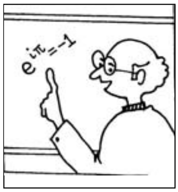
Classroom



In this section of *Resonance*, we invite readers to pose questions likely to be raised in a classroom situation. We may suggest strategies for dealing with them, or invite responses, or both. “Classroom” is equally a forum for raising broader issues and sharing personal experiences and viewpoints on matters related to teaching and learning science.

It’s a MATERIALS World!

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In this article, we describe our experiences of conducting a series of workshops titled ‘It’s a MATERIALS world!’ to popularize Materials Science among school children in India. Some of the hands-on activities that can be performed with easily available ingredients/equipment in a classroom are described for the benefit of educators.

Introduction - VIGYANashaala: Communicate and Inspire!

Vision India: GenY Applied Science Network (VIGYAN)shaala is a science, engineering, math, and technology (STEM) outreach initiative run by a group of US and UK based Indian graduate students and early career scientists. VIGYANshaala envisions bringing a holistic STEM classroom experience to its participants through multidimensional efforts such as holding hands-on workshops, augmented lectures, web resources and STEM conversations, both in-person as well as through social media platforms. The ultimate goals of VIGYANshaala are two-fold:

- Science is a collective effort. One person cannot solve all the problems. We need a workforce and not just any kind, we need a well-versed, inclusive, and diverse one to tackle modern day problems. We, through VIGYANshaala, want to help in building that multi-tier pipeline of STEM professionals, decision-makers

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and business people alike.

- To create a network of professionals (peer graduate students as well as experienced scientists/STEM enthusiasts) to mentor the next generation of scientifically sound citizens. In the process, we would like to boost their own confidence and likelihood of success through practising what we preach – science communication – leading to improved communication and transferable skills, mentoring and networking opportunities for early career scientists who volunteer as mentors, and leadership skills development for coordinators at various levels.

Team VIGYANshaala travelled more than 10,000 miles all over India between December 2016 and January 2017, reaching hundreds of schools, more than 250 teachers, and inspiring more than 5,000 students.

Team VIGYANshaala travelled more than 10,000 miles all over India between December 2016 and January 2017, reaching hundreds of schools, more than 250 teachers, and inspiring more than 5,000 students. Our small team of four grew to a network of around 250 volunteers including mentors and advisory members. Nearly 40% of our volunteers and 30–50% (depending on the location) of the participants were females. We conducted hands-on workshops for middle and high school students from varied social, economic, and regional backgrounds. The geographical locations included Forbesganj near the India-Nepal border, Delhi, Puducherry, as well as towns in Uttarakhand, Uttar Pradesh, Maharashtra, and Tamil Nadu. The social panorama included NGOs working for empowering young lives, youth organizations and schools, regional and national government schools, public and private schools in varied income regimes, all-girls' college campuses, and undergraduate colleges. Each time we were surprised and humbled by the special welcome, honour and acceptance we received from all our hosts. Teachers and students alike participated enthusiastically and jumped to our rescue in challenging situations such as language barriers. Many times, students and teachers organically took over the sessions helping us achieve our next tier goals of inculcating leadership skills. One important aspect of these sessions was helping fellow graduate students and early career scientists build transferable skills.

Founding team of VIGYANshaala (left to right): Aditya Sadhanala, Darshana Joshi, Vijay Venugopalan, and Shruti Sharma.

It's a MATERIALS World – A Hands-on Approach to Introducing Materials Science to High School Students.

The overarching theme of the workshops is to introduce participants to the amazing diversity and interdisciplinary nature of Materials Science. Typical sessions comprise of demonstration-based lectures, where randomly chosen student volunteers are guided to perform the demonstrations while their peers observe and ask questions. Details of some of the hands-on demonstration sessions are given below. These include several experiments, which one can perform with easily available ingredients/equipment in a classroom.

The overarching theme of VIGYANshaala workshops is to introduce participants to the amazing diversity and interdisciplinary nature of Materials Science.

