INTERWOVEN

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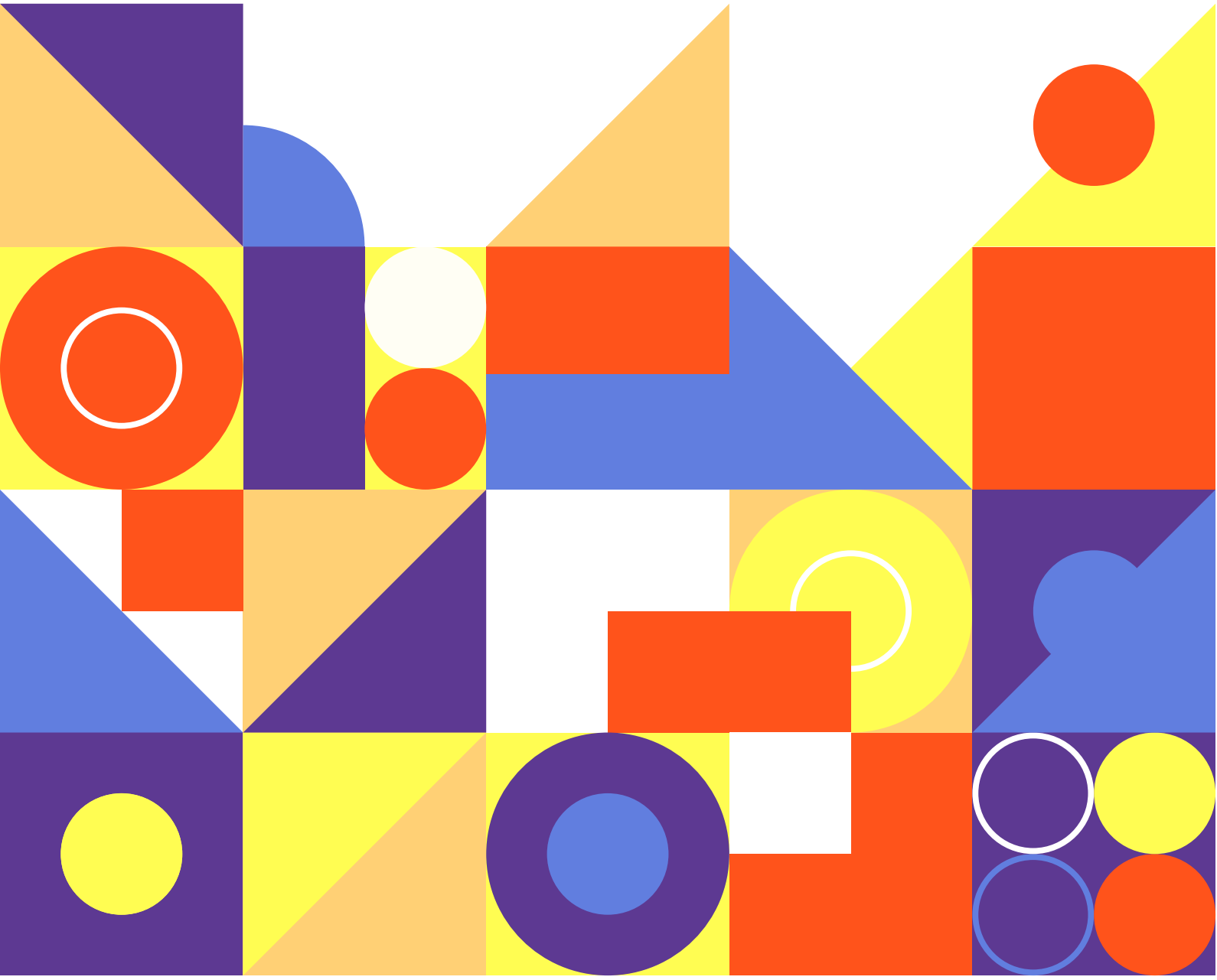
Issue 1 & 2

Special Volume on **Sustainability**



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Interwoven Editorial Board

Sustainability

Sustainability is a non-negotiable goal to be pursued in the present. The concept of sustainability has evolved and will continue to do so as practices about it get contested, experimented with, and implemented. The term got attention, mention, and definition in 1987 in the Bruntland report as "Meeting the needs of the present without compromising the ability of future generations to meet their own needs". The three goals of sustainability were identified as environmental, economic, and social. Cutting across these three goals is the concern over availability and access to natural resources, discriminatory forces influencing it, right to natural resources, and right to quality life- material and non-material.

The very nature of sustainability, thus, demands an interdisciplinary as well as a disciplinary investigation. The three goals of sustainability present a broad framework and points of inquiry into the unpacking of the idea of sustainability. In addition to these three, there could also be other points of inquiry that can be explored and undertaken. The questions in this process appears to be twofold: cognizance and questioning of past and current practices and processes that might have become a barrier to sustainability and potential alternatives to these practices and processes.

Several questions that can be raised here are:

- How far removed are our practices from Nature and its ecosystem?
- Will following Nature and its ecosystem facilitate a restoration of balance and sustainability? If this is the way out, how can present practices be modified to align with Nature and its ecosystem?
- What kinds of advancements in science and technology offer solutions for sustainability?
- What kinds of insights from indigenous knowledge systems offer solutions for sustainability?
- What kinds of socio-cultural, economic, policy, and governance interventions offer solutions for sustainability?

This special issue of the journal on sustainability encourages the publication of original research articles, perspectives, review articles from various disciplines as applied to sustainability. Scholars are invited to publish theoretical, experimental, applied research, documentation, or conceptual papers.

Following are some of the themes on Sustainability:

1. Evolution and changes in the dimensions and facets of the concept of sustainability
2. Waste and waste management, recycling, and upcycling
3. Circular economy, traditional economy, and environment

4. Design for sustainability and vernacular architecture
5. Relationship between language, ecology, and representation
6. Policy and governance and implementation concerning sustainability
7. Education for sustainability
8. Health and Sustainability
9. Livelihood and Sustainability
10. Agricultural issues of sustainability
11. New, clean, and renewable sources of energy
12. Sustainable materials
13. Net zero technology and green engineering
14. Sustainability tools: Measuring and monitoring sustainability
15. System analysis methods, including life cycle assessment and management
16. Sustainable chemical processes
17. Land and aquatic ecosystem maintenance and biodiversity preservation
18. Biomimicry and Biomimetic processes
19. Representation of Nature, environment, and idea of resource
20. Biodiversity, linguistic diversity, and cultural diversity: Indigenous knowledge system and preservation of the environment
21. Population growth and sustainable development (Computational sustainability)
22. Artificial intelligence and Data science for sustainability

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Volume - 7
Issue - 1

Rediscovering Ancient Indian Wisdom: A Path to Sustainable Solutions

Conversation with

Prof. A.V. Ramachandran

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This conversation explores a fascinating intersection of the past and present. Amidst present complex global challenges such as climate change, social inequality, and mental health struggles, there is an increasing call to look beyond only the latest technological advancements. Immense possibilities exist for the quest for answers amongst which the ancient wisdom that has shaped human civilizations for thousands of years offers potentially sustainable solutions. National Education Policy 2020 encourages revisiting and relearning from the Indian Knowledge System. Let us engage in a discovery of ancient knowledge wisdom from the perspective of a scientist with Prof A V Ramchandran.

Prof. Ramachandran is a renowned academic and researcher with decades of expertise in Life Sciences, Zoology, Endocrinology, and Developmental Biology. His pioneering work spans regenerative biology, hormonal programming, and metabolic physiology, significantly contributing to understanding developmental plasticity and reproductive processes. He has received numerous accolades for his research and has mentored many scholars globally. In recent years, he has focused on integrating science and spiritualism holistically.

Jerrin Jacob: Are there specific scientific fields or disciplines that you find particularly helpful in exploring ancient wisdom?

Prof. A.V. Ramachandran: Yes, some scientific fields such as quantum physics or neuroscience provide fascinating guidelines for exploring concepts that resonate deeply with ancient wisdom. Quantum physics for example presents ideas like entanglement which shows how particles can be instantaneously connected no matter the distance between them. This aligns with ancient wisdom or spiritual beliefs around interconnectedness and the idea that everything in the Universe is intricately linked.

Neuroscience also intersects with ancient wisdom especially in how it studies the effects of meditation and mindfulness on the brain. Research has shown that meditation can change the brain's structure, enhancing qualities like empathy and emotional regulation. This scientific evidence validates long-standing spiritual practices suggesting that personal transformation is possible and has measurable effects on the brain.

Jerrin Jacob: Do you think Ancient Indian Wisdom will be helpful to tackle modern environmental challenges?

Prof. A.V. Ramachandran: Absolutely. So, as we know the source of ancient Indian wisdom is deeply found in texts such as the Vedas, Upanishads and Bhagavad Gita which offer significant and valuable lessons for living sustainably in today’s time. These scriptures are not only just old writings, but also important ideas for addressing current environmental challenges. One key principle associated with those texts is Ahimsa or non-violence, which emphasises respecting all forms of life including the environment and, in a way, the entire Universe. Ancient India also practiced sustainable farming methods that reduced harm to nature and valued revered forests that helped protect biodiversity, highlighting a harmonious relationship with the natural world.

Jerrin Jacob: Do any ancient philosophies highlight the importance of balance and responsibility in our interactions with the environment?

Prof. A.V. Ramachandran: Yes, ancient concepts like Rita, Brahman, and Dharma emphasise the importance of balance, unity, and responsibility in caring for the Earth. The Vedas introduced the idea of Rita or cosmic order which shows the delicate balance seen in the Universe. It reminds us of our connection to all living things and the need to care for the Earth.

The Upanishads went deeper and discussed the unity of everything (Brahman), highlighting how important it is to honor that unity through our actions.

Our Holy Book- the Bhagavad Gita serves, is a practical guide for life, emphasizing Dharma or our duties and purposes. It encourages us to fulfill our roles in ways that help everyone which calls for responsible care and a long-term perspective when we interact with the environment.

Jerrin Jacob: In your opinion, what are the Real-World Solutions for the problems we face today?

Prof. A.V. Ramachandran: There are a good number of solutions that we can follow from the ancient world approaches in tackling the current world problems. Firstly, an **Eco-Friendly Economic approach.** The Vedic principle of 'apana,' or 'taking only what is needed,' aligns well with an eco-friendly economy's goals. These traditional practices such as using every part of a plant, support and encourage this idea. Another approach which we can adopt is **Conscious Shopping.** The Bhagavad Gita emphasises moderation (yoga) and letting go (vairagya) encouraging mindful shopping. By practicing 'svadhyaya' (self-study), we can better understand our true needs and reduce our environmental impact. **Appreciation for Nature** is another important approach we can inculcate in our lifestyle. The respect for rivers, trees, and other natural elements in India is called 'gram-devata,' It fosters a strong sense of community and collective responsibility for the environment. This unity is very much essential for addressing global environmental challenges.

Jerrin Jacob: How do you see the role of spirituality in shaping scientific curiosity within a community?

Prof. A.V. Ramachandran: Spirituality brings a mindful awareness and responsibility to scientific practice. It promotes humility in pursuing knowledge, reminding us that science is part of a larger quest to understand life and its mysteries. This perspective encourages all to pursue knowledge for its own sake and in a way that benefits humanity and the planet. By integrating values like compassion, respect, and responsibility, spiritual perspectives can provide a moral compass, helping every one of us to navigate the social and ecological impact of our work in ways that honor the interconnectedness of all life.

Jerrin Jacob: How can we use ancient teachings to address the challenges of the 21st century and create a sustainable future?

Prof. A.V. Ramachandran: Application is the Answer. By applying these ancient teachings in our everyday lives, we can certainly create a future where people and our planet can thrive together. This also means that we should not ignore modern advancements but improve them with our ancestors' wisdom.

As we face the challenges of the 21st century, let us draw from the past to help us build a sustainable future.

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Prof. A. V. Ramachandran is a distinguished academic and researcher with over 56 years of experience in the fields of Zoology, Developmental Biology, Endocrinology, and Reproductive Physiology. He completed his PhD in 1972 at The M. S. University of Baroda, focusing on biochemical and histochemical aspects of tail regeneration in the Scincid lizard, Mabuya carinata. Over the years, Prof. Ramachandran has held several significant positions, including Professor of Zoology since 1988, Head of the Department of Zoology from 1998 to 2008, and Dean of the Faculty of Science from 2003 to 2008 at The M. S. University of Baroda. He also served as the Honorary Director of the All-India Civil Services Training Centre at the university from 1997 onwards. His academic journey includes collaborations with esteemed institutions, including the Cancer Research Institute in Bombay and the Department of Endocrinology at the University of Madras, where he conducted pioneering research in endocrinology and cell biology. He significantly contributed to regenerative biology, reproductive endocrinology, and metabolic physiology. He is recognized for pioneering research on tail regeneration in reptiles, particularly lizards, establishing India as a key centre for regenerative studies. His work on the pineal gland's role in reproductive and metabolic processes, especially in birds and mammals, has also earned him international acclaim. Prof. Ramachandran's research also includes exploring neonatal hormonal programming and its effects on metabolic disorders, such as diabetes, and the concept of developmental plasticity.

He has guided 31 doctoral students, many pursuing global post-doctoral research and academic careers. He has published about 300 research papers with more than 4700 citations, maintaining one of the highest research profiles at The M. S. University of Baroda. His scientific excellence has been recognized with numerous awards, including the International Society of Andrology Award for "Scientific Excellence" in 2001 and the prestigious "Prof. Pera Naidu Govindarajulu Gold Medal" for his career research in reproductive endocrinology. Through his contributions to research and mentorship, Prof. Ramachandran has left a lasting impact on the scientific community.

After retiring from active service in 2008, he has devoted himself actively to his lifelong interest in spiritualism. Having a background in science and being innately drawn to spiritualism, Prof. Ramachandran has been involved in linking the two and establishing scientific spiritualism and spiritual science. He believes that spiritualism and science have been more dogmatic and less pragmatic as they have tended to remain dualistic and on opposite poles. According to him, neither side rationally attempted to end this dualism and integrate it into merged oneness. He strongly believes that consciousness-integrated holistic science and scientifically driven holistic spirituality are not mutually exclusive but mutually inclusive. Prof. Ramachandran has a number of books, some translated and some original scripts, related to these fields.

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Mr. Jerrin Jacob is a seasoned professional with over 8 years of experience in education, counselling, and project coordination. He has worked in various capacities, including as a teacher, a school counsellor, and a project coordinator, before joining Navrachana University.

Mr. Jerrin is a double NUV alumni, who holds a bachelor's degree in computer applications (2009-2012) and a master's degree in social work (2016-2018). His academic interests are reflected in his research during master's on the challenges faced by female students in primary schools in Vadodara. He further expanded his expertise with a Post Graduate Diploma in Guidance and Counselling from Maharaja Sayajirao University in 2021, a Diploma in Hospital Administration from TUV-SUD - ISSD and recently graduated with a Master of Divinity from Carmel Theological Seminary, Trivandrum. Currently, Mr. Jerrin Jacob is currently a Teaching Assistant at the School of Liberal Studies and Education at Navrachana University, Vadodara.

Application of Ferrocement Technology for Construction of Water Storage Containers

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Abstract

The current study is to learn and know about ferrocement technology used in construction. The focus of this work is to design a prototype water storage tank made of ferrocement technology in the laboratory. Ferrocement gives a cost-effective sustainable solution for the design of durable structures to store large capacity of the water. It is required to understand the ferrocement technology in general, working with hands on materials and to understand the construction process by making the prototype for the cylindrical shape water storage tank in the laboratory. Initially, a review of ferrocement technology is given specifically for water storage containers. Using the locally available materials for design and fabrication, the simple technique is used to construct prototype water retaining structures. A small survey on awareness of ferrocement technology in rural and urban areas of Vadodara city is carried out to understand the scenario of use of technology. Cost calculation of larger capacity tanks is also being shown while working on the project.

