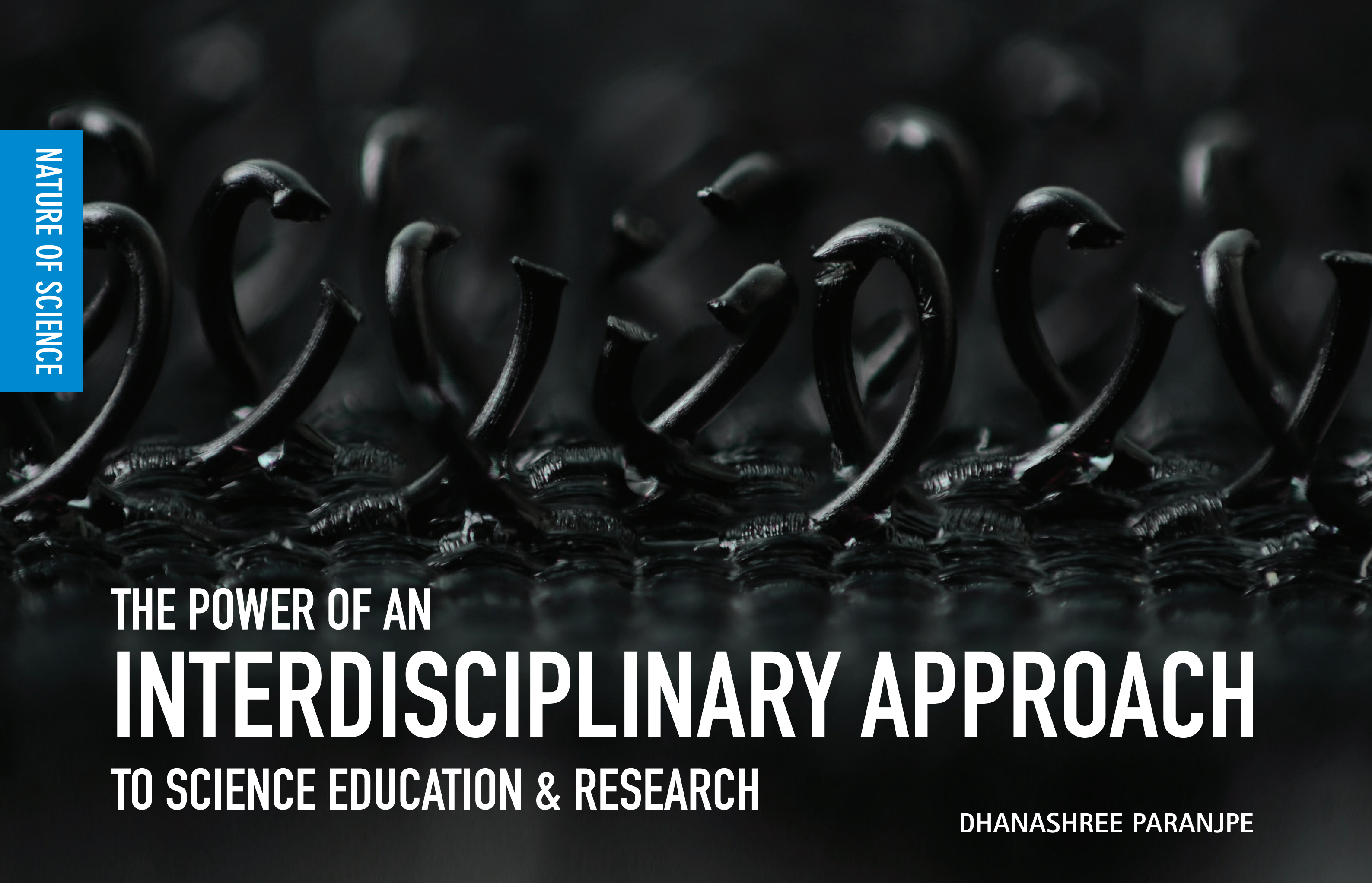

THE POWER OF AN INTERDISCIPLINARY APPROACH TO SCIENCE EDUCATION & RESEARCH

DHANASHREE PARANJPE

Examples from the history of science suggest that bridging the gap between seemingly unrelated fields may have rich rewards. Why? What are its implications for science education?