1. Polymers and Gels: From Plastics to Proteins

We begin by introducing polymers using a necklace of beads as a prop (*Figure* 1(A)). The lecturer then proceeds to challenge the classic definitions of states of matter by demonstrating 'silly putty', a toy based on liquid silicone that behaves both as a liquid and a solid, depending upon the time scale of force applied (*Figure* 1(B)).

The student volunteers then make their own silly putty, a squishy

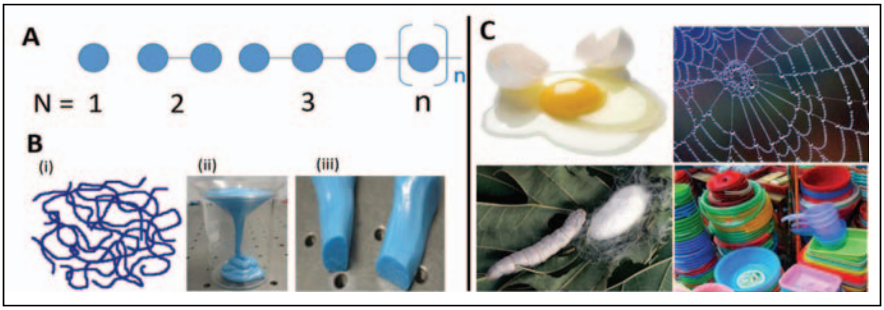

Figure 1. **(A)** Polymer – a Greek-origin word where, 'poly' means 'many' and 'mer' means 'units'. Polymers are made up of smaller units called monomers, where N = degree of polymerization, is usually very large and gives rise to unusual properties. **(B)** (i) A schematic depiction of a polymer melt. Silly putty, a silicone-based polymer melt behaving both as (ii) a viscous liquid over a long period of time but as (iii) an elastic solid over a short time period. **(C)** Examples of polymers around us.

solid ('slime') by mixing two transparent liquids (PVA and Borax), hence learning about cross-linking. This leads us to introduce a variety of examples of polymers in the world around us (*Figure* 1(C)).

1.1 *Making Your Own Silly Putty/Slime*

Polyvinyl alcohol, (-$[CH_2CH(OH)]_n^-$) – PVA solution can be cross-linked and turned into a squishy solid by adding borax (hydrated sodium tetraborate, ($Na_2B_4O_7.10H_2O$)) solution. To do so, make a 4% solution of PVA and 4% solution of borax. For better mixing, you would be required to heat the solutions gently, stirring occasionally. Take 4 parts of PVA solution and 1 part of borax solution in separate containers. You can add a few drops of food colour, if you like, to the PVA solution. Now, add the borax solution to the PVA solution while stirring vigorously. You will observe that the mixture of two liquids becomes more and more viscous and eventually turns into a squishy solid. Remove the solid from the container and knead it slowly to remove air pockets. Your 'slime' is ready. You can also use diluted common craft glue instead of making PVA solution. If you add acid to the slime, it will break the cross-linking and produce a liquid with lower viscosity. The slime can be regenerated by adding alkali.

We also demonstrate other interesting polymer applications like super-absorbent and super-hydrophobic materials using props like fake snow (used in diapers) and super-hydrophobic (magic) sand.

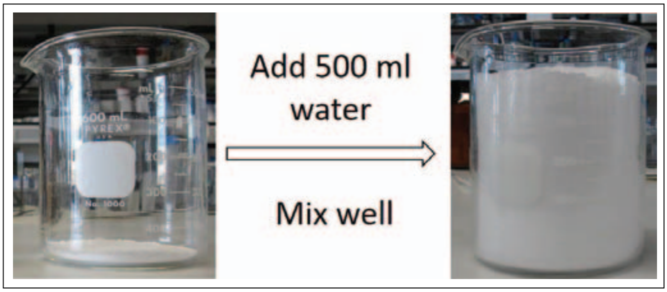

Figure 2. A superabsorbent polymer – sodium polyacrylate – before and after adding water. Two spoonfuls of the salt nearly absorbed half a litre of water here.