Keywords

Ferrocement, Sustainable materials, Water tank, Durable structure

Introduction

Ferrocement is a material discovered in 1848 by French engineer Joseph Louis material, used first time for the construction of his boat. It is a versatile material that possesses excellent engineering property including flexural strength, toughness, fatigue, impact and most

important the crack resistance due to fine wire mesh interlocking with cement mortar. It is an innovative composite material in the range of variety of construction materials. It is the material that is before proven to be considered to save cost of the materials and produce low carbon emission. It is proven to be one of the best construction materials for low cost, long lasting, energy efficient system with locally available materials and cheap labor in countries like Africa, Bangladesh, Thailand, Malesia and other Asian countries. The green housing effect of the structures built using ferrocement demonstrates a high standard of energy efficiency rating in the housing construction industry. Various construction panels, and low-cost affordable housing solutions using ferrocement gives the highest level of thermal performance. The applications of ferrocement are not limited to low-cost housing but also the other structures, water tanks, boats, swimming pools, shells roofs, pipelines and thin structures. The resulting product of a ferrocement gives a thin structure with mortar and wire mesh. The thickness of the ferrocement sections ranges from 10 mm to 40 mm and consists of layers of small diameter steel mesh with cement mortar. The structural behavior of ferrocement is uniquely different than conventional reinforced concrete sections in terms of strength and performance. Due to its unique property ferrocement has potential applications that separates it from a class of innovative building materials. Additionally, it requires minimum skilled labor and utilizes locally available materials. Its simplicity in construction procedure, easily moldable in various structural forms and economy are the prime attraction and popularity. In the past, attempt for experimental and numerical analysis of ferrocement of large size in Brazil is studied[1]. The literature shows the improvement in the current practice of design of ferrocement tanks. Detailed design and construction of ferrocement tanks are given in literature2 where the authors have added silica fumes to reduce the content of the cement. Comparative study of hybrid design of ferrocement tanks with conventional reinforced cement concrete material is shown[3]. Ferrocement design involves a large capacity of 1000 m^3 including hyperboloid of revolution in walls to improve structural behavior[4]. The testing and test methods are developed for ferrocement materials are given in the litrature[5].

American Concrete Institute code ACI PRC – 549 code[6] gives the information on the design guidelines, mechanical and physical properties of ferrocement. Also, it provides information on various testing standards to be performed on ferrocement specimens. Code describes data for choice of materials, for example, guidelines for choosing sand is cited in table 3.1, common

types of sizes available for steel meshes used in ferrocement are cited in table 3.2, minimum values of steel wire mesh yield strength to be adopted in designing ferrocement components are cited in table 4.1, it cites various stress strain relationship obtained on the tested specimen in flexure, tension and compression for both steel wire meshes and mortar specimens. Also, Standard test methods for the ferrocement material have been described by many researchers. Scientific experiments and verification for the various tests have been given and provided the measurements of deformation and cracking for compression, axial tension and tension in bending as well as bending.[5]. Behavior of ferrocement water pipes as an alternative to steel water pipes have been studied[7]. In the article, pipes are cast and subjected to experimental testing to evaluate various properties such as cracking patterns, tensile and compressive stress, failure mechanism, elastic stiffness and energy absorption properties. Experimental programs to evaluate flexural performance of ferrocement focusing on high performer mortar have been studied[8]. Experimental results are given related to various flexural properties such as modules of rupture, elasticity, flexural toughness. Flexural behavior of septic tank wall panels reinforced with glass fibers are given[9]. Load deflection responses are given based on various glass fibers added in different volume fractions. Water leakage from water tank walls and base made of reinforced concrete and masonry tanks is a problem which is faced by the practiced engineers very frequently. Mostly, epoxy applications to repair this is a tedious task. In this comparison, ferrocement is a material known for its high impermeability and ease in application on any surface[10]. Experimental work related to seismic retrofit material for masonry walls is carried out[11]**.** Numerical study is also mentioned on the behavior and performance of composite and hybrid ferrocement tanks[12]. Ferrocement construction techniques for water tanks are studied by many researchers. The present work adopts some of the basic and feasible features suitable for construction of small tanks [2, 3, 4]. Typical load-deflection behavior of fiber-ferrocement sheet and conventional ferrocement arc shown[13]**.** Ferrocement is also used as a material which has numerous retrofitting applications and gained interest during recent times [14,15].

Force transfer mechanism

The force transfer mechanism of the ferrocement tank is qualitatively explained in this section. As in the water tank, water pressure acts on the walls and floors of the tank. The thickness of the walls should be such that it does not produce cracks generated due to the excessive hoop stresses which are prominent in the walls due to the water pressure. Hoop stresses are termed

as forces on the cylinder which are acted in all directions including circumferential and axial direction inside the thickness walls of the tank and happen usually in the case of cylindrical body. Hoop stress is directly proportional to the water pressure, radius of the tank and inversely proportional to the thickness of the wall. Because of tank's curved shapes, it resists the stresses due to membrane stresses which gives primary action of force transfer mechanism to the wall. Such membrane stresses are much higher as compared to smaller tanks due to high water pressure as water pressure depends on the height of the tank. Fig. 1 shows the hoop stresses in the walls of the cylinder.

Figure 1: Hoop stress σ_1 and axial stress σ_2

Behavior of wire – reinforced mortar

It is known that concrete and mortar material are both stronger in compression and weak in resisting tensile load. Also, structures constructed using such materials are subjected to tensile loads mostly in practice. Additionally, the structure will bend and fracture without warning and develop fine cracks before failure. It is a brittle failure that can occur. Conventional reinforced cement concrete is used to overcome this difficulty by allowing tensile loads to be taken by reinforcements in the concrete. However, it is a complex phenomenon that how much a reinforcing bar is contributing to controlling the tensile cracks in the practice. This is the reason why the working stress method is used in designing RCC water tanks to prevent cracks in the structures which give conservative results and provide better factors of safety. Water tanks are subjected to high tensile hoop stress in the walls due to water pressure. In ferrocement material, if the wire mesh is densely distributed with the mortar, it allows to arrest the cracks produced due to critical tensile stresses generated in the walls. Also, if cracks are generated, those cracks are not wide enough to enter the wire mesh and support reinforcements to have corrosion in them.

In view of the literature, there have been successful attempts to design and construction large sizes of ferrocement water tanks. The objective of the present work is to understand the ferrocement technology, working with materials and gain hands on experience with the materials by constructing a very small size water container of cylindrical shape and size of nearly 3 liters. The work is carried out by a group of interdisciplinary students with the help of laboratory technician on social innovation KHOJ project conducted at Navrachana University. The aim is to introduce undergraduate students to work on a project and be familiar with the technology which is in demand in today's world of sustainability and sustainable materials. While working on the project, students learnt the simple techniques of construction, working with hands on materials of ferrocement and to know how efficiently the technology can be utilized as an affordable alternative to plastic and other artificial material tanks.

Materials and methods

The basic materials used for ferrocement construction are as follows (1) wire mesh, (2) cement (3) sand (4) mild steel rod. Steel rods are used to support the wire mesh and used as skeletal reinforcement. As mentioned previously, unlike other construction materials, ferrocement requires minimum labour and utilizes locally available materials. A detailed method and construction procedure is mentioned in the following section of the article.

Material Specifications

Wire mesh

Wire mesh is the primary important component in ferrocement technology. Wire mesh can be constructed in various shapes such as square, hexagon, or zigzag pattern, are usually 0.5 mm to 1 mm in diameter and, spaced at 5 mm to 25 mm apart. Wire mesh is manufactured in such a way that it is handled properly and bend easily for achieving the sharp corners. The basic function of the mesh is to provide and act as support to the mortar mix. It is important to know that wire mesh withstand mainly the tensile stresses of the structure which mortar is not able to withstand. In the present case mesh having square woven is used having 1 mm diameter with 5mm spacing is used. (Fig. 2).

Figure 2: Chicken wire mesh used in the project.

Steel rod (skeletal)

The main framework of the structure of steel bar is used on which the layers of meshes are laid. The rods are spaced with equal distance of 6 cm, centre to centre. Since cylindrical tank is used, the cage is made of total diameter of 15 cm and height of 30 cm for the prototype model. (Fig. 3). Inner steel skeletal after casting is shown in Fig. 4.

Figure 3: Steel Skeletal

Figure 4: Inner Steel Skeletal

Cement

Ordinary Portland cement, which is most common, is used in the present project work. (Fig. 5).

Cement Mortar

It is very important to mix the mortar ingredients water, cement and sand in such a way that it gives the consistency of proper strength. Material used for cement mortar is used is shown in Fig. 5. Imperviousness of ferrocement can be obtained by w/c (Water to cement) ratio less than 0.4.

Figure 5: Material used for ferrocement for cement mortar.

Sand

Utilised clean and dry sand that is well-graded, consisting of particles with varying sizes.

Cement-to-Sand Ratio

The standard volume ratio of cement to dry sand is 1:3. To achieve this specific ratio, a bucket can be employed for precise measurement of sand and cement proportions. It's important to note that damp sand from a stockpile occupies more volume than when it's dry. Considering the bulking of cement, it is advisable to utilise a complete bag of a known volume un cubic meter. In the entire process of mixing, sand and cement were mixed uniformly. After that water is added part by part in order to achieve the required workability of the mortar mix.

Water-to-Cement Ratio

The water-to-cement ratio significantly influences the ultimate strength of the mortar. An optimal ratio falls within the range of approximately 0.4:1 to 0.5:1 (water to cement by weight), corresponding to 20 to 25 litres of water per 50kg bag of cement.

Methods of Construction

The ferrocement structure was fabricated in the Civil Engineering Material Testing Laboratory of Navrachana University. As per main outer dimensions of the structures, the amount of longitudinal and transverse direction steel was separated and cut for various segments. Once the steel was cut to the desired length, the skeletal frame was constructed as per the shapes of the structures, which is, cylindrical tank in the present case. Connection between steel bars was made by welding and through steel ties. Following the shape of the structures, two layers of wire mesh - one inside and one outside of the steel frame, were placed and tied with steel wire maintaining the thickness as minimum as possible, which is, a crucial and challenging component in the entire construction process. Since this is the prototype work of student's project work, it is limited till the construction with the basic ingredient and plastering work was not carried out. Primary objective of the present study is to obtain the hands-on experience with the materials of prototype made by the students.

In this approach, a sturdy wire frame is needed. Surrounding sturdy frame, flexible mesh-like 'chicken wire,' is wrapped. To make the prototype on this work, students applied a layer of mortar on both the inside and outside of the tank. While one student worked on one side, the

other student worked on the other side holding a plastering float to keep the mortar in place and compacted without it slipping through the mesh. Since this is a smaller prototype the formwork of wood was not needed. Final product is seen in Fig. 6.

Curing

The main objective of curing is to keep the cement mortar in moist and saturated condition and to promote the hydration of cement. There were many options for the curing, however, jute mat was used, and it was kept for about 5 days. The prototype structure which is a cylindrical tank is of capacity of about 3 litre capacity. It is shown in Fig. 6. The cylindrical tank was easily shifted from one place to another as it was light in weight. Depending on the capacity of water to be stored in the tank, the structure size can be expanded to 5 to 8 litres for household and domestic purpose. So larger tank can be built based on the capacity of water to be stored.

Figure 6: Final prototype of ferrocement cylindrical tank

Due to flexibility in forming shape, the tank can be made of any desired shape. In the present work, cylindrical shape which is chosen as it is convenient while constructing the tank. The schematic of entire construction steps with material specification are shown in Table 1. Also, Fig. 7 shows the images of various construction steps.

Sequence	Tasks
1	Decide the dimensions according to the size in litres to store water
2	Decide depth and diameter (300 mm, 150 mm)
3	Lay out plan and drawing
4	Calculate the material quantities required as per the size of the tank
	Material specification
	Cement (Standard ordinary Portland Cement)
	Sand (Clean, dry and well graded)
	Wire mesh (0.5 mm to 1 mm in diameter and, spaced at 5 mm to 25 mm apart)
	Steel rods (6 mm to 8 mm)
	Tie wires (1 mm)
	Water to cement ratio (0.4), Clean Water
5	Prepare cement mortar mix (The standard volume ratio of cement to dry sand is 1:3)
6	Prepare base of the tank (15 mm to 20 mm)
7	Lay out wire mesh with rods and tie based on the thickness (Thin shells are designed between10 mm to 15 mm)
8	Apply cement mortar from outside through in such as way wire mesh is covered
9	Apply curing as per the standard
10	Store

Table 2: Schematic of construction stages with material specifications

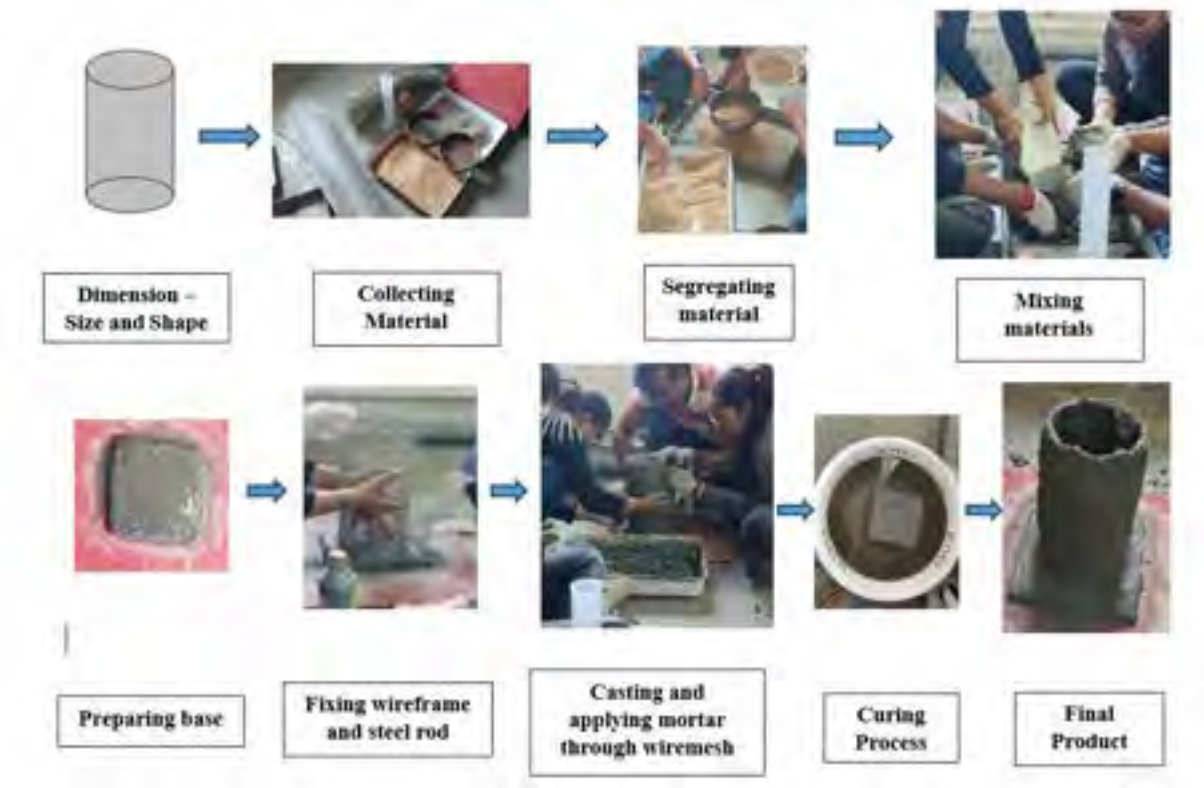

Figure 7: Construction Stages of the process

Promotion effort for sustainable solution

Also, promotion effort was made for creating awareness of ferrocement technology as one of the storage sustainable solutions. A survey was conducted by students in rural and urban localities in Vadodara to learn and understand the conditions and requirements for water storage. Responses were received from civilian surveys from both rural and urban areas on percentage of residents that have considered using Ferrocement water storage. The chart shown in Fig. 8 shows an observation that very few communities in urban and rural areas in Vadodara city in Gujarat were aware of such technologies. The primary and important related to the present work survey questions are listed in Table 2. The first two questions are related to the chart shown in Fig. 8. Fig. 9 shows the primary source of water being used by communities is municipal water supply (question 3 in table 2), however, little community is aware about rainwater harvesting and knowing the techniques available. From Fig. 10, most communities depend on the water tank available in society rather than storing water in drums as question 4 in Table 2. Fig. 11 shows the type of water treatment the community prefers before using it. It is mentioned as question 5 in table 2. From the survey results, it is understood that special efforts and awareness programs are required to be pressed upon to know about sustainable technologies, storing water in emergencies especially during calamities and optimum usage of water by storing it and using it in small quantities to save the resources.

Question Number	Question
1	Are you aware of ferrocement water storage systems?
2	If yes, have you considered using ferrocement for water storage?
3	What is your primary source of water?
4	How do you store water at home?
5	What methods do you use for water treatment?