Sometime last year, I happened to visit the Pimpri Chinchwad Science Park with my family. It had exhibits on a range of scientific concepts – such as, energy, laws of physics, motion, ecosystems, and food webs – on display, along with some simple tricks of illusion. I'd never seen so many people, of varying age groups, with an interest in science gathered in one place. While most adult visitors expressed surprise that science could be so enjoyable, the many children entertaining themselves with the fascinating 'toys' on display were oblivious that they were learning science while having fun. The experience left me with an appreciation for the effort and ingenuity of the many people – scientists, artists, engineers, designers, architects and scientific illustrators; not to mention good organisers and administrators – who had made the science park possible. What I found most striking was that the exhibits were arranged under 'themes' (such as, sound, illusion, natural wonders, etc.) rather than 'subjects' (such as, physics, chemistry, and biology). When you're having fun engaging with science, who would want to remember which school subject a theme falls under?!

Our brain is bombarded with enormous amounts of information every day. It's ability to find patterns is one way the brain categorises and stores relevant information for quick recall. This categorization starts fairly early in our life. For e.g., we learn science at the school or college level as separate subjects that are not to be mixed together. Often, even those pursuing science as a profession are expected to develop specialised areas of expertise over years. For e.g., a cancer biologist may not have the expertise to diagnose and treat malaria, while a chemist is not expected to know how to operate an X-ray machine. In general, the deeper you dive into a scientific field, the narrower your focus is expected to become. As a result, we often tend to forget that the seemingly exclusive boundaries in disciplinary knowledge and expertise are artificial – we classify science under 'subjects' or 'topics' only for convenience and simplicity of understanding. What if people went beyond the boundaries of their subject?

What is an interdisciplinary approach?

An interdisciplinary approach to research or education involves the integration of knowledge from two or more academic disciplines into one activity. Seemingly unrelated fields (introduced in school as subjects) can have much to offer to each other in terms of new information, data, techniques, tools, perspectives, concepts, and/or theories. Thus, addressing a problem by bringing knowledge of different fields together may:

- Allow us to study the same problem or concept from different disciplinary perspectives and help us understand it better or in a more holistic way.
- Lead us to novel solutions.
- Advance science and give rise to useful technologies that did not exist before.

This approach is not new to science. Some of the most spectacular, path-breaking scientific discoveries have been made by scientists going beyond the boundaries of their specialised area of expertise (see **Fig. 1**). Consider one of the greatest scientific discoveries of the 20th century – the elucidation of DNA structure. This discovery was only made possible through the contributions of many physicists, chemists, and biologists. Phoebus Levene, a biochemist, was the first to discover nucleotides (composed of phosphate, nitrogenous bases and carbohydrates) – that form the backbone of a DNA molecule. Erwin Chargaff, another biochemist, discovered that the four nucleotides – Adenine (A), Thymine (T), Guanine (G), and Cytosine (C) – were arranged in a specific linear sequence in each strand of DNA (like 'beads' in a necklace). Rosalind Franklin, a chemist, and Maurice Wilkins, a physicist and molecular biologist, were the first to obtain a clear X-ray crystallographic (a technique used to study crystal structure) image of DNA. It took the combined efforts of James Watson, a biologist, and Francis Crick, a physicist, to put together this evidence and discover the three-dimensional, double-helical structure of DNA.

Fig. 1. Sharing ideas and building collaborations leads to interdisciplinary research.
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Many educational researchers have described the advantages of including an interdisciplinary approach to science education at the school or college level. For e.g., Repko (2009) asserts that interdisciplinary instruction fosters advances in the cognitive ability of students.[1] Other educational researchers describe its many distinct educational benefits – including gains in critical thinking, tolerance to ambiguity, recognition of bias, and an appreciation for ethical concerns.[2, 3]

In spite of its many rewards, using an interdisciplinary approach to the learning and practice of science may often seem like a tedious task, best suited to established scientists working in large labs with advanced instruments and facilities. Let's consider a few examples that challenge this notion.

One problem, many perspectives

There is a famous parable about six blind men who come across an elephant and try to describe it as they perceive it to be! One of them touches the tail and says that an elephant is like a rope, while the second touches the ears and describes it like a fan. The third blind person touches the elephant's belly and declares that it is like a wall, while the fourth touches its trunk and describes the elephant as a thick snake. The fifth blind man touches one of the elephant's legs and describes it as tree-trunk, while the sixth one touches its tusk and describes the animal as being like a spear. Their argument about which of these descriptions is accurate is resolved when they realise that they can only approach an understanding of the 'true nature' of an elephant by bringing together their partly correct observations or experiences of it (see **Fig. 2**).