1.2 *Fake Snow – A Superabsorbent Polymer*

Take a spoon full of sodium polyacrylate powder ($[CH_2CH(CO_2Na)]_n$) in a beaker and add 500 ml of water to it while constantly stirring. You will see that the powder absorbs all the water and yet it does not feel wet at all on touching (*Figure* 2). Sodium polyacrylate is an anionic polyelectrolyte that can absorb hundreds of times its weight in water. Superabsorbent polymers are very useful in everyday applications such as diapers, spills and odour controls, waterproofing coating, and maintaining the moistness of soil.

Take a spoon full of sodium polyacrylate powder in a beaker and add 500 ml of water to it while constantly stirring. You will see that the powder absorbs all the water and yet it does not feel wet at all on touching.

Instead of buying sodium polyacrylate powder for this demonstration, students can be encouraged to tear open some fresh diapers and extract the salt from there.

These demonstrations set the stage for introducing biological polymers like silk, spiderwool, proteins, and DNA. Using a bead necklace as a prop, we explain how proteins fold into various conformations as a function of entropy, and how denaturation of proteins is nothing but cross-linking of polymer chains.

1.3 *Denaturation of Proteins – Cooking an Egg Without a Burner!*

Break an egg and separate the egg white into a beaker. In another beaker, take about 50 ml of 70% rubbing alcohol (isopropanol or alternatively, high-proof ethanol). Now pour the egg white gently into the alcohol while continuously stirring it. You will notice that the translucent egg white starts to turn cloudy and slowly turns into a white solid lump-like texture, similar to a cooked egg.

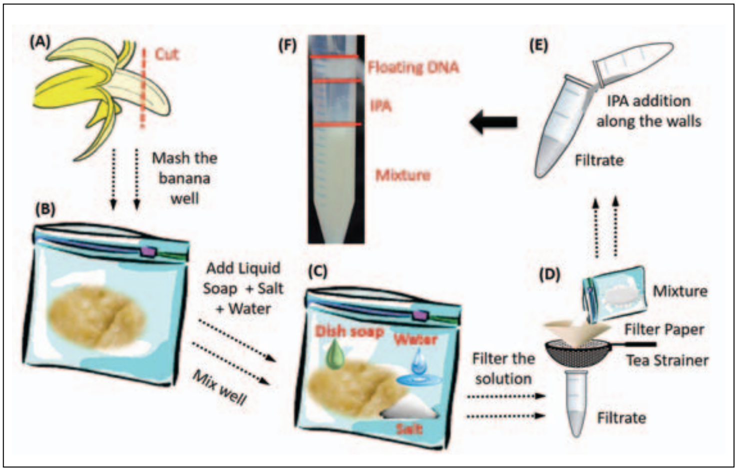

Figure 3. DNA extraction from banana **(A)** Cut a quarter of the banana. **(B)** Mash it into a puree inside a ziplock bag, ensure that there are no lumps remaining. **(C)** Add 50 ml water, a few drops of dishwashing liquid soap and a pinch of salt to this banana slurry and mix well, avoiding formation of foam. Soap breaks the cell wall and brings all the intercellular material into the solution and salt helps stabilize the DNA in solution. **(D)** Filter the solution using a tea strainer and a filter paper. **(E)** Now, take a portion (around 5 ml) of the filtrate in a test tube. Add 5 ml of ice-cold ethanol by tilting the two test tubes so that ethanol travels along the wall of the test tube. **(F)** Ethanol forms a separate layer on top due to density difference. The acidic nature of alcohol cross-links the DNA in the solution and a jelly like structure appears at the interface of the mixture and ethanol. This jelly then rises to the top and can be extracted using a toothpick.