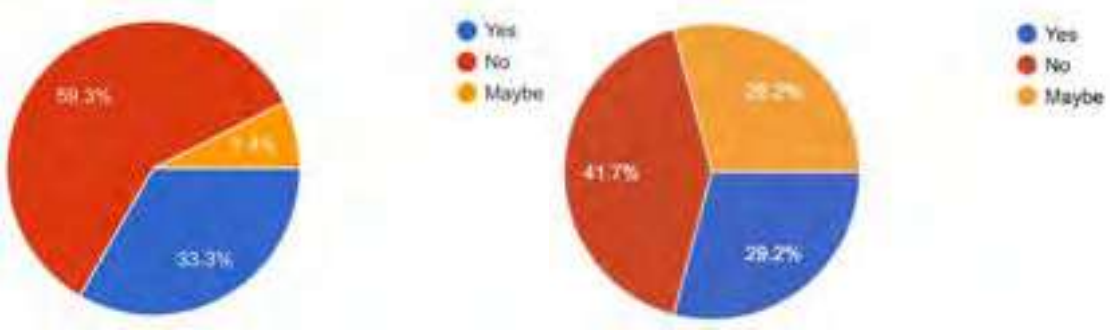

Figure 8: Survey on awareness of ferrocement technology

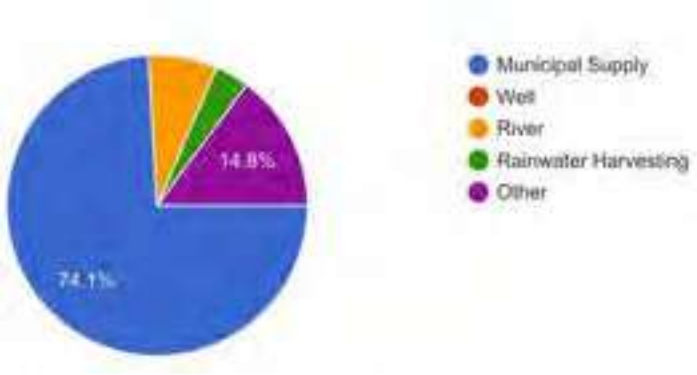

Figure 9: Survey on primary sources of water

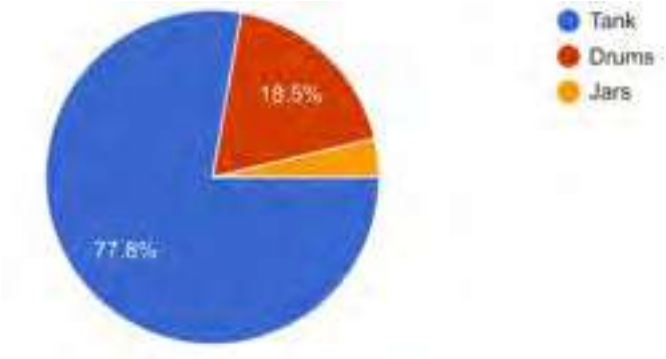

Figure 10: Survey of water storage devices

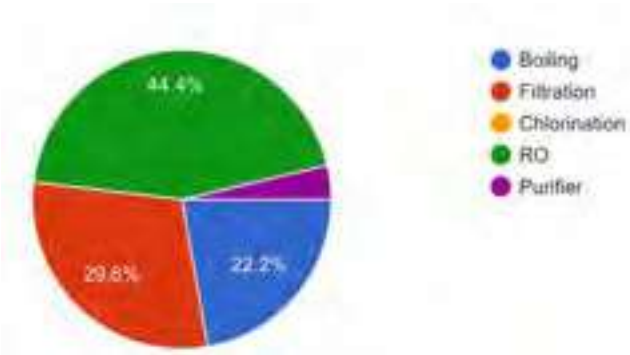

Figure 11: Method of water treatment

Sr. No.	Material	Cost in INR
1	Weld mesh 7.00 m² at INR 8.85/ m²	61.95
2	Chicken mesh 13.0 m²at INR 26 /m²	338
3	6 mm M.S rod 0.7Kg at INR 43 /M.T.	30.1
4	Cement 2.2 bags at INR 385 /bag	847
5	Sand 0.147m² at INR 42/ m²	6.01
6	Labour L.S.	40
7	Welding of fins for outlets and scour	10
8	Oil, grease, mixer, etc. L.S.	12
	Total	**1344.95**

Table 3: Cost of ingredients used in Ferrocement

The cost calculation is done to arrive at the cost of per litre tank. Table 3 shows the cost of various ferrocement materials estimated based on cost of materials and labour. The cost mentioned above are calculated as per 800 litre capacity. The purpose of cost analysis is to show that it is a cheaper material as compared to other costly material such as timber, steel etc.

Conclusion

The prototype of ferrocement cylindrical tank has been made in the laboratory. Using a simple construction process which utilizes the readily available materials, it is shown that ferrocement is easily handled material which can be moulded in various shapes. It also gives structurally sound product which carries water without any cracks arising in the thick walls of the tank. It is a good alternative source of storing the water in hygienic condition to the tank made of plastics. From the field survey carried out, it has been found that ferrocement technology is not known to the community in villages as well as urban areas. A recent study by the Gujarat Ecological Society (GES) has revealed that the quality and quantity of groundwater is affected due to contamination of total dissolved solids as well as the lower position of water table and deeper bore wells respectively. A major step in the direction of water harvesting is necessary to reduce dependence on the condition of ground water tables only in such a situation, it is also important to provide a sustainable solution to water scarcity as well as supply of good quality clean water especially in the rural areas of the city. Ferrocement material is a sustainable technology and a good way to store water. A cost analysis and material methods have been developed to construct the small cylindrical tank in the laboratory. Cylindrical ferrocement water storage containers, a structure identified in the present work, can be constructed for

domestic larger capacity water storage using ferrocement technology. It is understood that the observations made from this work will carry new concept of ferrocement technology used for the construction. It is a low-cost technology yet gives strong and sustainable structures for domestic rural and urban water storage uses.

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Glossary

Ferrocement – Ferrocement is a building construction material made of thin cement layer reinforced with steel wire mesh

Cement – cement is a binder, a chemical substance used for construction that hardens and binds other materials to bind together

Cement Mortar – It is a mixer of cement, sand and water used to bind various blocks in construction such as bricks. It is also used for plastering.

Reinforcement – It is a steel rod used with concrete in construction for providing tensile strength in concrete

Concrete – It is a binding material which is made of mixing broken stones, sand, cement and water

Wiremesh – It is a two-dimensional lattice made from two or more smaller diameter metallic wires

Cylinder – It is a long solid body having two parallel side along the axis with a circular cross section

Cylindrical Shell – It is a thin structural element shaped in a cylinder defines relatively having lesser thickness to its diameter has widely usage in industrial applications

Hoop Stress – It is the internal intensity of the force distributed around the circumference of the pipe due to pressure

Circumferential Stress – It is same as hoop stress

Axial Stress – It is the intensity of the forces distributed along the axis of the solid body

Water Cement Ratio – It is the ratio of the mass of the water to the mass of the cement added to the concrete. The typical water cement ratio varies between 0.40 – 0.60 for different mixes of concrete

Cement to Sand Ratio – Example 1: 3, It is the proportion mix indicates one part of the cement and 3 parts of the sand as per the ratio given

Sustainable Solution – It is the innovative practices of the technologies that provides the long-term solution to improve upon social, economic and environmental impacts.

Curing – Curing is the process of maintaining adequate moisture in concrete in order to aid cement hydration process to gain strength in the concrete

Hydration – Hydration of the cement refers to the chemical reaction that occurs when water is added to cement helps to obtain the hardened mass of the concrete.

Prototype – A first preliminary basic version of a device from which higher versions are formed and developed

Low-Cost Technology – They are the design principles used for the development of solution replaces costlier version by not compromising the quality of the technical features

Compressive Stress – It is the maximum intensity of the force distributed over the body or material that can support without failure when it is being compressed

Tensile Stress - It is the maximum intensity of the force distributed over the body or material that can support without failure when it is being stretched

Pressure – It is the physical force exerted on the object and vice versa

Structural Behavior – It is the phenomena, the way a structure or a body responds to the external forces. It can be measured in the form of internal forces or the displacements

Forces – It is the physical action of the push or pull on an object

Retrofit – It is the process of modifying the part of the body for the improvement and its performance

Force Transfer – It is the mechanism of transferring force from one part of the body to another part through its connection or joints

Mild Steel – It is the low carbon steel which is more flexible compared to other class of steel suitable for many industrial applications

Estimation of Landfill Volume of Municipal Solid Waste Quantity in India using Artificial Neural Network

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Abstract

This study examines the application of Artificial Neural Networks (ANN) to predict landfill requirements for solid waste disposal. As urbanization and population growth accelerate, effective waste management becomes extensively critical. Traditional landfill forecasting methods often struggle with the non-linear and complex nature of waste generation models. ANN, known for its ability to model non-linear relationships, is used to improve prediction accuracy. We developed an ANN model using historical data on solid waste generation, population growth, economic indicators, and other relevant factors. The model was trained and validated using a large metropolitan data set, ensuring that it captures variation and trends in waste generation. The results show that the ANN model significantly outperforms traditional linear regression methods and provides more accurate and reliable predictions about landfills. The sensitivity analysis revealed that population growth and economic activity are the most influential factors in forecasting waste production. The study says ANN is an effective tool for urban waste management planning and helps to ensure adequate landfill and sustainable waste management.

Keywords

Artificial neural network, solid waste disposal, landfill prediction, waste management, urbanization, predictive modeling.

Introduction

Municipal solid waste (MSW) is described as solid and semi-solid garbage generated by a country or states by daily basis. Generation and disposal of municipal solid waste is one of the biggest challenges in India which requires effective management of solid waste. This is a complex issue that requires careful consideration and innovative solutions. India is the 10th biggest country generates municipal solid waste from different states and cities[1]. The municipal solid waste mainly generates from Residential, Commercial, Industrial, Institutional, Agricultural, Construction, Demolition. Municipal solid waste generation is based on Population of country. Municipal solid waste is highly effect to climate like water pollution, air pollution and mainly land pollution and creates health and other issues. Generally municipal solid waste quantity expresses or shows in (Kg/capita/day) or (MT/D). For solid waste Generation or solid waste disposal Landfill area calculation is based on population of state or city, and daily basis solid waste generation.

Today, the main challenging task consists of the sequential stages of collection, transportation, and disposal of municipal solid waste. Solid waste management is significant problem since increasing population and increasing consumer demand is directly relating to increase in solid waste quantity each year. Municipal solid waste highly impact on the environment, legal, economic aspects. These problems arise from lack of data and information and the adoption of advanced modelling techniques. Today smart cities are adopting advanced techniques like Artificial Neural Network (ANN) by predicting waste generation and managing solid waste required area for dumping the garbage. ANN gets high attention because of easy to use and good performance network system. Artificial Neural Network gives precise results of prediction of generation of solid waste rate.

Study area

India is the diversify country. India is the 2nd largest country in Asia based on area which is 3,287,263 square kilometers. India Co-ordinates are 20.5937° N, 78.9629° E. There are 28 states and 4000 cities and towns in India[3]. There are 1874 municipalities with the population of 141.72 crores on Average. there are 3100 landfill presents for dumping solid waste in across India.

Figure 1: MSW Generation in India[9]

Artificial Neural Network

An Artificial Neural Network (ANN) is a computer programming crafted after biological neural networks, such the human brain. The artificial neural network is the main element in artificial intelligence system. Artificial neural networks are constructed of artificial neurons. These units are grouped into layers, which together form the framework of the whole artificially generated neural network. A layer may consist as little as a couple units or as many as millions of units, based on the complexity required for neural networks to detect hidden patterns in the data set. In general, a neural network is made up of three layers: input, output, and hidden[5]. The input layer collects inputs from the outside world that the neural network is supposed to analyze or learn. This data is passed via several layers that are hidden, which transform the input into beneficial data for the output layer. Furthermore, the output layer constructs an artificial neural network's response to the given input data. The majority of neural networks have units that link between layers. Each of these links has a weighting system that determines the influence of one unit on another. As data changes from one unit to another, the neural network gains increasing knowledge about the data, ultimately culminating in the response from the output layer[6]. The artificial neural network (ANN) is capable of performing complex calculations in a timely manner. The artificial neural network encompasses the interconnection of multiple neurons and hidden layers. Uses of ANN: Artificial neural networks find application in social media, such as Facebook's "People You May Know" feature, to propose potential real-life friends based on profiles, interests, and connections. Facial recognition

serves as another application, linking reference points on an individual's face to existing databases. E-commerce platforms like Amazon and Flipkart employ personalized marketing strategies to recommend products based on previous browsing behaviors. This technology extends to modern marketing sectors, including bookstores, movie services, and hospitality websites, employing artificial neural networks to tailor campaigns accordingly.

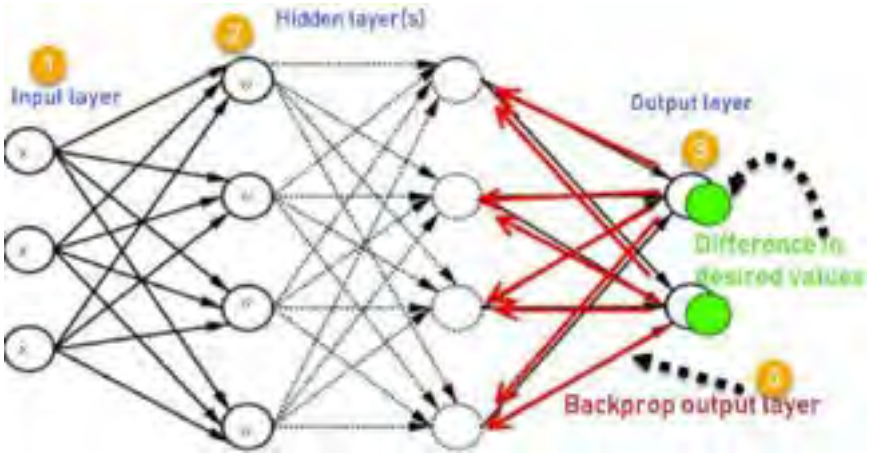

Figure 2: **Typical layout of artificial neural network**

Methodology

To estimate the landfill extent of municipal solid waste (MSW) the use of Artificial Neural Networks (ANN) in India, a scientific technique is needed that mixes statistics collection, version education, validation, and prediction[4]. Here is a step-by-step approach:

1. **Data Collection:**

Gather applicable and great statistics for the education and validation of the ANN version. The key statistics reasserts may include:

- **Historical MSW Generation Data:** Collection of every day or month-to-month waste era statistics from municipalities.
- **Waste Composition**: Breakdown of organic, recyclable, and inert waste types.
- **Population Data:** City-sensible populace and demographics influencing waste era.
- **Landfill Data:** Existing landfill potential, area, height, and extent statistics from municipal authorities.
- **Waste Collection Efficiency:** Information on the gathering methods, performance rates, and recycling efforts.

- **Socioeconomic Data:** Urbanization, earnings levels, and life-style elements influencing waste era.

Sources: Local municipalities, Central Pollution Control Board (CPCB), or Ministry of Housing and Urban Affairs (MOHUA).

2. Preprocessing the Data:

- **Normalization/Scaling:** Waste statistics can range significantly in magnitude. Scale the enter features (e.g., waste extent, populace) so that they have got a comparable range, frequently among zero and 1, to assist the ANN carry out better.
- **Data Cleaning:** Remove outliers or lacking values from datasets to make certain easy education.
- **Segmentation:** Break the statistics into education, validation, and trying out sets (typically 70%-15%-15%).

3. Feature Selection:

- **Independent Variables (Inputs):** Waste era rates, populace size, waste composition percentages, socioeconomic elements, and recycling rates.
- **Dependent Variable (Output):** The expected landfill extent required over a period.

4. Model Selection and ANN Design:

- **Network Architecture:** Use a Multi-Layer Perceptron (MLP) with an enter layer, hidden layers, and an output layer. The quantity of hidden layers and neurons may be optimized through experimentation.
- **Activation Functions:** Use activation features like the neural network employs ReLU (Rectified Linear Unit) activation functions in its hidden layers and a linear activation function in the output layer to make certain correct non-stop variable predictions.
- **Loss Function:** Use Mean Squared Error (MSE) because of the loss characteristic because that is a regression problem.
- **Model Training:** Train the ANN the use of the accrued and reprocessed statistics. During education, the version learns to map the enter features (waste era statistics, populace, etc.) to the goal output (landfill extent).

- **Backpropagation:** Adjust the weights and biases the use of backpropagation to reduce the loss characteristic over iterations (epochs).

5. Validation and Testing:

- After education, validate the version with the validation set to fine-song hyper parameters consisting of the gaining knowledge of rate, quantity of layers, and neurons in every layer.
- Test the skilled ANN at the check set to assess its overall performance the use of metrics consisting of Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and R^2 score.

6. Model Deployment:

- Once the ANN version gives first-rate predictions, it is able to be deployed for forecasting landfill volumes. The version can expect the destiny landfill necessities primarily based totally on forecasted waste era patterns.

7. Scenario Analysis:

The ANN version may be used for state of affairs evaluation:

- **Population Growth Projections:** Analyze the effect of populace increase on landfill necessities.
- **Waste Management Strategies:** Evaluate how distinctive waste diversion strategies (recycling, composting) lessen landfill extent.

8. Software and Tools:

- Python with libraries like TensorFlow or PyTorch for constructing and educating the ANN.
- **Data Analysis Tools:** Pandas, NumPy, and Matplotlib for statistics processing and visualization.
- **GIS Software (optional):** For spatial evaluation of landfill site capacity and waste distribution patterns.

9. Validation Against Real-global Data:

- Validate the predictions in opposition to real landfill extent statistics from towns in India to make certain the version's reliability and accuracy.

Experimental Work

This study is to predict landfill area required for municipal solid waste dumping in 2026. Rapid increase in population rate led to higher municipal waste generation. Improper waste management system are major reasons for requirement of larger landfill areas. This paper discusses prediction the landfill area required based on waste generation and treatment given.