This parable aptly captures the power of interdisciplinary research. Scientists or students of science trying to understand a complex system, phenomenon, or concept from the perspective offered by a single discipline or subject are like the blind men trying to know the elephant

Fig. 2. The six blind men and the elephant.

Credits: Charles Maurice Stebbins & Mary H. Coolidge, "Golden Treasury Readers: Primer", American Book Co. (New York). URL: https://commons.wikimedia.org/wiki/File:Blind_men_and_elephant3.jpg. License: CC-BY.

by "feeling" one of its parts. Integrating knowledge about the different aspects of a complex system allows us to develop a more accurate and comprehensive understanding of the system.

Consider the example of a fairly complex phenomenon — photosynthesis. This process is first introduced in the school curricula in Grade III or IV. A student of science continues to engage with it, in increasing detail, in each subsequent grade till the bachelors or master's level (depending on the student's specialization). In fact, some people have studied this phenomenon for their entire lives! Even at school-level, we can study this process from many different viewpoints, such as:

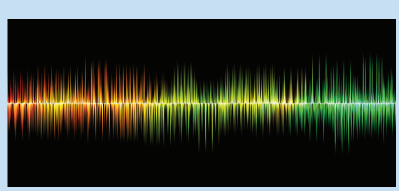
- how it ensures flow of energy across biological systems (chemistry; thermodynamics),
- the cellular organelles, genes and proteins involved in the process (biology),
- the biochemical reactions involved in the process (chemistry),
- the economy of photosynthesis — how much the plant invests in the process of photosynthesis, how much light energy is 'fixed' per plant per unit time, and
- the ecology of plants — how availability of light influences types of plants and where they grow (e.g., C3 and C4 plants) and so on.

Thus, a deeper and more holistic understanding of the concept can be gained by combining our knowledge from various sub-fields (see **Box 1**).

Box 1. Interdisciplinary lesson plans for the classroom:

Here are some examples that attempt to incorporate knowledge from different disciplines, along with useful life skills:

1. **Food on my plate:** To help students delve into nutrition, agriculture, local food habits and economy, encourage them to design a school lunch plan for a week, keeping in mind that each meal:
   - Includes all essential food groups (proteins, carbohydrates, fats, vitamins) in appropriate proportions.
   - Includes locally available, seasonal vegetables.
   - Meets appropriate calorific values.
   - Including all the raw material and other necessary ingredients does not cost more than Rs. 100 per day per student.
2. **Fresh air:** To develop an understanding of air by engaging with:
   - Geography: the composition of the earth's atmosphere; air currents and their importance.
   - Chemistry: the composition of air; typical air pollutants and their physical or chemical nature; and experiments around air pressure.
   - Biology and environmental science: the human respiratory system, and how it is affected by air pollutants.
   - Innovation: designing a simple air purifier, filter, wearable mask, a simple homemade vacuum cleaner, or a road cleaner.
3. **Sound:** To develop a deeper understanding about sound waves and how it can affect us in our day-to-day lives through:



   - The physics of sound waves: how sound waves travel through air; echo and overtones; and, factors affecting the transmission of sound, etc.
   - The biology of sound: how sound is 'heard'; the structure of the human ear, auditory nerves, and the brain areas which recognise sound; defects in speaking and hearing, and the hearing range of different animals including humans.
   - The environmental science of sound: the typical decibel range of sounds in places like roads, schools, office spaces, libraries, factories, airports etc.; sound pollution, its impacts on humans and other animals and how can it be reduced or avoided.
   - Music: harmony and cacophony; how music (sounds) affects mood and the brain; understanding sound patterns or waves with the help of musical instruments.
   - Innovation: making models (of the structure of ear, or a 'voice box'), and playing with or making simple musical instruments.

What variations would you bring to these plans? How would you use an interdisciplinary approach to develop a lesson plan?