Proteins are very sensitive to changes in their surroundings. Adding alcohol changes the pH of the medium, making it acidic. The acidic medium denatures or changes the conformation of ovalbumin (protein in egg white), hence forming new linkages with each other or cross-linking the protein melt.

2. DNA Extraction From Banana

Invariably, the most loved session of our workshop is the extraction of DNA from bananas using common household ingredients like dish soap, salt, and ethanol. Students perform this hands-on activity in groups of three to five. They are thrilled to take away their small portion of extracted DNA jelly at the end. *Figure* 3 describes the protocol for extracting DNA from banana.

3. Green Energy and Storage

We introduce several demonstrations that use potatoes or soft drinks as batteries to light up an LED; concepts of heat; and solar electricity generation. Finally, we introduce the principles of nuclear energy.

We introduce the participants to the current global warming issues caused by the combustion of fossil fuels (coal, oil, gas) across the globe thus motivating the audience towards the need for green energy to combat global warming. As it is one of the green energy options, we start a discussion about nuclear energy and explain the mass-energy conversion principle behind it (Einstein's famous $E = mc^2$ equation). Then after mentioning the hazards related to it, particularly the effect of radiation and nuclear waste management, we demonstrate how a Geiger–Muller counter's reading changes near radioactive materials such as bananas and rocks (due to presence of trace radioactive isotopes of commonly found elements). We then talk about safer candidates such as wind and solar energy. We explain the basic principle behind the solar cells (again thanks to Einstein, but this time, $E = h\nu$, which is the equation for the photoelectric effect). Since the energy produced by solar cells and wind mill farms requires storage, hence building batteries should go hand-in-hand with green energy production.

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We then explain the functioning of a battery using the following demonstration.

3.1 *Soft-drink Do-it-yourself Battery Experiment*

A battery is a device that can store energy through electrochemical reactions. It consists of three major parts: cathode, anode, and electrolyte. The electrolyte is the medium through which the anode loses electrons, and the cathode collects them. Thus, if one connects the cathode and anode through a conductive wire, electrons in the electrolyte find a free path to flow. Thus, a closed electric circuit is established, and electrons continue moving following the anode → cathode → electrolyte → anode cycle. Zinc and copper are typical anode and cathode materials, while an acidic medium commonly plays the role of an electrolyte (it contains lots of free H^+ ions). Important chemical reactions are

a) $Zn \rightarrow Zn^{++} + 2e$ b) $Cu^{++} + 2e \rightarrow Cu$ c) $2H^+ + 2e \rightarrow H_2$.

Many fruits are naturally acidic, so are potatoes and even soft drinks. To create an effective battery, fill two glasses with a fizzy soft drink. Into each glass, dip a pair of zinc and copper rods.

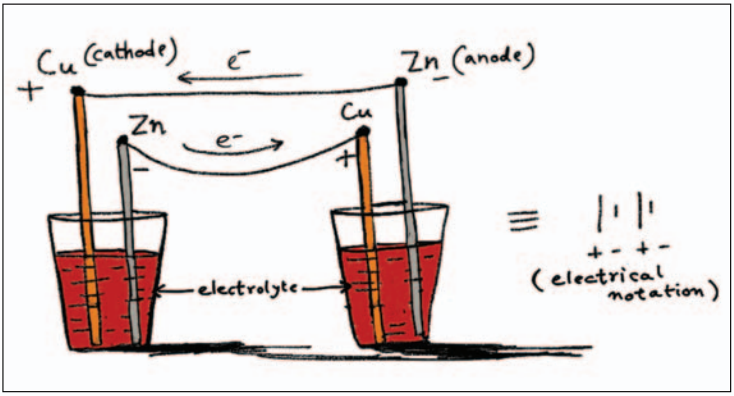

Figure 4. A double cell battery using copper (Cu) and zinc (Zn) rods as electrodes and soft drink as electrolytes. In the battery, electrons flow from Zn (anode) to Cu (cathode).