An ANN is composed of three layers: the input layer, the hidden layer, and the output layer. In this research the data has been taken from Central Pollution Control Board (CPCB) website[5]. The data is given in APPENDIX-1. And the data is year 2020-21. Various states of India have been taken for the study. Here, waste generation rate of a particular state, amount of waste treated and landfilled waste data has been collected and trained on ANN.

Waste generation data: Past data on the amount of waste generated per day, month, or year.

Demographics: Information about the population of the landfill, as waste production is often correlated with population size.

Economic data: economic indicators such as GDP, as economic activity affects waste production.

Seasonal and Weather Information: Seasonal trends and weather conditions that may affect waste production.

Information on Operational Landfills: Information on landfill capacity, usable area and operational aspects.

Data pre-processing Prepare the collected data for ANN training: Normalization: Scale the data to an appropriate range for the ANN (typically between 0 and 1 or -1 and 1).

Missing values: Handle missing data using interpolation, averaging, or other appropriate methods. Selection of Characteristics: Identify the most important characteristics of the model (e.g., population size, economic indicators, seasonality).

Model design the ANN architecture: Input layer: The quantity of neurons is equivalent to the number of inputs. Hidden layers: Specify the quantity and dimensions of hidden layers. Common practices involve experimenting with various configurations (e.g. one to three hidden layers with differing numbers of neurons). Output layer typically consists of a single neuron that signifies the predicted volume of garbage. To summarize, data from 35 states in India is compiled. Following data preprocessing and partitioning, we formulated an ANN with: Input layer: 3 neurons (denoting 3 input functions) Hidden layers: 3 layers containing 6 Hidden Nodes. Output layer: We trained the model utilizing a learning rate of 0. 01, comprising a set of 35 values. Utilizing this model, we subsequently projected the Landfill area necessary for

the disposal of municipal solid waste in 2026, which assisted in the planning of landfill management capacity and the adjustment of operations.

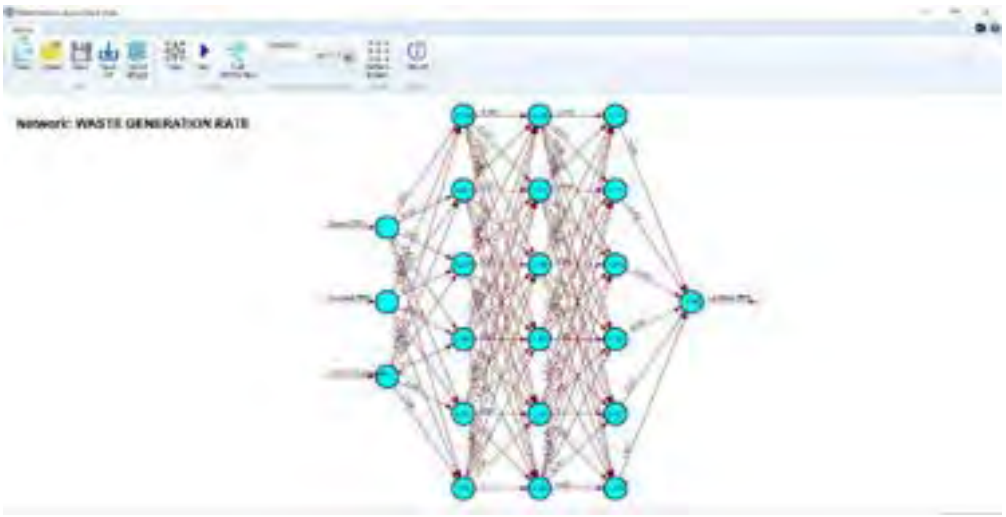

Figure 3: Artificial Neural Network Training for Future Prediction of Landfill.

Results and Discussion

In India 59 cities 35 metro cities and 24 state. today India is the largest country in population. Municipal solid waste Management is biggest task for India in today's time. The CPCB 2021 municipal solid waste data based on this prediction has been performed on NProcessors software for the next 2 years[8]. Artificial Neural Network was used to predict landfill on depending upon the solid waste Generated and Treated the solid waste. The current error is 0.019 and the network type is Feed forward back propagation. After applying Artificial Neural network, we get the predicted values. And then plot the Predicted Landfill values in scatter graph and get R^2 (Co-officiant of Regression) value is 0.8355.

Landfill (TPD)	**Predicted Landfill (TPD)**
27.5	61.863
51.55	62.592

Table 2: Predicted Value from ANN

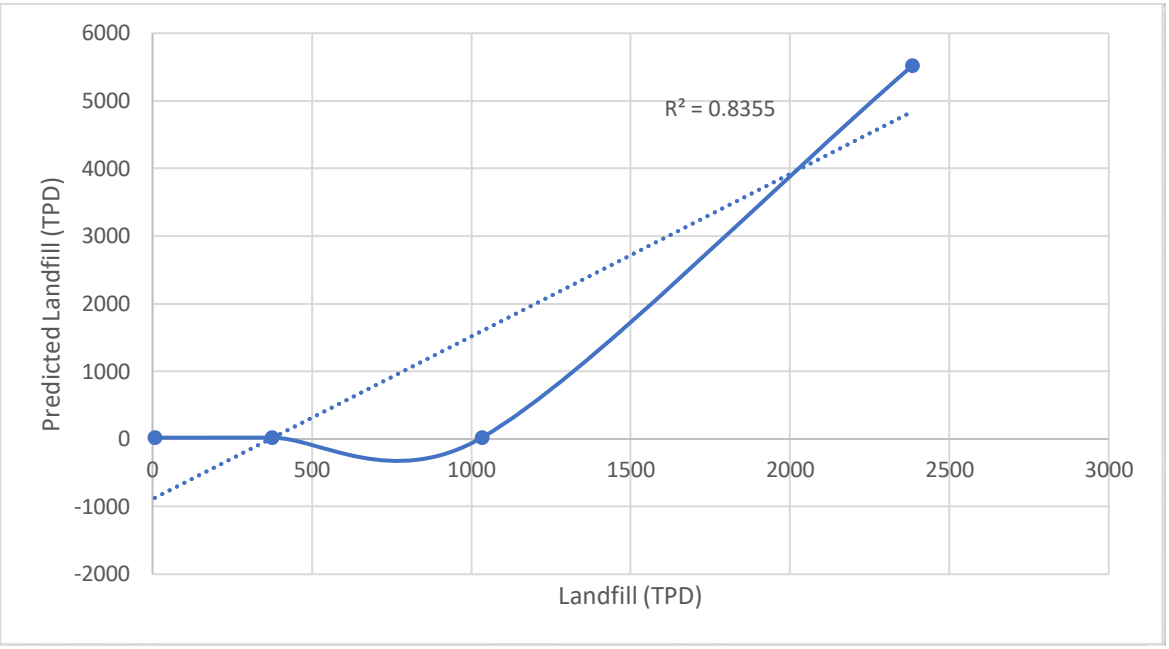

Figure 4: Graph of R^2 (Co-officiant of Regression)

Conclusion

In conclusion, an experimental approach to using ANN for landfill solid waste forecasting involves careful data processing, model design, training, evaluation, and deployment. When properly implemented, it provides accurate forecasts that can significantly improve landfill management and planning. Overall, the application of ANNs to MSW landfill forecasting represents a forward-looking approach that can significantly promote sustainable waste management and help municipalities manage waste more efficiently while minimizing environmental impact.

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APPENDIX – 1[7]

SI No	State	Solid waste generated (TPD)	Collected (TPD)	Treated (TPD)
1	Andhra Pradesh	6898	6829	1133
2	Arunachal Pradesh	236.51	202.11	0
3	Assam	1199	1091	41.4
4	Bihar	4281.27	4013.55	0
5	Chhattisgarh	1650	1650	1650
6	Goa	226.87	218.87	197.4
7	Gujarat	10373.79	10332	6946
8	Haryana	5352.12	5291.41	3123.9
9	Himachal Pradesh	346	332	221
10	Jammu & Kashmir	1463.23	1437.28	547.5
11	Jharkhand	2226.39	1851.65	758.26
12	Karnataka	11085	10198	6817
13	kerala	3543	964.76	2550
14	Madhya Pradesh	8022.5	7235.5	6472
15	Maharashtra	22632.71	22584.4	15056.1
16	Manipur	282.3	190.3	108.6
17	Meghalaya	107.01	93.02	9.64
18	Mizoram	345.47	275.92	269.71
19	Nagaland	330.49	285.49	122
20	Odisha	2132.95	2097.14	1038.31
21	Punjab	4338.37	4278.86	1894.04

22	Rajasthan	6897.16	6720.476	1210.46
23	Sikkim	71.9	71.9	20.35
24	Tamil Nadu	13422	12844	9430.35
25	Telangana	9965	9965	7530
26	Tripura	333.9	317.69	214.06
27	Uttarakhand	1458.46	1378.99	779.85
28	Uttar Pradesh	14710	14292	5520
29	West Bengal	13709	13356	667.6
30	Andaman and Nicobar Islands	89	82	75
31	Chandigarh	513	513	69
32	DDDNH	267	267	237
33	Delhi	10990	10990	5193.57
34	Lakshadweep	35	17.13	17.13
35	Puducherry	504.5	482	36

Table 1: - Solid waste generation and Treated data in (TPD) (data= Year- 2020-21)[2,3]

Retrieved from https://cpcb.nic.in/uploads/MSW/MSW_AnnualReport_2020-21.pdf

Glossary

Solid Waste Management- Typical steps to be followed from waste generation to disposal in a scientific manner.

Landfill- An ultimate location for disposal of solid waste in a scientific way without polluting other natural resources.

Artificial Neural Network- A programming language of series of networks which behaves like human brain.

Landfill prediction- Forecasting of future space requirement for disposal of solid waste into the ground.

Digitalization in Education for Sustainable Development: A Pathway to Achieving SDG4 and NEP 2020

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Abstract

This article explores the intersection of sustainability in education, digitalization, and the quality of higher education, with a particular emphasis on socio-cultural, economic policy, and governance interventions. The contribution of these factors in the achievement of Sustainable Development Goal4 (SDG4), National Education Policy 2020 (NEP 2020), Gross Enrollment Ratio (GER), and Viksit Bharat 2047 have been explored. The article highlights the evolving concept of sustainability and its interdisciplinary nature, emphasizing the need for educational institutions to adopt digital solutions to meet present and future needs without compromising quality. India aspires to achieve its vision of becoming a Vishwa Guru by achieving 50% enrolment in higher education by 2035 and 100% for Viksit Bharat, thereby moving towards universalization of higher education. With the largest population and significant young demographic dividend, the traditional educational ecosystem faces huge pressure to meet the growing and diverse demands of the youth. The inability of the conventional system to ensure both quality and equity in higher education is creating a pressing need for alternate education systems.

Keywords: Sustainable Development, Quality Education, Digitalization in Higher Education, NEP 2020

Introduction

Education for sustainable development (ESD) seeks to balance human and economic well-being with cultural traditions and respect for the world's natural resources. It emphasizes aspects of learning that enhance the transition towards sustainability, education for culture of peace, health education, gender equality, respect for human rights, inclusive education, citizenship education, population education, and education for safeguarding and managing

natural resources. ESD must explore the economic, political, and social implications of sustainability, encouraging learners to reflect critically regarding these issues in their own areas of the world and examine the factors leading to tensions among the conflicting objectives of development.

Gross Enrollment in Higher Education in India

As of 2021-22, India's GER was approximately 28.4%, with NEP 2020 aiming to increase this to 50% by 2035.The Gross Enrollment Ratio (GER) is a critical indicator of accessibility and inclusivity in higher education. Achieving this target necessitates substantial investment in infrastructure, faculty, and innovative pedagogies. This is consistent with the overall objective of the targets given in SDG4.

Viksit Bharat: Vision for 2047

'Viksit Bharat 2047' is the current government's roadmap to making India a completely developed nation by 2047. The vision for Viksit Bharat 2047 emphasizes a dynamic, innovative, and adaptable education system responsive to job market needs. Key components include universal access to achieve 100 % gross enrolment ratio, inclusive education, lifelong learning, quality education at every level and bridging all the gaps.

Characteristics of Education for Sustainable Development

- Based on principles and values that underlie sustainable development
- Addresses the economic, social, environmental realms and well-being.
- Promotes lifelong learning.
- Locally relevant and culturally appropriate
- Accommodates the evolving nature of sustainability.

These characteristics are to be addressed by engaging in formal, non-formal, and informal education using a variety of pedagogical techniques, promoting participatory learning and encouraging higher-order thinking skills.

A brief overview of Sustainable Development Goal (SDG) has been presented with a focus on alignment of Sustainable Development Goal 4 (SDG4) with education for sustainability. SDG were adopted by the United Nations in 2015 under the agenda for international development. The objective was to produce a set of universal goals that meet the environmental, political, and economic challenges facing world. SDG 4 is about achieving sustainable development through quality education and is among the 17 Sustainable Development Goals adopted by the

United Nations Sustainable Development Summit in September 2015 at New York. The goal of this initiative is to "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all"[8]. "NITI Aayog is the nodal institution for achieving SDGs in India"[9]

The SDG4 lays out a comprehensive agenda for global development by 2030. By leveraging these digitalization aspects, educational institutions can make significant strides in achieving SDG4 targets. Seven targets were set for the achievement of SDG4 in terms of Quality Education.

1. "Target 4.1: By 2030, ensure that all girls and boys complete free, equitable, and quality primary and secondary education leading to relevant and effective learning outcomes.
2. Target 4.2: By 2030, ensure that all girls and boys have access to quality early childhood development, care, and pre-primary education so that they are ready for primary education.
3. Target 4.3: By 2030, ensure equal access for all women and men to affordable and quality technical, vocational, and tertiary education, including university.
4. Target 4.4: By 2030, substantially increase the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs, and entrepreneurship.
5. Target 4.5: By 2030, eliminate gender disparities in education and ensure equal access to all levels of education and vocational training for the vulnerable, including persons with disabilities, indigenous peoples, and children in vulnerable situations.
6. Target 4.6: By 2030, ensure that all youth and a substantial proportion of adults, both men and women, achieve literacy and numeracy.
7. Target 4.7: By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship, and appreciation of cultural diversity and of culture's contribution to sustainable development"[8]

   (Source: UNESCO https://www.unesco.org/sdg4education2030/en/sdg4)[8]

In the Indian context, there is an alignment between the NEP 2020 thrust areas and SDG4 for Quality Education. Table 1 presents it in a nutshell.

NEP 2020 thrust area and alignment with SDG4.

NEP 2020 Thrust areas	Description	Alignment with SDG4
Digitization	Promote the use of digital tools and resources for education. Implement digital libraries and e-learning platforms.	"Ensure inclusive and equitable quality education for all (Target 4.1). Promote lifelong learning opportunities (Target 4.3)"[8]
Leveraging Technology and Innovation	Utilize AI and ML for personalized learning experiences. Implement IoT for smart classrooms and campuses.	"Increase the number of youth and adults with relevant skills for employment (Target 4.4)"[8]
Online and Blended Learning	Develop online courses and MOOCs. Integrate blended learning models.	"Ensure equal access to affordable and quality technical, vocational, and tertiary education (Target 4.3)"[8]
Participatory Teaching-Learning Methods	Encourage active student participation. Implement inquiry-based and experiential learning approaches.	"Ensure learners acquire knowledge and skills needed to promote sustainable development (Target 4.7)"[8]
Flexible Curriculum	Integrate sustainability across subjects. Offer elective choices and interdisciplinary programs.	"Eliminate gender disparities in education and ensure equal access (Target 4.5)"[8]
Training Educators	Provide ongoing professional development for educators. Equip educators with resources and methodologies for teaching sustainability.	"Increase the supply of qualified teachers, especially in developing countries (Target 4.c)"[8]
Empowering Students through Leadership Programs	Encourage student-led initiatives in sustainability. Provide platforms for youth engagement and leadership training.	"Promote global citizenship and appreciation of cultural diversity (Target 4.7)'[8]

Table 1: NEP 2020 thrust area and alignment with SDG4.

As seen in the above table, the thrust areas from NEP 2020 are mapped to the targets of SDG4, with accompanying rationales for each one-to-one mapping. This establishes a clear relationship between the thrust areas of NEP 2020 and the SDG4 agenda.

Five Dimensions of Sustainable Development

- Ecological Sustainability: Conserving critical ecological capital.
- Economic Sustainability: Generating continuous wealth and well-being.
- Social Sustainability: Meeting basic needs and reducing inequalities.
- Cultural Sustainability: Promoting cultural diversity and appropriate knowledge.
- Personal Sustainability: Promoting physical and mental health.

Socio-cultural, economic, policy, and governance interventions are essential for the successful adoption and implementation of digital education.

Cultural attitudes towards education and technology play a crucial role in this process. Digital literacy programs enhance digital literacy among students and faculty through targeted training and involving local communities in educational initiatives enhances the acceptance and effectiveness of digital education.