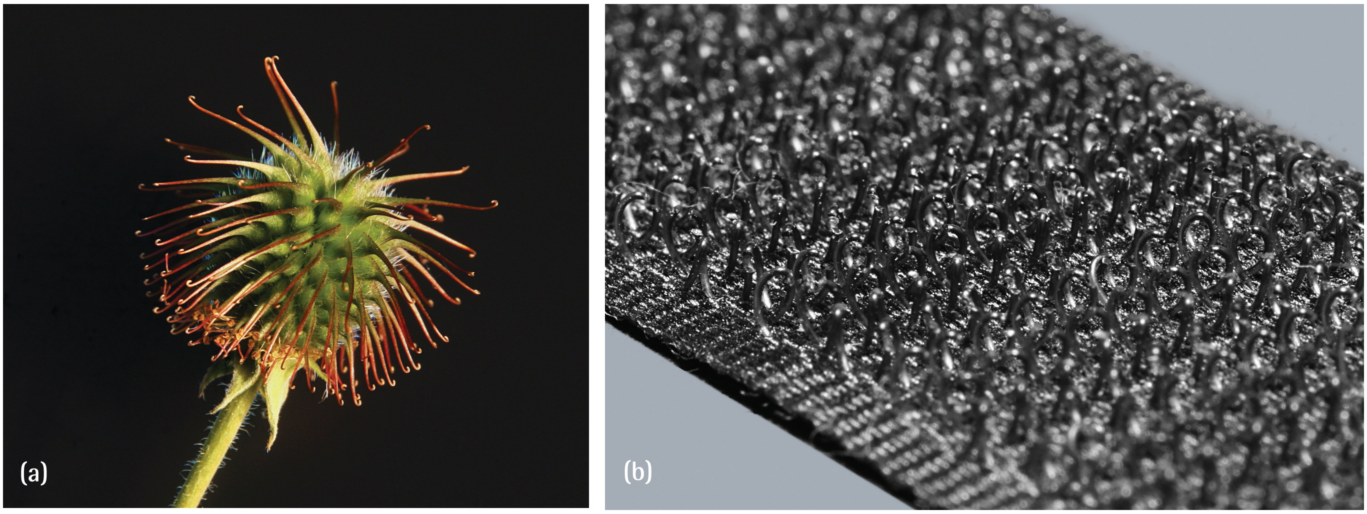


Fig. 3. The hooks on the dried fruit of burdock (a) inspired the invention of Velcro (b).

Credits: (a) Zephyris, Wikimedia Commons. URL: https://en.wikipedia.org/wiki/File:Bur_Macro_BlackBg.jpg. License: CC-BY. (b) Credits: Alexander Klink, Wikimedia Commons. URL: https://en.wikipedia.org/wiki/File:Velcro_Hooks.jpg. License: CC-BY.

Finding solutions to complex problems

An interdisciplinary approach is not only useful in arriving at simple, everyday decisions, but also in making more complex and once-in-a-lifetime decisions.

Often, simple everyday decisions require a knowledge of various fields. For e.g., our decision to purchase a new bike or car is made after we gather information about its many dimensions:

- engine power (physics);
- fuel type, mileage of the vehicle, safety features and design (engineering), and
- cost compared to other available options, affordability etc. (economics).

More complex decisions also benefit from an interdisciplinary approach. Consider a large-scale project like the construction of a dam. Decisions about its design will require a knowledge of geography, geology, hydrology, engineering, architecture, and economics. Predictions of the dam's impact on people and ecology will require a study of the local biodiversity, as well as the socio-economic conditions, agricultural and water needs of human populations at the dam site (environmental science). In another example, fighting a large-scale disease outbreak, like malaria, requires a team of scientists, doctors, chemists, administrators, public health workers, and state officials to work together. Entomologists study the behaviour of mosquitoes (vectors of the malarial parasite) to come up with measures to control them. Based on this information, public health workers and state officials help raise awareness about the disease and measures to mitigate its spread. Parasitologists study the parasite to determine the species causing the outbreak and its effects on infected people. These studies help physicians diagnose the infection and arrive at an appropriate treatment plan (e.g., combinations of drugs), with the help of chemists and pharmacologists, that is targeted at the species causing the local outbreak. Other large-scale complex projects, like planning an industrial development or demarcating sanctuaries or protected areas for wildlife etc., are impossible without an interdisciplinary approach.

Innovative solutions and technologies

Humans have always looked at nature for inspiration to solve problems such as manoeuvring in air, staying underwater, surviving in low oxygen environments for extended duration, and so on. Today, such studies are classified as 'biomimetics' — an applied field that focusses on the development of new technologies and products inspired by nature.