Then, connect a zinc rod of one glass to a copper rod of the other glass using electric wires (see *Figure* 4). Thus, the other free rods become free electrodes of a battery. If a voltmeter (V) is connected to the electrodes you will see a finite voltage reading. You can repeat the same steps by inserting the metal electrodes into various fruits or vegetables and compare.

4. Scientifically Fun Science

In keeping with our aim of introducing basic scientific concepts in a fun and easy way, we include a range of other easy science experiments that can be done using simple materials. Students are encouraged to try them at home as well, under adult supervision and with proper safety gear.

This session starts with the 'magic milk fireworks' that uncovers the scientific secrets of the surface tension of water and how soap breaks it. It is an easy hands-on learning experiment.

4.1 *Magic Milk Fireworks*

Pour enough milk in the container such that it completely covers the bottom of the container to the depth of about 1 cm. Then, add 3–4 drops of different food colors, very close to each other, to the milk. You will notice that the colours don't spread and remain

Figure 5. Eruption of colors in the milk after dish soap is added.

mostly static. However, as soon as we place a cotton swab soaked with liquid dish soap in the middle of the food colour drops for 10–15 seconds, you will notice the eruption of colours in the milk forming colourful patterns and it will continue to move even when the cotton swab is removed (*Figure* 5).

This experiment helps in explaining how the addition of dish soap to the milk disrupts its surface tension. Soap breaks the bonds along the surface that spreads out of the surface molecules. Hence, the colours erupt like fireworks.

4.2 *Density Sugar Rainbow*

A density sugar rainbow experiment helps students to understand the concept of density in liquids using a simple combination of sugar, water, and food colours to produce vivid colourful rainbows.

First, fill three glasses with water and dye using different food colours. Stir them and add different amounts of sugar into two of the glasses. Now, you will have one glass with no sugar and another 2 glasses with, say, 1 teaspoon and 3 teaspoons of sugar, respectively. Dissolve the sugar by stirring it properly. Then, grab one transparent straw and hold it near one end. Place your thumb over the straw's top opening. To make a sugar rainbow, lift thumb off the opening, dunk the lower end of the straw to about 2–3 cm into the glass with no sugar. Again, cap the straw firmly with the thumb and lift it out of the water. Now, dip it quickly into the 1 tsp solution (a little deeper than what you did in the first glass). After lifting the straw, you will observe the first and second colour

A density sugar rainbow experiment helps students to understand the concept of density in liquids using a simple combination of sugar, water, and food colours to produce vivid colourful rainbows.

Figure 6. Density column of sugar–water – A sugar rainbow.

solutions in a stack inside the straw. Continuing the same dipping process in the third glass, you will have all three different colour solutions inside the straw. This shows how the density of water changes upon the addition of different amount of sugar into it.

A glass can also be used as an alternative to demonstrate the stack of colours as shown in *Figure* 6.

4.3 *Elephant's Toothpaste*

Further, we explain the role of catalyst in a chemical reaction using an experiment popularly known as the 'elephant's toothpaste'.

Pour about 50 mL of 30% hydrogen peroxide (H_2O_2) solution into a graduated cylinder. Squirt in a little dishwashing soap and swirl it around for a while. Then, add 10 ml of potassium iodide (KI) that plays the role of a catalyst, and helps in speeding up the chemical reaction. This chemical reaction produces a large yellow colour foamy mess that looks like a toothpaste coming out of a tube. This reaction principally produces water and oxygen gas. The decomposition of hydrogen peroxide also releases a small amount of heat. The oxygen gas produced gets trapped in the soap which further produces the big ball of foam (*Figure* 7). Thus, the reaction produces oxygen gas, water, and iodine as a result of which the foam is yellow in colour.