Economic policies and investments support the infrastructure and resources needed for digital education. Providing financial support for digital infrastructure ensures that economic barriers do not hinder access, while public-private partnerships drive innovation and resource allocation in digital education through collaborations.

Effective policies and governance structures ensure equitable and sustainable implementation of digital education. *National education policies* must align with sustainability goals to promote flexibility and accessibility, and robust quality assurance and accreditation mechanisms ensure that digital education meets high standards.

Inclusivity is a fundamental goal, necessitating efforts to ensure all children are enrolled in schools. Outreach programs, scholarships, and support for marginalized communities are essential. Creating opportunities for lifelong learning through flexible learning pathways, such as evening classes, online courses, and vocational training, can support adolescents and adults in continuing their education. A flexible curriculum that incorporates sustainability principles and competency-based learning can help students develop the necessary skills to address global challenges. Ensuring the curriculum is adaptable to change and includes emerging topics and technologies relevant to sustainable development is vital.

Capacity building focuses on reorienting teacher education towards sustainability and modern pedagogical techniques. Mandatory regular professional development programs and supportive policies that provide teachers with necessary resources and a conducive working environment are essential.

Increasing the relevance of education is also imperative. Aligning educational programs with job market needs and societal challenges, and incorporating critical thinking, problem-solving, and adaptability skills into the curriculum, can maximize education's impact. Developing industry partnerships to provide practical experiences and ensure curriculum relevance is also beneficial.

Promoting integrated strategies for sustainable development education balances ecological, economic, and social concerns. A holistic education approach ensures students understand the interconnectedness of global challenges. Encouraging interdisciplinary learning and research that combines different fields can address complex sustainability issues effectively.

Gaps and future direction

An analysis of the implementation challenges and best practices that can facilitate the achievement of these goals. Examples of successful implementation strategies from other countries or regions needs to be studied.

The curriculum needs to stay relevant to the evolving job market and advances in technology. The alignment of educational outcomes with future workforce will be significant. Research is required to determine how pedagogy and the curriculum at educational institutions need to evolve to fulfil these requirements.

A thorough analysis of the specific measures needed to provide equitable access to digital education is necessary. One of the main challenges in implementing digital education is the disparity in infrastructure, especially in remote areas. These regions often lack access to high-speed internet and modern digital devices, creating a substantial digital divide.

Teacher training is another critical area needing attention. Many teachers lack the skills needed to effectively incorporate technology into their classes. The adoption of digital education tools and methodologies may be hampered by this lack of expertise.

The Role of Technology and Digitalization in Higher Education to achieve Sustainable Development Goals.

Technology enhances accessibility, personalization, and efficiency in education, ultimately fostering a more educated and skilled global population equipped to contribute to sustainable development.

Digitalization in higher education plays a crucial role in enhancing access, equity, cost efficiency, and the overall quality of education. By democratizing education, digital tools provide broader access to learning resources across socio-economic and geographical boundaries. To ensure equal access for all women and men to affordable and quality technical, vocational, and tertiary education, including university education, digitalization offers several transformative solutions. One key aspect is the development of Massive Open Online Courses (MOOCs) and other online platforms. Platforms like Coursera, edX, and Khan Academy offer free or low-cost courses from top universities. These tools enable a broad range of students from various geographical locations to access high-quality education. By breaking down the barriers of physical distance and financial constraints, online courses and MOOCs democratize education, making it more inclusive. Learning management systems (LMS) like Moodle and Canvas facilitate efficient course management and personalized student engagement. Adaptive learning technologies use data analytics to tailor educational content to individual learning needs.

Virtual classrooms (Diksha, e-Pathshala) and Virtual labs (NCERT in partnership with IITs and other research organizations in subjects like physics, chemistry, biology, mathematics) are another crucial aspect. Digital classrooms and virtual environments enable remote learning, providing quality education to students in remote areas. These digital environments allow students to engage in interactive and immersive learning experiences remotely. Through virtual labs, students can conduct experiments and participate in practical sessions, which are essential components of technical and vocational education, without the need for physical presence. This approach ensures that educational activities can continue uninterrupted, even in situations where traditional classroom settings are not feasible. Virtual labs offer practical experience without the high costs associated with physical lab equipment. Moreover, digital tools enhance education quality through interactive, personalized, and data-driven learning experiences. Digital education also reduces reliance on physical infrastructure and materials, leading to significant cost savings and environmental benefits.

Additionally, the promotion of e-books and Open Educational Resources (OER) plays a significant role in reducing dependency on printed materials. E-books and digital resources are more affordable and easily accessible, making learning materials available to a wider audience. By adopting these digital resources, educational institutions can provide students with up-to-date information and a diverse range of learning materials, fostering an inclusive learning environment. E-books and online journals also reduce printing and distribution costs while ensuring access to up-to-date information.

In the pursuit of equipping learners with the knowledge and skills necessary for sustainable development, digitalization introduces advanced technologies that enhance educational experience. Artificial Intelligence (AI) and Machine Learning (ML) are at the forefront of this transformation. These technologies personalize learning experiences by tailoring educational content to individual student needs. AI and ML can predict student performance and identify those who may require additional support, ensuring timely interventions and improving educational outcomes.

Big data and analytics further contribute to this goal by providing valuable insights into student performance, engagement, and learning patterns. By analyzing large datasets, educational institutions can refine teaching strategies, optimize curriculum delivery, and make informed decisions that enhance the overall effectiveness of the educational process. This data-driven approach ensures that educational practices are continually improved, benefiting both students and educators.

The implementation of Internet of Things (IoT) technologies in educational settings creates smart campuses that offer interactive and experiential learning opportunities. IoT devices can support various functions, such as automated attendance tracking, real-time feedback, and dynamic classroom environments. These technologies foster an engaging and technologically advanced learning environment, which is essential for developing the skills and knowledge needed for sustainable development.

Strategies for Universities to achieve SDG4 in NEP 2020

- Develop Digital Infrastructure: Invest in robust digital infrastructure to support online and blended learning.
- Promote Digital Literacy: Enhance digital literacy among students and faculty.

- Address the Digital Divide: Implement strategies to bridge the digital divide and ensure equitable access.
- Foster Collaborative Learning Environments: Encourage collaboration and interaction through digital means.
- Quality and Accreditation: Maintain high standards and accreditation for online and blended learning programs.

Summary and Conclusion:

- Sustainable Development Goal4 (SDG4) aims to "ensure inclusive and equitable"[8] quality education and promote lifelong learning opportunities for all. Digitalization supports this goal by ensuring inclusive access to education for marginalized and underserved communities and providing opportunities for continuous education and skill development.
- National Education Policy 2020 (NEP 2020) sets a comprehensive framework for transforming India's education system, emphasizing the use of technology to improve access, quality, and governance. Integrating technology enhances learning experiences and administrative efficiency, while flexible learning pathways promote the use of online and blended learning modes.
- To achieve SDG4 and NEP 2020 goals, universities should invest in robust digital infrastructure to support online and blended learning, enhance digital literacy among students and faculty, encourage collaboration and interaction through digital means, maintain high standards and accreditation for online and blended learning programs, and implement strategies to bridge the digital divide and ensure equitable access.

Sustainability in education through digitalization is a viable and necessary goal. By embracing digital technologies, fostering innovation, and promoting inclusive and equitable access to quality education, India can build a sustainable education system that prepares students for the challenges of the future. This requires a commitment to continuous improvement, interdisciplinary collaboration, and a flexible, adaptive approach to curriculum design and teaching methods. Aligning these efforts with SDG4 and NEP 2020 goals ensures that higher education institutions contribute to a sustainable and equitable future. Implementing the suggested strategies will help institutions navigate the complexities of digital transformation while maintaining high standards and inclusivity in education and propel the nation towards the goal of Viksit Bharat.

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Brief Review of Organic Inorganic Hybrid Perovskite Solar Cells (HPSCs)- An Initiative towards Green Energy Sustainability

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Abstract

The global trend in the automobile and fuel industry has shifted towards the aim for "***green and clean energy*** "and shall remain in that domain for the coming decades. Solar Panels are one of the most common yet effective methods. They are found to be installed everywhere ranging from small shops to housing societies to small/large scale industries to the machinery used for outer space like "space satellites" that fly up high in space and sustain for decades by travelling millions and billions of kilometers! Have you wondered; how they travel in space for "millions of kilometers" with limited "fuel" without getting tired/stopped mid-way? Well, the answer to it is "Solar Energy." Most of the time, they utilize the "Solar power" in space and convert it into an electrical form that not only helps in the satellite movement but also helps run/work other pieces of machinery and tools installed in it that are required for data capture, and analysis. Nowadays, we see lots of "electric vehicles" moving around us. Nowadays, electric charging stations are installed and available everywhere for use. Could you guess how the charging stations get energized? You guessed it right, via "Solar Panels" installed at the roof top. These panels consist of "solar cells" of P and N-type layered materials/substrates composed of organic and inorganic constituents indigenously designed/structured using various solution/coating/fabricative techniques. Using this technique, one can achieve a solar cell of optimal and efficient power conversion capacity while remaining thermally stable at

"pocket-friendly" costs to provide a ***"greener," "cleaner" as well as a "sustainable"*** future to our nature, society, and mankind.

Keywords

Solar Cells (SCs), Hybrid Perovskite Solar Cells (HPSCs), Power Conversion Efficiency (PCE), Tolerance, Octahedral tilts.

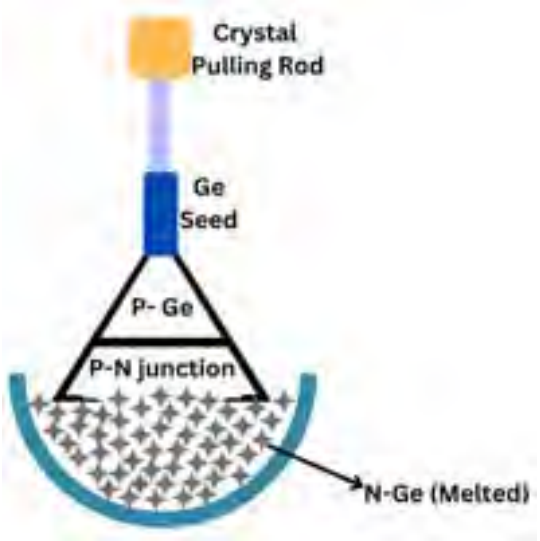
Introduction

What are semi-conductors and P-N junction materials?

The materials that exhibit resistivity between the range of conductors and insulators are termed semiconductors. Silicon (Si), Germanium (Ge), Gallium Arsenide (GaAs) etc.[1,2] are a few common examples of materials of such types. Ge was the first material to be used in manufacturing electronic devices back in 1939 and 1947, respectively due to its high availability and low manufacturing cost.[2] But, as it was highly temperature sensitive, it was not used in device fabrications at large-scale. During the 1950's, Si became the prior choice for device construction and fabrication as it was less sensitive to temperature compared to Ge and was available in abundance[2]. Although replacing Ge by Si solved the temperature sensitivity problem in electronic networks, the field of electronics got concerned about the speed issue[2]. As with time, the computers and communication systems operated at faster speeds with high performance, a semiconducting material capable of catering to new needs was required. This resulted in the development of GaAs in the early 1970s[2]. GaAs marked its entry in the field of electronics to overcome high speed issues- i.e., response time required for the fast communications between the devices and networks[2]. To understand the working of these materials, let us dive into their bonding arrangements and understand the underlying mechanism of them. Starting with the bond arrangement of pure Si and Ge crystal- the four valence electrons (i.e. tetravalent) of each atom are shared with their four adjoining atoms to form bonds[1,2]. Whereas, in case of GaAs, The Ga and As have three and five valence electrons, respectively and so Ga atom bonds with three As atoms while As atom bonds with five Ga atoms. This type of electron shared bonding in the atom is known as covalent bonding[1,2]. Further, these valence electrons can absorb enough amount of energy by external cause (like temperature) and break the covalent bonding to attain "free state"- A state wherein the electron can move freely inside the material[2]. These free electrons are termed as intrinsic charge carriers and their ability to move inside material is known as carrier mobility. It is important in device

networks as these free electrons can be quickly manipulated for desired functions. As intrinsic charge carriers of GaAs are low, it has the higher carrier mobility of all three materials[2]. Moreover, to improve the characteristics of these intrinsic materials- (i.e. existing in their pure form), the impurity of the level of one part in 10 billion[2] is added to improve the conductivity of semiconductors.[2] The process of adding impurities to pure semiconducting materials in a specified amount is known as doping.[2] Depending on the type of impurities added in to a semiconductor, hole or electron density increases and the respective charge carriers are mobilized inside it[1]. By adding pentavalent (i.e., donor) and trivalent (i.e., acceptor) impurities, N and P-Type semiconductors are formed respectively[1].The charge of donor and acceptor ions are positive and negative, respectively. Further, the majority and minority charge carriers in N -type materials are electrons and holes, whereas in p-type materials are holes and electrons, respectively[2]. The p and n-type materials are then combined with external cause- i.e., high temperature heating to form a junction between them. There are three methods that are widely used for p-n junction diode formation. 1). By Grown Junction Method: This is the oldest and most popular method for constructing a diode. It involves use of pure intrinsic semiconductor along with P-type impurity are heated high. They are heated to such an extent where both the matters melt and dissolve in each other. Further, a small semiconducting crystal known as "seed" with required impurity is then placed in the melted solution through the rod/shaft as shown in fig.1a. Then the rod is pulled out while rotating so that melted solution that has stuck to the seed becomes hard when cooled down. Once the material cools down, it forms a crystal with the same characteristics as that of seed. Furthermore, this larger size crystal is then cut into small sized diode pieces. This is the process of obtaining P-type semiconductor. By adding N and P-type impurities one-by-one, one can form PN junctions, and they can be further cut into small pieces for studying its characteristic properties. As the crystal size is large, it implies that the grown junction region is large and therefore it would be difficult to handle or pass high currents due to high power rating[53]. Next method is the "Alloy junction method" which is the general one. In this method, a small indium block (of trivalent impurity say) is placed above the N-type material (say Ge slab due to high temp. sensitivity) and heated up to 500° C[1,2]. After puddle formation, it is solidified again to normal temperature[1]. During the process, the indium block mixture penetrates inside the Ge slab and becomes thick like a button/switch on its outer surface[1] as shown in fig.1b. Another method is the "Diffusion junction method". In this method, a thin N or P-type semiconductor is mixed with the impurity present in the gaseous or

vaporized form. Firstly, a think mask type layer which is open with space in the middle part is put on N-type crystal and then they both are exposed to gaseous or vapor impurity. Then they are heated to a very high temperature in which the vapor impurity enters inside the crystal from the open space of the mask as shown in fig.1c. The impurity gets diffused across the N-type crystal which produces a P-type semiconductor and hence P-N junction is formed. This method provides more control over the accuracy in performing and is widely used; however, it takes more time compared to alloy process[53]. Hence, the alloy junction method seems to be the simpler and most effective of the three methods. Further, during the junction formation in alloy method, the free electrons and holes in the N and P-type materials diffuse across the junction and combines with each other-i.e., holes from the p-type combines with electrons of the N-region and electrons of N-type combines with the holes of P- region near the junction. This loosens the free electrons and holes of N and P-regions that creates a layer of positive and negative charges near the junction. This is the region of depletion of charge carriers. Hence it is known as depletion region.[2] The depletion regions stop the further diffusion of electrons and holes and act as a barrier.[1,2] Due to the positive and negative charges near the depletion region, electric field is produced, and potential developed by it is called barrier potential[1]. Due to the barrier potential, the free electrons flow from the N-region across the junction is stopped.[1,2]



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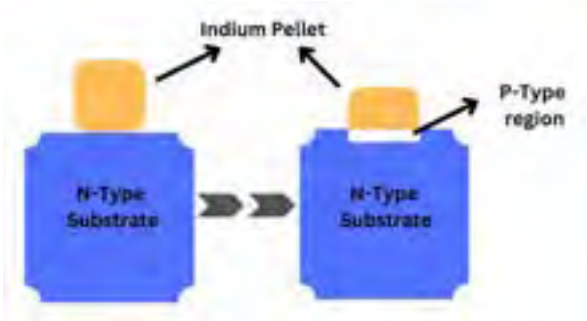

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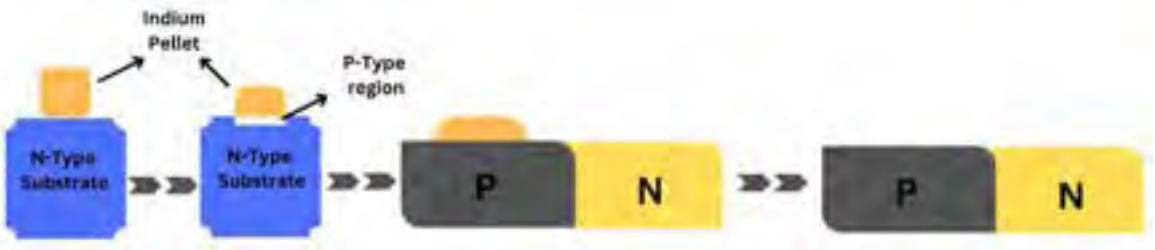


(c)

Figure 1: P-N junction formation by (a) Grown Junction Method, (b) Alloy method and (c) Diffusion Junction Method[53]. The above figures shown are originally inspired from the website (https://todayscircuits.wordpress.com/2011/06/19/semiconductor-diode-fabrication-types/. However, the permissions of use/modify have been obtained from the website www.electroniclinic.com.