One of the most famous examples of such innovations is Velcro. Used in shoes, clothing, and household items, Velcro was inspired by the tiny hooks or teeth found on the dried fruits of some plants (see **Fig. 3**). The fruit use these

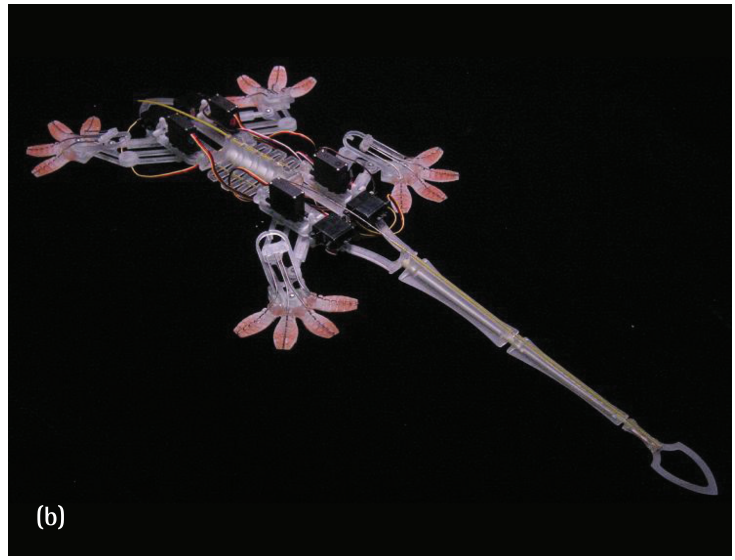


Fig. 4. The Gecko's foot (a) inspired the Stickybot (b) developed by Sangbae Kim from MIT.

Credits: (a) Bjørn Christian Tørrissen, Wikimedia Commons. URL: https://en.wikipedia.org/wiki/File:Gecko_foot_on_glass.JPG. License: CC-BY-SA. (b) Biomimetics and Dexterous Manipulation Laboratory, Stanford University, Wikimedia Commons. URL: https://en.wikipedia.org/wiki/File:Stickybot.jpg. License: CC-BY-SA.

hooks to attach to animals or humans passing by, increasing their chances of seed dispersal to faraway places.

Inspired by the structure of a gecko's (yes — the small lizard-like animal that scares us in our homes!) foot, scientists are developing robots that can climb vertical walls (see **Fig. 4**). Similarly, the design of robots or machines that can move on the surface of water is inspired by water striders. These insects, that you may have seen "skating" on the surface of stagnant water, have special hydrophobic structures on their long legs that allow their feet to remain dry. They make use of the surface tension of water to keep afloat (see **Fig. 5**).

Another very useful innovation is that of artificial arms and legs for soldiers and other people who have lost their limbs in war or accidents. Developing artificial limbs that can function almost like natural ones requires an understanding of the biological structure and function of the organ. It also requires a knowledge of the various materials available for reconstructing the limb, and expertise with electronics and computer programming (sometimes brain imaging as well) to make it functional. New age artificial limbs have improved the lives of many unfortunate people. Today, scientists are even studying neurons and their networks in the human brain to build complex machines that can 'learn' and 'perform' complex tasks.

This is not all. Innovative solutions and new technologies to improve agricultural yield, water conservation and purification, and harvesting clean energy etc. are being developed every day. I would also like to highlight the many 'new', yet simple and low-cost technologies that are being developed in India, particularly those from small

