize the rules that the spiders use to build a web.

Recently, the first batch of BSc Biology students graduated from Azim Premji University. Some have gone on to the top research institutes within the country and abroad, while others have chosen paths in the teaching profession - the range is wide. Whatever their choice for the future, their research experiences have provided them the right tools to look at real world problems more critically, and engage with them at a different level.

As young faculty, such a research environment has challenged us in unique, exciting ways, and importantly shown us a new way of thinking about how to do research and how to choose new problems to tackle.

Many faces of teaching: Research as an important component in University teaching

Rama Krishna Kancha

Rama Krishna Kancha is an Assistant Professor at the Centre for Plant Molecular Biology (CPMB), Osmania University, Hyderabad. In this invited piece, he speaks about the influence and importance of research techniques in aiding the education of undergraduate and postgraduate students in Universities.

Rama Krishna Kancha

The transition from Postdoc in Heidelberg to Assistant professor in Hyderabad was joyful but had a lot of surprises in store. Interestingly, my cancer biology lab is located at the Centre for Plant Molecular Biology (CPMB). I teach MSc and Pre-PhD courses in the Department of

Genetics and Biotechnology. We actively collaborate with the Department of Chemistry and frequently visit them. Even though I work in Osmania University, my salary is paid by the University Grants Commission (UGC). Thus, I am both an insider and an outsider at multiple locations, which demands a lot of flexibility.

This is not possible without active support from senior professors in the University, directors who facilitated smooth access to resources, heads of departments who are welcoming, supportive administrators and friendly colleagues. Sharing lab space with the then-director of CPMB was very helpful in starting the work immediately and a couple of grants from UGC and DST were crucial to conduct research work at a decent pace. In the early stages of your career, associating with the right people is the key.

Importance of research in universities

Universities provide the majority of the manpower that caters to the needs of national research institutes and private companies. The quality of education received at the universities determines the overall performance of scientific enterprise in the country. An up-to-date training in theoretical knowledge and practical expertise makes students employable in the industry and also lessens the burden on research institutes to conduct graduate programs.

Conscious of the importance of training skilled scientific workforce, I take a special interest in training MSc students for their dissertation, in addition to supervising PhD students. A decade-long experience at the Technical University of Munich in training medical and biotechnology students equipped me to guide masters' students towards dissertations with tangible outcomes within the short duration of their stay. Conducting quality research in a university setting is thus very important for training postgraduate students with adequate technical and scientific skills.

Classroom vs Practicals vs Dissertation

Our teaching basically is of three forms: theory, practical and project work. I employ a story-telling approach to teach theory in which an initial overview and context are presented followed by explaining the topic with the help of relevant experiments that helped at arriving at those concepts. In addition, I share relevant information with students via email and social media.

For teaching practicals, I present an elaborate theoretical background before training students to perform experiments. In addition to conducting practicals in the Department laboratory, I also conduct some practicals in my own lab so that the students experience a research laboratory setting first-hand and also gain awareness about a PhD students' life by interacting with them.

The MSc dissertation students in my lab are trained in multiple aspects of scientific exercise on par with PhD students, including designing a project, defining objectives, theoretical and practical methodology, data analysis and presentation. I assign students to present a topic each semester to improve their language and presentation skills. It is, however, a very difficult task to achieve all this due to a huge diversity in student community with respect to the socio-economic background, subjects studied at undergraduate level, language skills and personality traits. Attending the Wellcome Trust-DBT sponsored EMBO scientific leadership workshop was very helpful in dealing with many of the issues we encounter on a daily basis.

Networking - an essential component of teaching/learning

I make sure that any friend from India or abroad visiting Hyderabad also gives a lecture at our institute, facilitating our students gaining deeper insights into various disciplines. We also arrange informal meetings with visiting scientists so that our students have first-hand knowledge regarding the work culture and expectations of potential future employers. Given the multi-disciplinary nature of our work, the students often have an opportunity to interact with chemists and physicians both on campus as well as at hospitals.

Attending orientation and refresher courses helped me network with many faculty friends in the region. The Regional YIM organized at the University of Hyderabad and the Wellcome Trust-DBT annual fellows meeting were very helpful in networking with researchers of the region and country, respectively. I also frequently share my experiences with faculty friends and constantly learn from their perspective regarding teaching and research in India.

I believe that a teacher with a lot of dedication and sound research background combined with excellent communication skills can impart knowledge to university students in a meaningful way to meet the current demands of the country. Upon graduating, some students may take up various non-scientific roles such as teaching or management for decades to come; a brief but decent research experience that cultivates scientific temper is essential for them to easily update their knowledge in the future and stay relevant in their respective jobs. It is thus important to conduct high-quality research in universities to give students a valuable learning experience combined with a taste of laboratory research.

Education should enable youth to focus on local problems

Navodita Jain

Anil K Rajvanshi, Globe Awardee for Sustainability Research, talks about the need for orienting the education system to look for problems and solutions that might impact rural livelihood. In the current scientific scenario, it would offer students and scientific institutions an edge in impactful research.

Rajvanshi with his invention: ethanol powered lantern cum stove (lanstove)

What according to you are indigenous problems and what are the perks of solving them?

All my work is centered around this one thought – “how to improve the quality of life of our rural population." Any time spent on the study of this idea could qualify as working on an indigenous problem. I would suggest interested people to visit the rural livelihood. To youth who is motivated to work in this area, my question would be - "what is it that fires your imagination?"