Note that the movement of free carriers inside the material is random and to unify the flow of current, biasing must be done. "biasing" is providing the external voltage across the junction to get response. It is classified into three biasing conditions- No Bias (Zero bias), Forward bias and Reverse bias conditions, starting with no bias voltage- In this condition, as external bias is zero, no charge movement occurs. Due to the lack of free charge carrier movement, the positive and negative ions remain as they are and therefore no current flows through the depletion layer as shown in fig. 2a. During the forward bias condition, the p and n regions are filled with excess holes and electrons due to which charge carrier movement across p and n junction occurs[2]. The negative terminal produces an excess of electrons in the N-region, and these free electrons combine with positive charge near the junction, thereby making depletion layer smaller (thin). Further, the excess number of free electrons will be able to pass through the junction and combine with holes of p-region and become valence electrons[1]. Further, these valence electrons get attracted to the positive side of p-region and move towards the left side of p-region of external bias[1]. Similarly, the holes in p-region combine with negative charge near the depletion region, while excess holes get attracted to the right side of n-region of external bias[1]. Due to this there is charge carrier movement by the majority carriers, and so the current flows across the junction in the forward direction from p-to the-n-region as shown in fig. 2b. Whereas in the reverse bias condition, the situation is reversed. i.e. The positive terminal of battery is connected to n-region and negative terminal to p-region. Due to this, the electrons and holes get attracted towards the positive and negative terminals of external bias[1], while the minority

carriers absorb lesser amounts of energy. This energy makes them move towards the junction, but it is not enough to cross that. Therefore, they get accumulated near the junction in higher numbers, i.e. higher number of positive and negative charge accumulates, thereby making the depletion layer bigger (thicker) and a very tiny amount current flow occurs from the n-to-p region as shown in fig. 2c. The current flow across the junction in forward and reverse bias is called drift current denoted by I_D. Here, the current flow is done by minority carriers. After a certain time, if we increase the voltage, the current does not increase further. This condition is known as saturation condition[2] and the current is known as the saturation current denoted by I_S.[2] The term is common for both forward and reverse current. V-I characteristic curve is shown in fig. 2d. The total current I carried across the p-n junction is given by

$$I = I_e + I_h \tag{1.1}$$

The current equation in general form for biasing conditions is given as

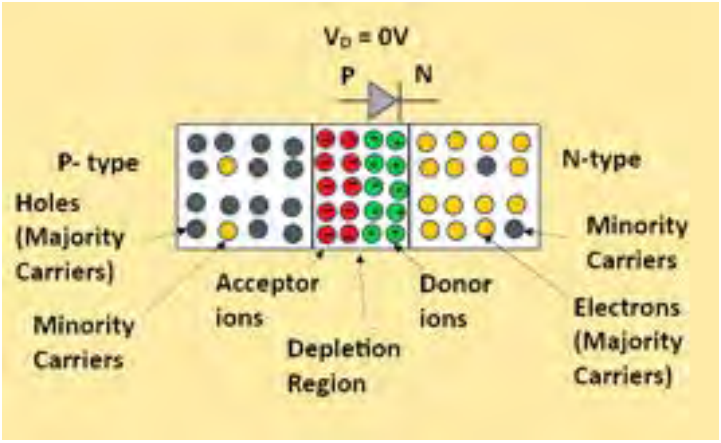
$$I_D = I_S\,(e^{V_D/nV_T} - 1) \tag{1.2}$$

$$V_T = kT_K/q \tag{1.3}$$

Where V_D, I_s, and n are the drift voltage applied across bias junction, saturation current (in forward and reverse bias) and the ideality factor (n = 1). V_T, T_K are the thermal voltage and absolute temperature in Kelvin, k is Boltzmann constant and q electronic charge magnitude (1.6×10^{-19} C).[2] It can be seen that the drift current increase exponentially with drift voltage during forward biasing while under reverse bias, the drift voltage starts to flow in the "breakdown" region- (region where barrier potential breaks and diode conducts current in reverse direction), The reverse current flows in extremely small quantity (i.e. in micro or nano ampere scale)[1,2], hence the exponential term of equation becomes very small and so drift current directly depends on the reverse current as shown in fig. 2d. Hence, the eq. 1.2 is re-written for forward and reverse bias as follows.

$$I_D = I_S\,(e^{V_D/nV_T});\, when\ V_D\ is\ positive \tag{1.4}$$

$$I_D = -I_S\,;\, when\ V_D\ is\ negative \tag{1.5}$$



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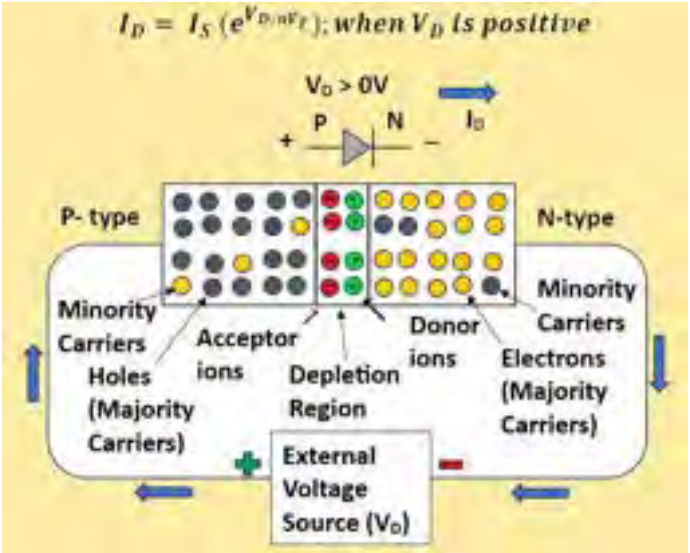

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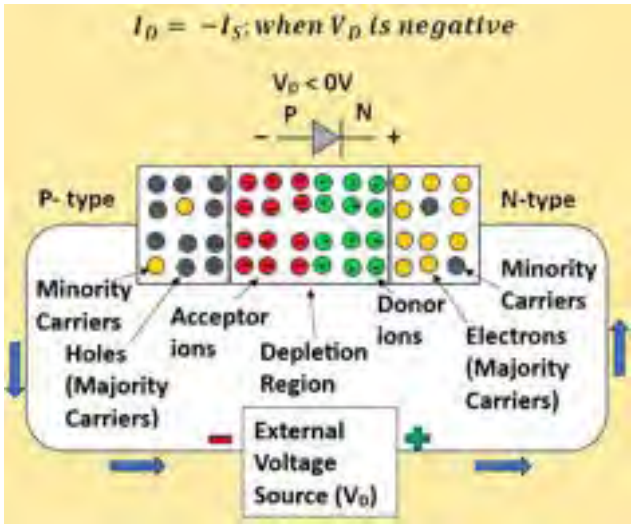

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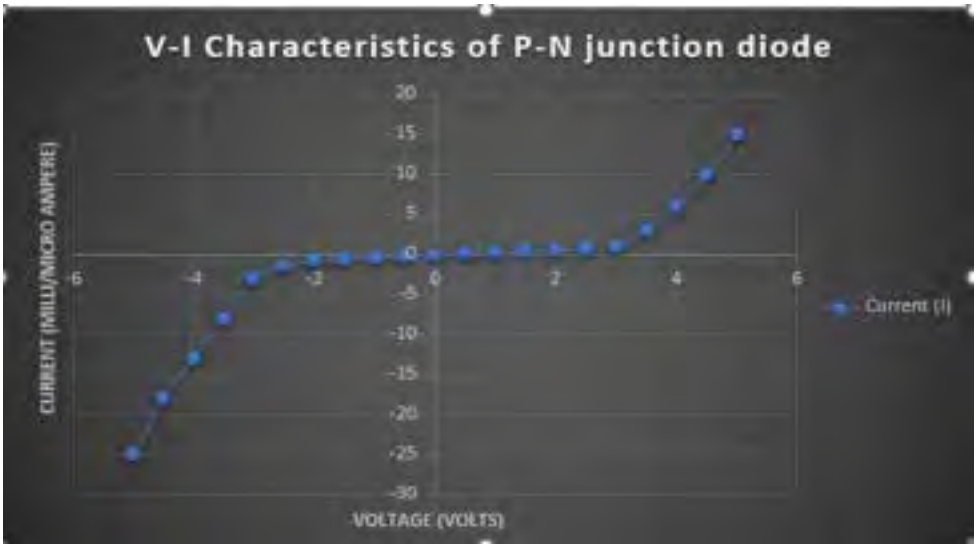


(d)

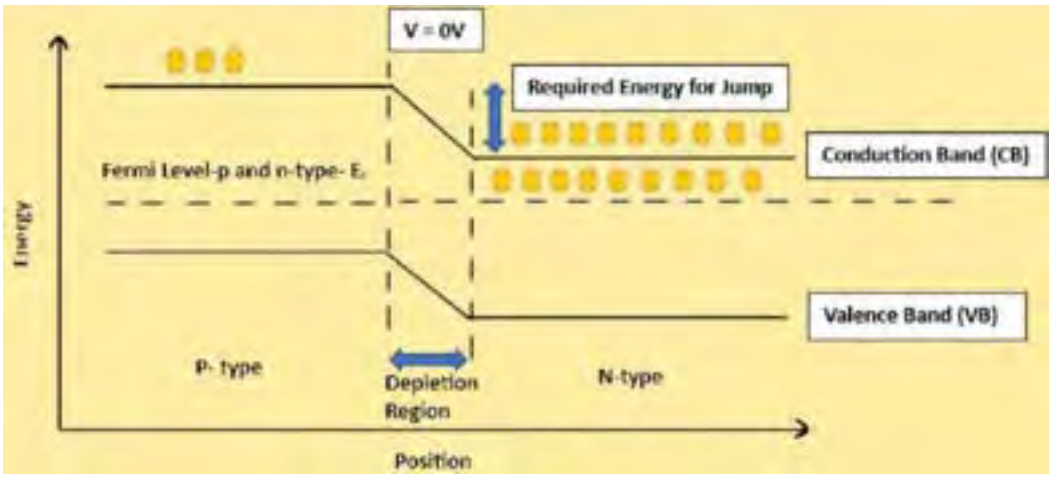
Figure 2 (a-d): Biasing conditions of P-N junction in (a) zero, (b) forward and (c) reverse bias conditions; (d) V-I curve of P-N diode.

Within the individual atom structure, certain energy levels are assigned to each orbital shell having energy range from low-to-high energy state while moving from nucleus to outermost shell[2] of the particular atom. Therefore, the valence electrons would have a higher amount of energy as compared to the free electrons[2]. When these atoms are brought close together for crystal formation, the electron energies of outer most orbital of the parent atom are slightly differ in energy with respect to the electron energy of the outer most orbital of the adjoining

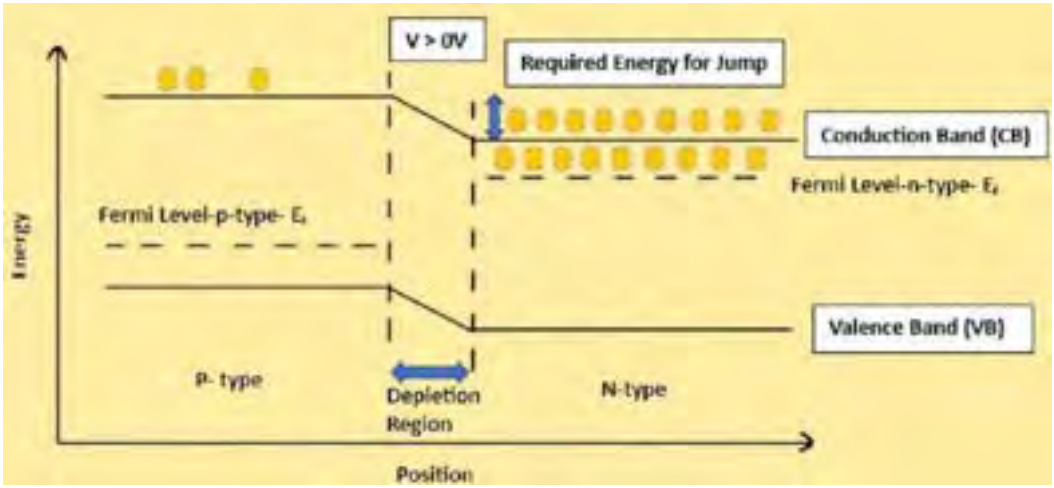
atoms[2]. (i.e. electron energy of orbit of parent Si/Ge atom is slightly higher or lower than that of the Si/Ge atoms sitting adjacent to the parent atom. It is because of Pauli's exclusion principle). Further due to these atomic interactions, the orbital energy levels of valence electrons smear out in the form of bands, resulting in energy band formation-i.e. the Valence Band (VB). Similar is the process for electrons present in the free state. This gives rise to conduction band (CB) formation[2]. Furthermore, due to this energy band formation, there is an invisible/forbidden gap created between the lowermost part of VB and uppermost part of CB. This forbidden energy gap created between the VB and CB is known as band gap[2]. Moreover. the highest energy state that an electron energy can occupy is known as fermi level denoted by E_F.[2] Moreover, in order to become a free charge carrier, valence electrons require external energy to cross the band gap to reach conduction band. Generally, the energy levels of VB and CB in n-type material are at a lower position than that of energy levels of p-type materials. It is due to trivalent impurity that exhibits lower force of attraction on the outer most shell of electrons, resulting to slightly larger orbits and more energy[1,2]. During the junction formation, the CB of n and p-regions overlap. It implies that electrons in CB of n-region can diffuse to CB of p-region if they get enough energy (or viz. external bias). It is also important to note that, once the electron crosses the junction and reaches the CB of p-region, it loses energy and rapidly falls on the VB and combines with holes of p-region[2]. Due to this, the depletion layer expands, and energy levels of n-region bands reduce[2,3]. This will continue until electrons in CB of n-region have llosttheir energy to cross junction. This condition is known as equilibrium condition[2]. Due to this process, the position of CB and VB of n-region lower down and therefore a "hill" type region gets formed which needs to be crossed by the CB electrons of n-region to reach to CB of p-region so as to generate current flow across the junction. Due to this band lowering, the fermi level of p and n-region coincides with each other as shown in fig. 3a.

In terms of energy band diagram in forward bias, as we know that due to electron-hole recombination at the depletion region, the region becomes smaller (thin). Due to this the CB and VB positions of p-region slightly lower down, and the free electrons that have absorbed sufficient energy can jump from n-region CB to p-region CB and current can flow across the junction as shown in fig. 3b. While in reverse bias conditions, as the minority carriers accumulate near the junction due to insufficient amount of energy, they are unable to cross the junction, hence the width of depletion region gets bigger (thick). Due to this, the position of CB and VB of p-region now lifts up higher. Therefore, the high amount of energy is required

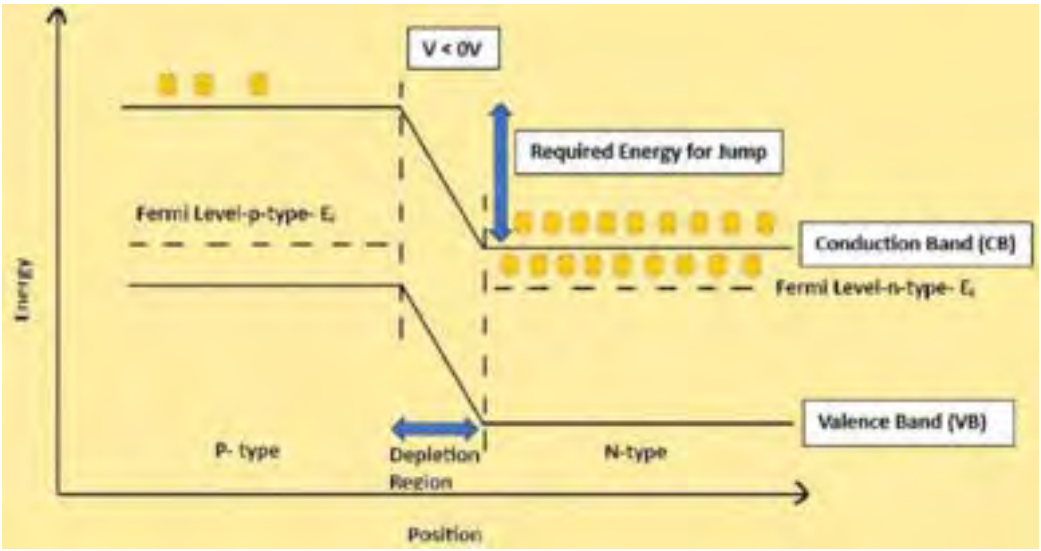
by the electrons sitting in the n-region CB so that they can jump to CB of p-region to generate current across the junction as shown in fig. 3c.