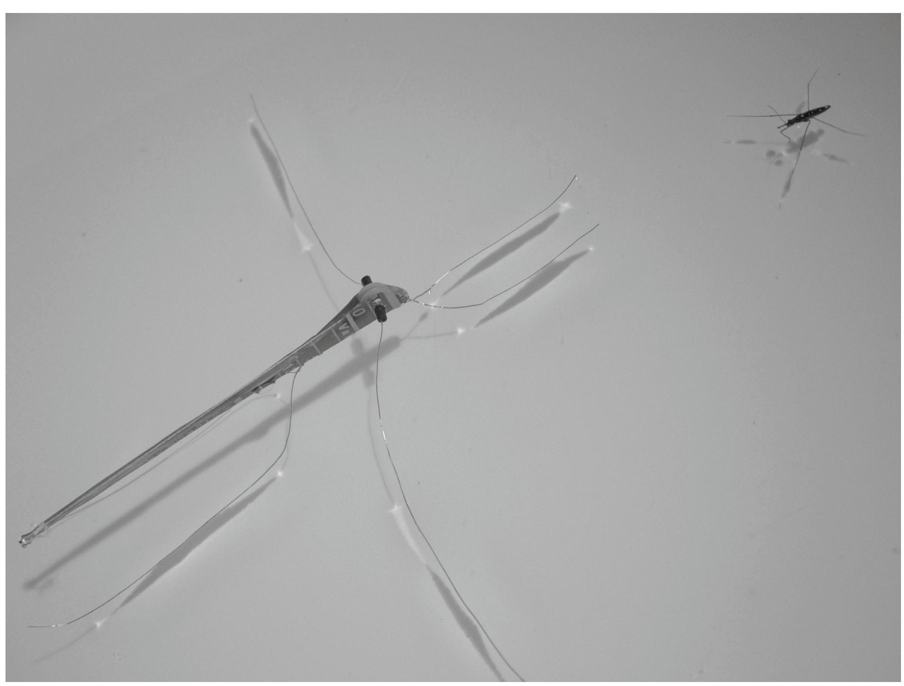


Fig. 5. The water strider (to the right) inspired the micro-robot (to the left) developed by scientists from Harvard University, US and Seoul National University, South Korea.

Credits: David Hu and John Bush, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Robostrider_faceoff2.jpg. License: CC-BY-SA.

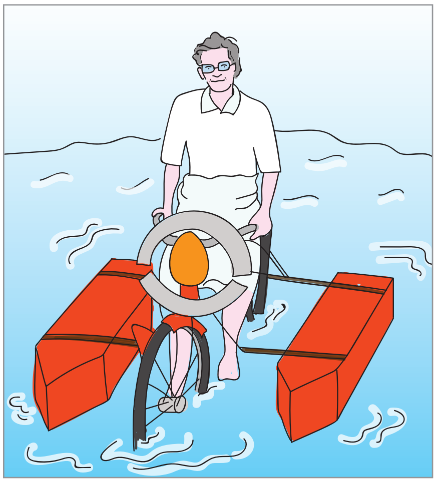


Fig. 6. This low-cost amphibious cycle developed by Dwarka Prasad Chaurasiya and Mohammed Saidullah won them the National Innovation Foundation's Lifetime Achievement Award.

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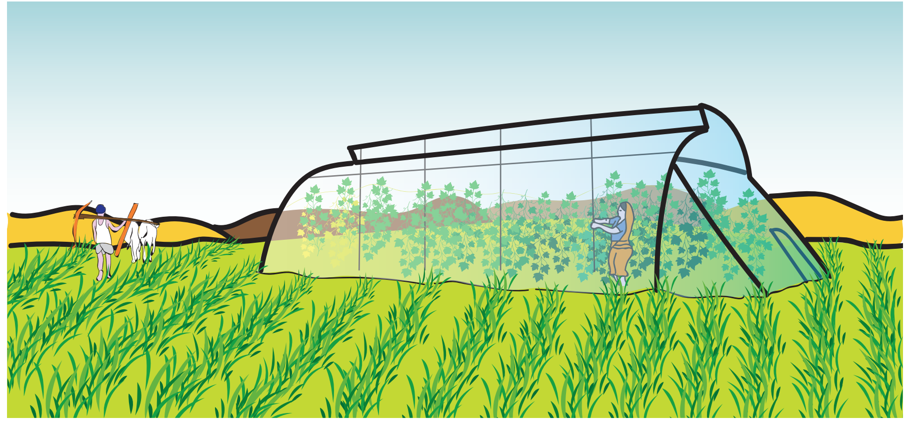

Fig. 7. A low-cost 'Greenhouse in a box' was developed by the Indian start-up company Kheyti. This simple setup protects crops from harsh weather and insect pests.

Credits: Adapted from the image from http://www.designindaba.com/sites/default/files/node/news/23415/gallery/greenhouse-box-3.jpg. License: Public Domain.

villages. These include a cycle-boat designed to cross a flooded river in Bihar (see **Fig. 6**) and a low-cost water filter developed from naturally occurring red laterite soil. A low-cost 'greenhouse in a box' developed to keep crops safe in drought and from crop pests (see **Fig. 7**), and a flame torch developed by school kids from Pune, Maharashtra to keep wild animals away from human habitations are just a few other examples of such innovations.