Note: Wear safety glasses and disposable gloves while perform-

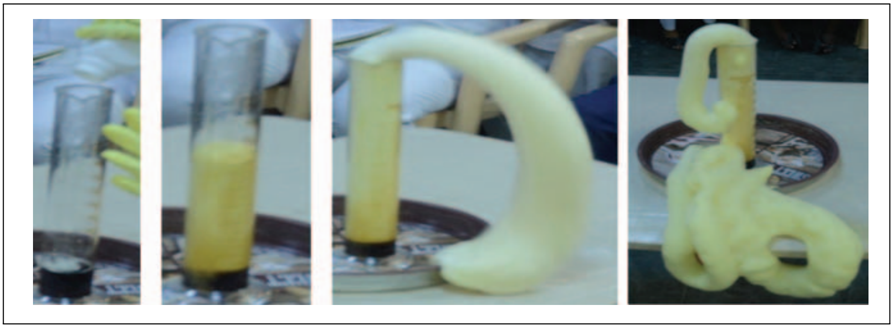

Figure 7. Oxygen filled bubbles coming out of the cylinder when a catalyst (KI) decomposes hydrogen peroxide (H_2O_2) into water (H_2O) and oxygen (O_2).

ing this experiment. Also, the reaction is exothermic, it produces a fair amount of heat so do not lean over the cylinder when the solutions are mixed.

4.4 *Chemical Chameleon*

The session concludes with a colour changing reaction (also known as the chemical chameleon experiment) that proceeds on its own through a number of different beautiful colours. Hence, is helps in explaining about some interesting chemistry of redox reactions.

The demonstration involves the preparation of two solutions.

Solution A: Dissolve a very small amount of potassium permanganate ($KMnO_4$) in 50 ml of water in a beaker. It will gradually turn water into a uniform light purple colour.

Solution B: In another beaker, add 5 g of sugar and 10 g of sodium hydroxide (NaOH) to 750 ml of water.

After preparing the solutions, slowly pour solution A into Solution B, and continuously swirl the beaker to mix everything very well. Immediately, the purple color of solution A changes to blue, and very quickly after that turns green. Then, much more slowly, over a few minutes, the green will fade into a yellow-orange (*Figure* 8).

This is due to the formation of a new chemical, manganese dioxide (MnO_2), during the reaction. This is called a redox reaction where new compounds are formed when one chemical takes elec-

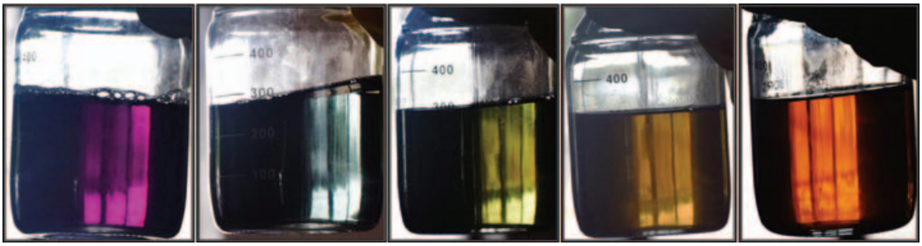

Figure 8. Different stages of the colour changing redox reaction between $KMnO_4$ and sugar.

trons from another chemical. Here, the potassium permanganate is reduced (it gains electrons) and the sugar is oxidized (it loses electrons).

5. New Age Flexible Optoelectronic and Solar Technology

We start with building the foundations by distinguishing between conducting and non-conducting plastics (polymers). The participants are then introduced to clean room processing of polymer devices like transistors, organic light emitting diodes (OLEDs) and solar cells. The advantages of polymer electronics over traditional silicon based electronics are their lower cost of production, technological ease of making large area devices, non-breakability and flexibility. Demonstrations introduce the basic principle of spin coating, cleanroom suits, and a roll of flexible printed solar cells, along with a working prototype of a printed solar cell and a flexible screen.

OLED screens have already been in use in many display devices such as TV and mobile screens. However, a number of technological challenges need addressing for large-scale printing of flexible display devices to take the next industrial leap and come into the market. Future of flexible device technology holds promises of flexible and lightweight screens and solar cells that could be rolled on and carried in a backpack everywhere. The lecture concludes by imagining a future where flexible and low cost printed electronics could help in the sustainable development of communities across the globe.