(a)



(b)



(c)

Figure 3(a-c): Energy levels of P-N junction under (a) zero bias, (b) forward and (c) reverse bias conditions.[3]

What is a Solar cell and how does it Work?

Until now, we saw the working of P-N junction diodes to generate drift current and how their energy bands variate near depletion region under un-biased as well as under three biasing conditions. But can we use p-n junction diode to generate voltage? Well, yes by applying light to this p-n junction diode, we can generate voltage potential across the p and n-region. We know that the p and n-type materials are doped with acceptor and donor impurities, thereby increase the hole and electron density at p and n-regions, respectively. Further, when p and n region combine, the depletion region is formed wherein electron-hole combines with each other and act as a barrier for further electron-hole flow across the junction[2] (according to fig. 2a). We also know that there is lack of free carriers near the depletion region, the VB must be completely filled while CB must be completely empty. When the light with minimum energy equals to the band gap energy falls on the depletion region, photons will strike the valence band and the electrons in VB will absorb energy and jump to the CB[2,3]. As electrons jump to CB, they leave holes behind it and electron-hole pairs gets generated inside the depletion region due to the light radiation[4]. Before recombination process starts, these electron-hole pairs get attracted towards positive and negative charges present near the depletion layer, i.e. electrons get attracted by positive charges near the n-region and they move towards the n-region, while

holes get attracted by the negative charges near the p-region and they move towards p-region[4]. This results in charge accumulation of positive and negative charges at both p and n-regions, and a small voltage potential is generated[4]. Further, by applying metal contacts at p and n-sides and connecting it with external circuit a small light bulb can be glowed. Therefore, the light energy was converted to electrical form and voltage was generated without using any external source and hence it is called as "photovoltaic (PV) effect".[4] As the p-n junction diode behaved as the cell/small battery that stores charge, which was further used to generate voltage, the p-n junction are also known as solar cells. One important thing to note here is that the activity of the depletion region becomes vital for generating the voltage potential across the p and n-regions as outside the depletion region, the electrons and holes will absorb the light energy and will recombine immediately[4]. Moreover, the solar cell generates direct-current DC. So, multiplying voltage with current will give power. Fig. 4[6] gives the general I-V characteristics of solar cell.

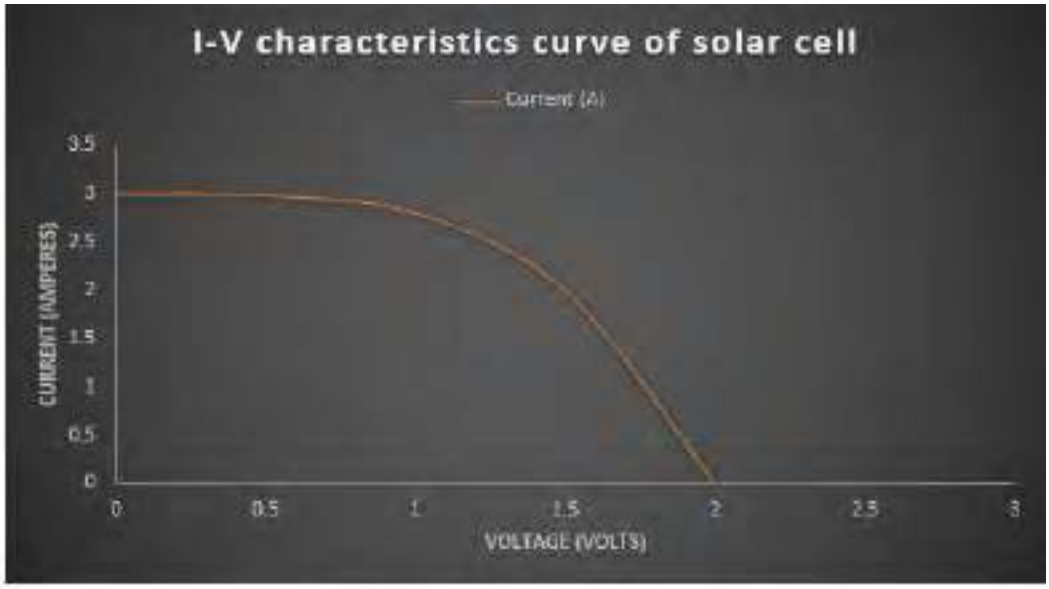


Figure 4: I-V Characteristic curve of the solar cell.

As we know, the solar cell, or PV cell converts light energy into electrical energy[4,5]. It is a form of photoelectric cell. Solar cell technology started with the discovery of renowned French physicist Antonie-Cesar Beccquerrel dating back in 1839[5]. He discovered the PV effect and observed voltage developed on the electrode when light falls upon it. Later in 1889, Charles Fritts designed "true solar cell junctions" from a semiconducting coating of selenium Se with a thin gold layer[4,5]. Although his device conversion efficiency was poor, it converted about 1%

of the total incident energy opening up the doors for semiconducting materials to be used for energy conversion at a cheaper cost. These solar cells were still stuck to a conversion efficiency of 1% until 1954, wherein a breakthrough was achieved by three American researchers. They showed the solar cell efficiency rise from 1% to 6% under direct sunlight[4,5]. By 1980s, Si cells were further replaced using gallium arsenide GaAs thereby increasing efficiency to 20%.[4,5]

Let's understand the working of solar cells of single/homo junction. Again, the basic building blocks P-N junction diode, i.e. they mainly consist of P and N-type material layers sandwiched between the junction layer with coated layers and metal grids at top and bottom layer cell surface. Starting with the top layer consisting of N-type Si material. This layer is heavily doped with donor impurity and made deliberately thin (thickness <1μm) so that light can easily pass through the layer for PV process.[5] The top layer is coated with anti-reflective (AR) coating made of oxides of silicon SiO_2, TiO_2, etc[4,5]. The metal contact at the top surface of the cells is the metal finger pattern arranged in the grid form. When the light energy in the form of photon falls on the top layer, electrons in the VB gets excited and jumps to the CB and become free electrons (carriers); i.e. moves from the ground state to excited energy state and reach to the absorber layer[5]. The absorber layer mainly consists of layer of silicon or tin oxides that helps in the electron-hole pair generation to start light-to-energy conversion process. Further, these free electrons that have jumped to higher state leaves hole/vacancy behind it and these electrons get attracted to the donor ions and moves towards the top surface of the cell and pass through the metal grid[5]. Hence, metal grid attains negative charge. Similar process happens with holes, i.e. the holes get attracted towards the back junction layer made of p-type Si. This layer is lightly doped so that holes can pass through them. It is thicker than the top layer (thickness around few 100's μm)[5]. These holes get attracted to the acceptor ions and moves towards the bottom surface of the cell having metal contact layer of Cu or Ag. Hence, they generate positive charge. This generates voltage potential between the top and bottom surface layers of the cell[5]. Now these two potential terminals created at top and bottom surface of the cell behaves as a small photovoltaic cell wherein the light energy has got converted to electrical form. Similar phenomenon of p-n diode is applied over here, i.e. voltage generation occurs due to electron-hole pair generation at the active/absorber layer. When the circuit is short (i.e. closed), the voltage generated is termed as short circuit voltage while when the circuit is kept open, it is termed as open circuit voltage denoted by V_{OC}.[5] Open circuit voltage plays an important role when it comes to improving device efficiency and performance. Ideally, one solar cell can

generate open circuit voltage V_{OC} of around 0.5V. Fig. 5[56] depicts the schematic diagram of a single junction solar cell[5]. As discussed earlier, there is immediate recombination of electron-hole pair when light falls on the surface of the p and n-regions. To reduce this recombination loss of carriers at the surface, multi junction solar cells came into picture. The multi-junction solar cells consist of two or more junctions that are introduced near the top and bottom surface of the cell, and they are commonly known as "hetero junction solar cells."[5,6] The heterojunction structure offers several advantages. It reduces carrier loss through recombination, leading to more available carriers for cell functioning and improving power conversion efficiency of solar cells. This simpler process also reduces costs[4], making the heterojunction solar cell a high-efficiency and cost-effective option.[5,6]

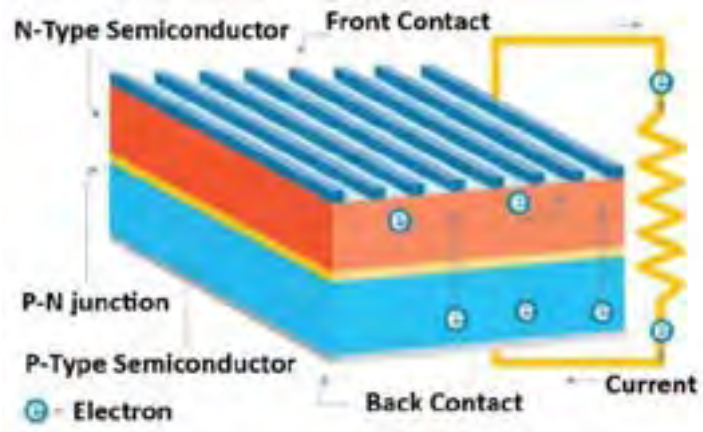
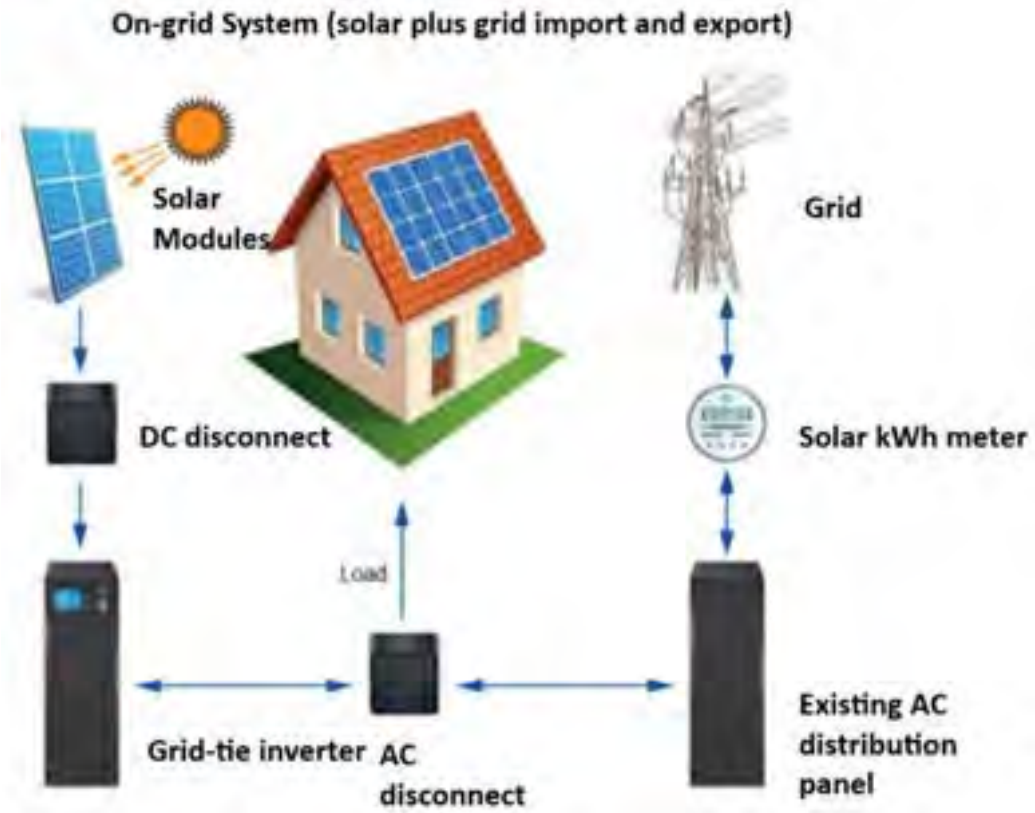


Figure 5: Schematic diagram of a homo-junction solar cell[56] License: CC BY 4.0

Solar Panels: Interestingly, the individual solar cells can be combined to form solar panels for electric power generation from direct sunlight[4]. The arrangement of solar cells can be grouped to form solar arrays consisting of over 1000's of tiny single solar cells to function as solar panels[5]. Each solar cell area size is of few square centimetres (sq. cm) covered by a thin glass coating or transparent plastic coat. For example, a 4" x 4" solar cell can generate a maximum of 2W of power[5]. Depending on the desired voltage or current, the cell arrangement is either in series or parallel configuration, respectively. Combination of group of 36 solar cells constitute photovoltaic (PV) module[5]. This module is interconnected and laminated to the glass of an aluminium frame. Framing and wiring multiple PV modules constitute a solar panel[5]. The back side of the panel contains standardized sockets to combine outputs of all the panels, thereby forming a solar array[5]. To obtain maximum output efficiency from solar panels, two things need to be considered: preferred orientation and angle of the panels. This can be adjusted with

help of latitude degrees of the area location where the panels are installed. Ideally, it needs to be adjusted 15° higher during winter and 15° lower in summer[5]. Reason is that as the sun shines at the front side during the winter and so the panels need to be raised upwards while the sun is at head side during the summer and that's why the panel angle needs to be lowered. In general, one can consider the standard tilt angle of panel with range of plus or minus to the latitude degree of city area to avoid moving panels.[4,5]. Generally, the PV system comprise of four components- Solar panels, a Power system for keeping electric loads, an external circuit and batteries for charge storage. Further, PV systems are of two types- stand-alone and grid-connected[5]. Stand-alone systems contain solar arrays and batteries connected to load circuits to waive off the absence of any electric output coming from the cells at night or during harsh weather conditions[5]. The battery stores charge in the form of direct current (DC) at a constant voltage specified in the panel by their respective companies. The voltage required according to DC and AC load power is fulfilled by DC-to-DC and DC-to-AC converters[5], respectively as shown in fig. 6a[57]. The stand-alone systems are used in remote areas say for water pumping or to provide power in lighthouses. Another type of PV system is the grid-connected system, i.e., combination of solar array with power grid. Further, this generated power is supplied to the power stations viz. grid network as shown in fig. 6b[57]. The major advantage of this PV systems is that they do not require any battery source to generate power, thereby reducing the component cost however, inverters are required for interfacing low DC volt output stored in the external batteries to be converted to the AC voltage in the grid[5]. Nowadays, the installation of solar panels is found everywhere- in residential places, shops, power stations, industries, etc. They are also used in remote areas where electrical power sources are expensive to install- an initiative towards green energy production[5].

(a)



(b)

Figure 6: (a, b): Stand alone and Grid connected PV cell systems[57] License: CC BY 4.0

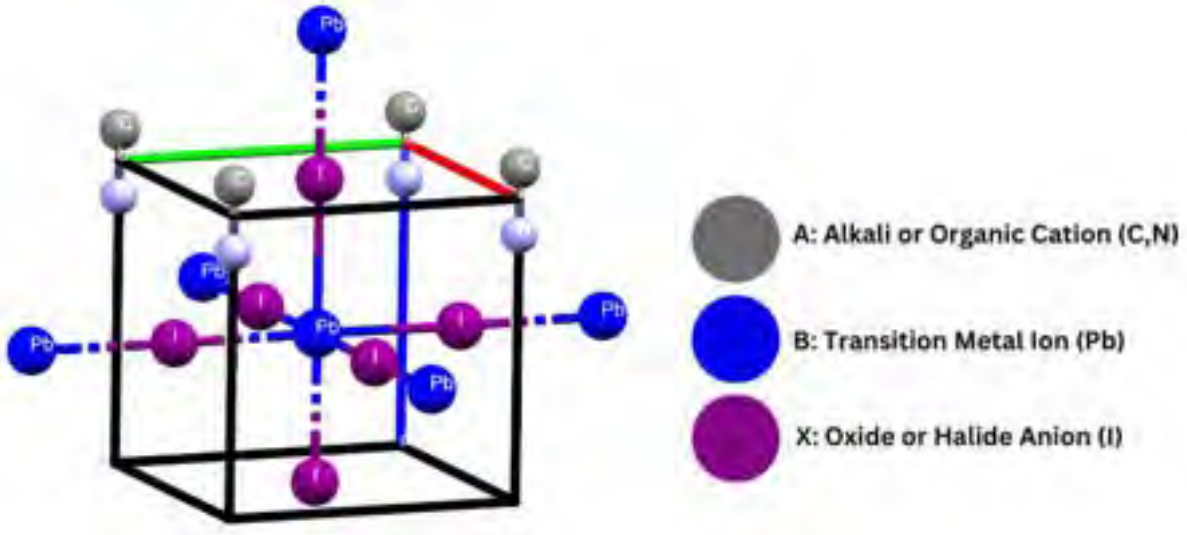
Hybrid Perovskite Solar Cells: What are they and why do we need them?