I believe that fundamental science and technology can be created by practicing applied science - I term it as the "Langmuir approach". Irving Langmuir was an industrial chemist who won the Nobel Prize for discovering atomic hydrogen and establishing the field of surface chemistry while developing a light bulb for GE. Our scientists at premier scientific establishments much too often work in areas of interest only to the western world - probably since they can publish in international journals. However, since 30% of our population is poor and 15% undernourished, it provides a large bed of challenges for scientists to study, assess, research and offer solutions. Working on such problems offers the advantage of novelty and creation of fundamental science.

The innovations of NARI stem from an experimental zeal, has that zeal explored the field of education?
When my wife and I decided to start base in Phaltan, there were no good kindergarten and elementary schools. We founded a school - Kamala Nimbkar Bal Bhavan (KNB) and enrolled our daughter - the school graduated up a standard along with my elder daughter! We initially faced reluctance as parents preferred English to a Marathi medium school, now, with the results nearing 100% (for 10^{th} standard), we receive hundreds of applications. It might come as a surprise that a lot of the school students are little journalists! Their reporting about their region and school can be found at the blog: KNB bulletin. The effort was fruitful as most alumni including my daughters have had successful careers (my younger daughter is a teacher at KNB, other notable alumni include the head of a literacy module operating at 150 Zila Parishad schools and the head of Balwadi programme at Pragat Shikshan Sanstha).

I focus on ethics and feel strongly about its teaching in schools, that in fact, is the mandate of the school. It's the teacher's job to provide role models to students in the fields they are interested in. The culture of good work has to be ingrained early – for example it is important for students to know the relevance of learning, as opposed to the mindset of qualifying exams. I, therefore, feel that experts in their own fields should regularly interact with schools of their cities/towns.

Another important area that needs attention is the teaching of the development or the history of science - discussing the lives of scientists, the challenges they faced and their contributions. The iconic figures of science could be good role models to students.

Your opinion on the state of higher education in India?
I feel that the curriculum of science and engineering colleges needs to be modified to emphasize on hands-on work. Students should do functional projects that will help them develop an interest in research. Education should focus on using analytical skills in problem solving. Students can then apply this methodology in any field they choose to pursue.

Students can also be exposed to research during their school days – for example, by emulating the USA-based - Maker Movement. The USA has an old tradition of youngsters tinkering in their garages - making household items and developing revolutionizing softwares! With 3D printing technologies and emphasis on hands-on training, schools in USA are making students interested in creating designs and toys. If introduced to students here in India, it is possible that they could engineer and create hardware oriented products early in their education.

Together with emphasis on research, the curriculum needs to include the topics of social entrepreneurship and technical management. Social entrepreneurship should introduce the students to the problems of rural India and the usage of science and engineering in solving them.

What according to you are key areas in agriculture that require innovative thrust? Are there possibilities of intervention by policymakers?

I have identified 3 key areas : rainwater harvesting, energy harvesting and precision agriculture. Rainwater harvesting has the potential to impact agriculture as well as watershed development.

The technology development requires large-scale deployment of qualified engineers - thus the technology and its management should be made a compulsory minor in all engineering and agricultural curricula.

India produces 600–800 million tonnes of agricultural residue per year (post-harvest plant remnants). A major portion of this dry residue is burnt in the fields and responsible for creating a brown haze over the subcontinent – also, an alarming contributor to climate change. Theoretically this residue has the potential of producing close to 80,000 MW of electricity through biomass - nearly 50% of India's total installed capacity! Farmers need to be incentivized for using the agricultural residue.

Currently, 80% of farms in India are less than 2 hectares in size. This small farm size is actually a boon, as it allows the use of small autonomous machines for precision agriculture which includes timely and precise crop management, consequently increasing productivity. Since precision farming is mostly robot and drone driven, students might be attracted to it. We need creative programmes in engineering and agricultural sciences to sustain this interest.

Policymakers and government could encourage industries to pursue research for rural areas as a part of their corporate social responsibility (CSR). Government gives sops and tax write-offs to the corporate sector to the tune of INR 5320 billion per year. This is in addition to the billions that the Indian banks write off as bad loans. Incidentally, this much money is five times more than the entire subsidy given to the poor via the Public Distribution System scheme. The prescribed 2% limit of spending on CSR can be increased by the government, hopefully enhancing funding towards rural research.

The mark of your innovations can be seen in their impact; however, you publish only in Indian journals. Why is that so?

I have three reasons for publishing in domestic journals:

- Papers are published relatively fast
- The journals charge no or very little money
- With the upward trend of science communication, our work reaches a bigger audience, even if we do not publish in famous journals

As far as research is concerned, I do not believe in metrics but in the true impact of the work, and feel sad that scientists are judged by the number of publications (and their impact factor). We started work on the electric powered cycle rickshaw in 1995 and published it later in 2002 in Current Science. We are proud that this paper popularized the concept of e-rickshaws throughout the country.

How can the youth community join your organization?
They can join us as interns – though we do not pay! Accommodation will be provided, and once you settle in, sky is the limit! Imagination, hard work (and a streak of madness!) is what we are looking for. A key contribution we are looking for is the enterprising zeal of the youth: to manufacture and market our products. Contact us if you are passionate about nation-building.

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