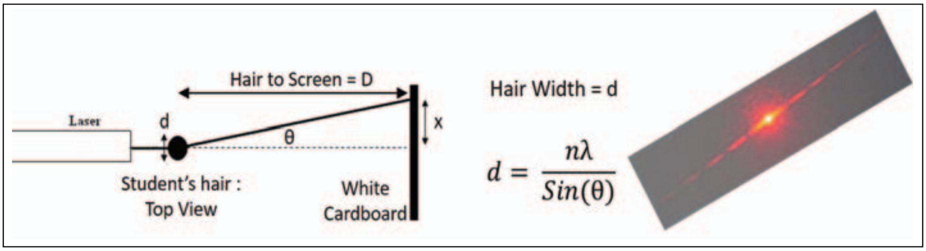

Figure 9. Measuring the thickness of human hair using laser diffraction.

6. Hands-on Optics

This session engages students in advanced optics experiments which are usually introduced only theoretically at the school level. The experiments in this session are based on the Photonic Explorer Kit distributed by EYESTvzw – a low-cost kit for supporting science educators. Some of these experiments include the concepts of total internal reflection, interference and diffraction of light, observing the spectrum of different light sources etc. Measuring the diameter of human hair by analysing the laser diffraction pattern, depicted in *Figure* 9, is quite popular among the students.

7. Water Rocket

We usually conclude our workshops on a fascinating high note by launching a water rocket in the end, sometimes soaring more than 50 m in height.

We hope VIGYANshaala will motivate many more such student-led initiatives for introducing the younger generation of students to the exciting world of scientific research and inspiring them to pursue science.

In future, as our volunteer base grows, VIGYANshaala hopes to design and deliver similar workshops focusing on other cutting-edge research disciplines, such as 'Advancements in Optoelectronics and Photonics', 'Genetic Engineering and Molecular Biology', 'Conservation and Ecology', to name a few. VIGYANshaala will now be collaborating with Science Resources Africa to conduct physics teacher training workshops and 'It's a MATERIALS world' workshops in Sierra Leone. We were recently awarded the Virdee Grant from the Institute of Physics, London for the same.

Box 1. United We Stand – Power of Peer Networking

"What started as a fun reminiscing conversation between two female PhD candidates took shape of a network leading to the journey of more than 10,000 miles, reaching thousands of students and hundreds of teachers across India. I was introduced to Darshana Joshi through a common friend who said, "You should meet Darshana. You both like science outreach so much, I think you will get along really well". Fast forward few months, I got a call from Darshana asking if I wanted to apply for this Materials Research Society Grant for materials focus outreach. I had seen the call for applications for this grant but had dismissed it thinking I will never get it but when Darshana asked I was hopeful, as our forces joined together were so much more!

Often, we ignore the power and potential of our peer network. As graduate students and early career scientists, the most important connections and relations one makes are those with one's peers. Our contemporary colleagues are the next generation leaders, thinkers and change-makers. With this idea, Vision India: GenY Applied Science Network (VIGYANshaala) was formed in 2016. It is an outreach initiative by a group of Indian graduate students and research professionals based primarily in the US and UK".

Shruti Sharma

Acknowledgment

The authors thank fellow members of VIGYANshaala – Himadri Barman, Vijay Venugopalan, and Aditya Sadhanala for their assistance.

Most of our experiments are based on educational content taken from the following:

Suggested Reading

[1] **The RSC's Learning Chemistry Community,** `http://www.rsc.org/learn-chemistry/`

[2] `https://en.wikipedia.org/wiki/Main_Page`

[3] https://www.cambridge.org/core/journals/mrs-bulletin/article/mrs-fuels-a-panindia-materials-science-education-program-led-by-early-career-scientists/804A0DC787D75C4912BA2EEBB4D6815B