These innovations are possible not just because of human creativity, but also as a result of interdisciplinary approaches to problem solving. Such an approach allows adults and kids to approach a problem by tinkering with ideas, information, and/or techniques from different disciplines of science. Offering such opportunities in the teaching and learning of school science may help train young minds to form connections between different fields of knowledge from an early age. Consequently, we may be better equipped to unleash the power of an interdisciplinary approach to research and problem solving for the betterment of science and life on earth.

Key takeaways

- An interdisciplinary approach to research or education involves the integration of knowledge from two or more academic disciplines.
- Some of the most spectacular and path-breaking scientific discoveries (e.g., the structure of DNA, Velcro, robots, greenhouse in a box, amphibious cycle etc.) have been made by scientists going beyond the boundaries of their specialised areas of expertise.
- Offering opportunities to approach a problem by tinkering with ideas, information, and/or techniques from different disciplines in school science may help train young minds to see connections between different fields of knowledge from an early age.
- Studying a system from different perspectives helps us develop a more comprehensive understanding of it, and equips us to think out-of-the-box and look to various sources to formulate unique solutions.
- Engaging with this approach early in life helps contribute to the ability to find solutions for complex problems and decisions later on in life.
- Teaching science from this approach has been shown to have other educational benefits — students see gains in critical thinking, tolerance to ambiguity, recognition of bias, and an appreciation for ethical concerns.

Note: Image used in the background of the article title – A hook-and-loop Velcro fastener. Credits: Kamran Iftikhar, Wikimedia Commons. URL: https://en.wikipedia.org/wiki/File:Hook_and_loop_fastener_-_macro_photograph_of_%22hooks%22.jpg. License: CC-BY-SA.

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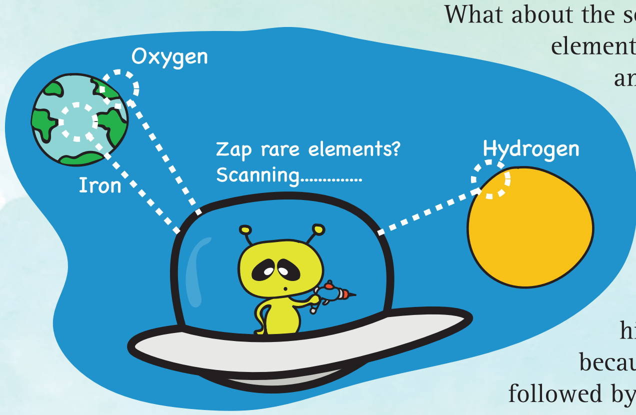
SNIPPETS

ABUNDANT AND RARE ELEMENTS

What are the most abundant elements on earth? Surprisingly, the answer to this question can vary. The most abundant elements in the earth's crust are oxygen (did you get that right?), silicon, aluminium, iron, calcium, sodium, potassium and magnesium (in that order). Seen as a whole, however, the earth is made up of 32.1% iron, 30.1% oxygen, and 15.1% silicon etc. This variation is caused because the distribution of elements at the core of the earth is different from that at its crust.



What about the scarcest element on earth? Among the naturally occurring elements, this would be astatine (At) – a radioactive halogen. At any given time, only as much as one ounce (28.35 g) of At is present on earth. This is a very tiny amount indeed! Many other radioactive elements, like francium, technetium, polonium, radium, actinium and protactinium are also found in scarce amounts. This may be because of the radioactive decay of their original stocks to today's negligible levels. We also know that some 'precious metals' are very rare – their high costs are not only due to their high demand, but also because of their scarcity. The rarest of these is iridium; followed by gold, rhodium, palladium, platinum and silver. The market value of these scarce metals is also determined by the costs of their extraction. Thus, the more difficult to extract platinum is more expensive than the less abundant gold.

We often assume that a discussion on abundant and rare elements refers only to the elements found on earth. What about the solar system? Today, we know the most abundant element in the solar system is hydrogen (70.5%), followed by helium (27.5%), and carbon (~0.6%). Much of this hydrogen and helium are concentrated in the sun. Hydrogen is also the most abundant element in the universe, making up ~73.9% of its mass. This is followed by helium (~24%), oxygen (~0.1%), and carbon (~0.046%). All other elements are estimated to be present at trace levels. Do keep in mind that these distributions do not take into account dark matter and dark energy; they are only true of the visible matter of the universe.

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