Hetero/multi-junction solar cells have geared up in the race of "energy sustainability" as lots of research has been carried out and still is the emerging area of research for material Physicists/experimentalists, as they tend to work proactively in this field due to two important reasons as follows (1) Due to the *"*ease*"* of cell preparation by spin coating or vacuum deposition technique and (2) Device fabrication by using common materials like Si, Ge, Ti, etc., one can create/design multi-junction solar cells that is stable with optimum conversion efficiency at *"*cost-effective*"* rates. It is also important to note that the top, active and bottom(back) layers are now commonly called as Electron transport Layer-ETL, Perovskite Layer and the Hole transport layer-HTL, respectively. These abbreviations will often be used in the discussion from now onwards.

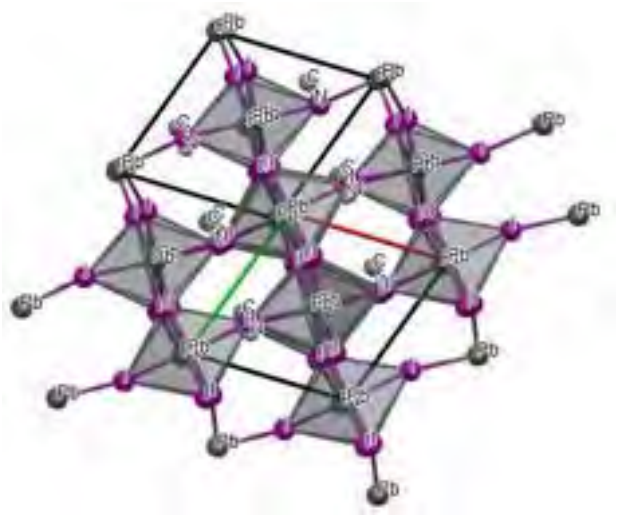
The discovery of the first-ever perovskite material was made in the Russian mountains of Ural back in 1839[7]. The mineral calcium titanate ($CaTiO_3$) was sent from Saint Petersburg, Berlin by Russian mineralogist August Kammerer to German crystallographer Gustav Rose for further investigation[11,7]. He found the chemical composition and requested to name the mineral in honour of decorated Napoleonic Wars veteran Count Lev. A. Perovskiy (1792-1856)[7].

The general perovskite comprises of ABX_3 formula. Before studying halide-perovskite-based materials these materials were known as "inorganic metal oxides (A= inorganic alkali cation, X= Oxygen anion)[11]. The basic structure consists of the cubic type having A- cation at the centre site and BX_6 connected internally inside it as octahedral form as shown in the fig.7a[31]. Fig. 7a is freely available at Cambridge Crystallographic Database (CCDC)[31]. However, metal-oxide-based perovskites are less efficient in terms of light collection capacity. As they have band gaps larger than 2.5 eV, they were not considered good photovoltaic semiconductors[19]. To overcome the light absorption efficiency problem, these perovskite materials were substituted with halide anions instead of oxide anions known as inorganic metal halides. These materials provide high light-absorbing capacity with semiconducting properties[24]. In 2005-2006, A. Kojima et al. researchers started forming various perovskite materials based on this composition. The most common material of study was Methyl Ammonium Lead Iodide (MAPbI3) which comprised of organic cations instead of inorganic alkali cations[26]. Also, the replacement of alkali with organic cation proved to be a suitable alternative for light absorbers by replacing organic dyes used in dye-sensitized solar cells (DSSCs)[26]. This group prepared a

light active layer by solution coating method to improve carrier transport efficiency[31]. They found out that organolead halide perovskite nanocrystals acted as visible light sensitizers on a TiO2 mesopore film in photoelectrochemical cells. The $MAPbI_3$ material was deposited with TiO2 electrode (anode), and Pt glass coated FTO as counter electrode (cathode). The anodic photocurrent got generated under light irradiation at visible wavelength at 800 nm that generated low open circuit voltage V_{OC}[31]. Due to the low V_{OC}, it showed band gap of around 5.3 eV when Iodine was changed with Bromine[26]. This showed that organic-inorganic perovskites exhibit different band gaps, thereby achieving power conversion efficiency (PCE) of 3.8% in 2009. This PCE got exceeded to 10% in 2012 when Michael M. Lee and coworkers increased the thickness of perovskite absorber during solidifying the cell structure [26,31]. The work also suggested improvements to the composition and structure of perovskite materials now commonly known as Hybrid Perovskite materials of organic inorganic type[26,31]. Generally, the band gap of metal-oxides- i.e. ABO_3 exhibit energy gap from 1.5-2.9 eV, whereas ABX_3 shows wide range of band gap from 1.23-2.5 eV[26,31]. When the central metal lead gets replaced by tin there is a shift in valence and conduction bands position, due to which the band gap gets reduced from 2.33 (Pb) to 1.9 6Ev (Sn) [31].



(a)



(b)

Figure 7: (a, b) General Unit cell structure of Methylammonium Lead Iodide Crystal- ABX_3 perovskites CCDC No: 968121, 968125[31].

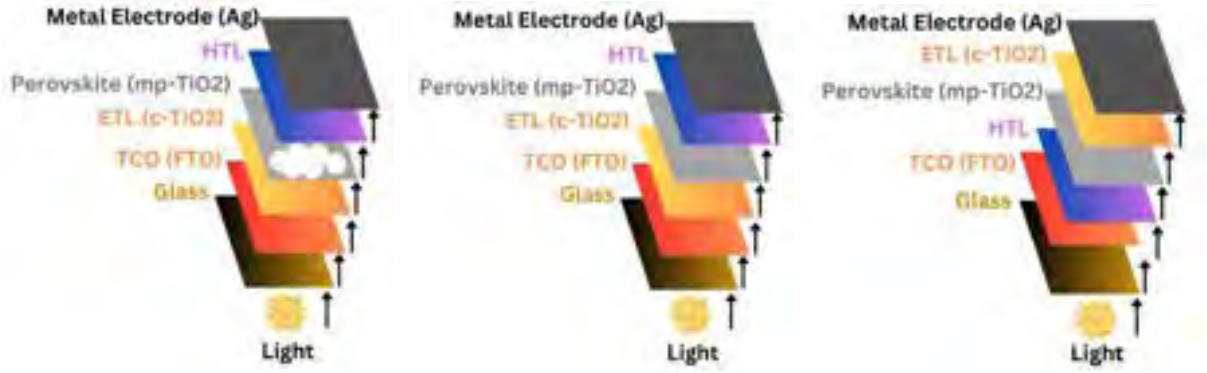
A structural understanding of these perovskite materials is important to analyse the physical properties and stability of these materials[32]. Fig. 7b shows the crystal structure of methyl ammonium lead iodide with different orientation that is freely available at Cambridge Crystallographic Database (CCDC)[31]. The struture of Methylammonium Lead iodide consists of ABX_3 type wherein A: Organic cation- i.e. Methyl ammonium CH_3NH_3 – sitting at the corners/ edge of the unit cell; B: Central metal- Pb located at the centre surrounded by X: Halide anions in the octahedral form BX_6. The structure of $MAPbI_2$ exist in the cubic form, whereas $MAPbI_3$ shows double-storey type structure[31]. However, there is no layered arrangement found. In 2013, three group of researchers discussed about the existence of three different phases of $MAPbI_3$ crystal; they were cubic (α- phase) (reported by Weber et al)[34], tetragonal (β- phase) (reported by Kawamura et al)[35] and orthorhombic (γ – phase) (reported by Baike. et al)[35]. The latter two phases were formed from the former phase. The latter phases are the most common non-cubic PSCs phase studied by the octahedral corner shared network. In terms of tilt angle, β and γ phases have one and all tilt angles other than zero, respectively. In the cubic phase, weber et al. observed large displacement in atomic parameters of MA groups with respect to the C/N and H sites near A-site cations, leading to re-orientation. This rapid reorientation of A-site cations was detected in temperature dependent NMR showing two phase transitions with respect to the low temperature leading to disordering in the structure.

While in the case of orthorhombic phase, the position of A-site cations was fixed and no dynamic movements were observed, leading to structural ordering. [35]. The work of Baike et al determined that phases are temperature dependent and reported that α, β, and γ phases occurred at high, room and low temperatures, respectively. [35].It highlighted the temperature effect on the hybrid perovskite materials in determining the stability with respect to the rapid reorientation due to C/N and H-site positions [11,35].

Using different cations and halides in hybrid perovskite materials like Cs, Rb, etc. along with Methylammonium MA and Formamidinium FA cations with I and Br halide combinations that helps in improving stability and device performance.[36]. Due to the large displacement in atomic positions of A-site cations, there is reorientation that leads to the tilting effect in the octahedra due to H bonding. As a result, it leads to shrinking of lattice structure.[35] Partially replacing MA/FA PbI_3 with Cs, Rb helps the material to get thermally stable and conversion efficient[36]. Recently, Rb-doped CsFAPbI3 reported PCE of around 20.3% that were used to fabricate highly durable PSCs that work for over 1000 hours under sunlight[36,37].

The structure evolved for PSCs are described below. It mainly exists in three forms: (a) mesoscopic structure (n-i-p), (b) planar structure (n-i-p) and (c) planar inverted structure (p-i-n) as shown in Fig. 8[58]. The (a) is the first and original design of perovskite photovoltaic material used in fabricating high performance devices. Device configuration for (a) is Glass/FTO (Fluorine-F doped Sn oxide)/c-TiO2/mesopore (mp)- TiO2 (ETL)/active layer/HTL/metal electrode[11,12]. In device fabrication, it starts from ETL layer which is the top layer deposition followed by mesopore mp-TiO_2 or mp-Al_2O_3 film on FTO layer coated with glass substrate. Further, the perovskite active layer- i.e., the absorber layer is deposited over ETL layer by annealing method[11,12]. After annealing, the thin HTL layer- i.e., bottom layer is deposited onto the active layer of perovskite and metal electrode. This completes the device fabrication process in (a)[12]. Similar type of fabrication process is carried out in (b). The only difference is that (b) structure is without mp-TiO2 layer. People found out that mp-TiO2 layer is not essential for PCE and so another form of planar structure using organic solar cells was derived that was named as inverted planar structure (c)[12]. This configuration opened the doors of wide range exploration of various hybrid materials for charge carrier layer. (c) structure configuration is: FTO/HTL/Perovskite active layer/ETL/Metal electrode[12]. PSCs results showed that PCE depends on the type of ETL and HTL materials chosen for fabrication

process, because they help in reducing carrier recombination [11,17]. Moreover, the ideal thickness of the ETL- top layer <1µm while the thickness of HTL- bottom layer lies in the range of few 100's µm. The thickness range of perovskite absorber and contact layers lies within the range of few 160-900 nm.[52] The fluorine doped tin oxide layer (FTO)- contact layer has the thickness of around 450nm.[54] The thickness of the layer is related to the carrier diffusion length. The higher the diffusion length, longer will be the time it will take to recombine with charge carriers. Hence, the lower the carrier recombination efficiency, the higher the PCE of the layer will be. Furthermore, it was found that by replacing the contact layers of FTO with ZnO configuration, the thickness was reduced from 450nm to between 300-400nm[54], well below 1µm. The lower the thickness, the higher will be the diffusion length and higher will be the power conversion efficiency. Thus, it is observed from the earlier literature carried out by researchers that the selection of contact layers plays a vital role in determining efficiency.



(a, b, c)

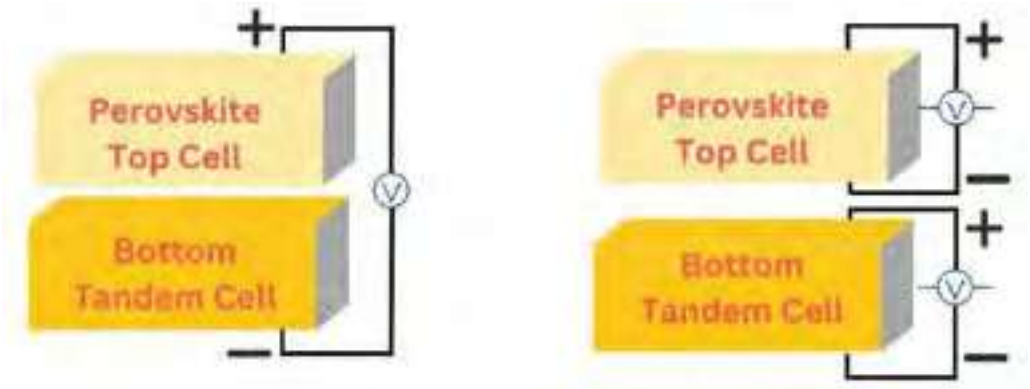
Figure 8 (a-c): Structural Improvements of PSCs; (a) mesoscopic structure (n-i-p), (b) planar structure (n-i-p) and (c) inverted planar structure (p-i-n).[58] License: CC BY 4.0

Up till now, the hybrid perovskite materials mainly consisted of lead Pb as the central metal ion are discussed. However, the fact that Pb is a toxic material when it comes to environment safety. This has been a point of concern and one of the biggest quests is to get the "best alternative"[12] to Pb that can maintain device stability but also give optimum conversion efficiency at the same time to researchers and scientists since late 1980s. The Lead is highly toxic to living organisms and it primarily results from human activity. While lead halide perovskite solar cells (PSCs) offer higher efficiency, they possess potential toxicity. Widespread adoption of PSCs could result in dangerous lead leakage into the environment, posing a significant threat.[55] It is important to implement solid management and preventive

measures for the safe utilization of PSCs, which includes the development of lead-free alternatives Sn has been one of the most promising candidates in this quest. As discussed earlier, the band gap reduction was observed when the Pb based perovskite material was replaced by Sn[12]. There are certain tin Sn-based metal halide materials comprised of MA and FA cations- i.e. $MASnI_3$ and $FASnI_3$[39,41]. They exhibit higher efficiency and are useful for photovoltaic applications. Further, the Sn-based halide systems are the best and most effective alternatives in photovoltaic semiconductors when treated under oxygen-free environment[41]. To overcome this, the reducing agents were inserted into the structural device to enhance the oxygen stability[41]. The film technique is common for all types, consisting of lead/tin-free inorganic metal halides. As discussed earlier, the organic-free compositions for photovoltaic absorbers, such as Cs-based lead perovskites, has been studied extensively to provide thermal stability with increased efficiency[36]. The $CsPbI_3$ PSCs have shown increased efficiency from 2.9% to 18.4% with moderate band gap accounting for phase stabilization[36,42]. Whereas, the Br-mixed $CsPbI_3$ and $CsPbI_2$ materials showed a bandgap of 1.9 eV, with a high-efficiency photovoltaic effect[36,42]. Although, it produced a slightly lower PCE of 15.5%, but with enhanced open circuit voltage Voc up to 1.43 V, the highest Voc obtained with visible-light harvesting PSCs[42] so far. Furthermore, it was found that replacing Pb with silver/bismuth-Ag/Bi absorbers showed higher capacity of PCE (>10%) under poor lighting conditions[43]. This work indicated the potential of PSCs applications of these lead-free devices in the field of information technology-IoT[43]. Moreover, the work on antimony (Sb) based halide perovskites have also displayed good photovoltaic response along with its conversion efficiency similar to that of Bi absorbers[44]. Cesium antimony-based halide material – $Cs_3Sb_2I_9$ reported high light absorption with an energy bandgap of 2.05 eV[45]. Seok and coworkers synthesized a chalcogenide-halide mixed perovskite, which demonstrated the best PCE of 3.08% with an optical gap of 1.3–1.4 eV[47]. Other interesting lead-free compositions studied by researchers include titanium-Ti-based halide perovskites showed bandgaps E_g of ~1.38 eV. Sn, Sb, Ag/Bi, and Ti-based hybrid perovskite materials seem to be the potential and reliable candidates for showing good photovoltaic semiconducting properties in terms of visible light absorption[36], providing thermal stability[39] as well as achieving PCE[45,46]. One of the important benefits of HPSCs is Voc which is dependent on defects formation in the bulk layer at the interface[42]. As seen above, E_g <1.6 eV implies Voc is higher along with minimal defects in the interface[42].

Dye-sensitized solar cells (DSSCs) have emerged as one of the important PV technologies when it comes to device fabrication in solar cells[48]. It was developed by Professor Grätzel in 1991 keeping in mind about environmental safety[47]. However, due to low conversion efficiency, it took time to gain attention similar to thin film technology. But, despite low attention, many researchers worked on this area and extracted organic dyes from natural materials like flower calyx, root, stem bark, leaf etc[68]. that is inexpensive when compared with thin film constituents and analyzed to determine their potential capability of having light absorption properties thereby giving good PCE[48]. Currently, around 13% PCE is achieved by this organic dye extraction in DSSCs technology, and it is believed to cross 15% by the time of the commercialization period[48,49].

As discussed earlier about the solar panels operation, it is important to design and fabricate hybrid solar cells aiming towards large scale production and commercialization in all the possible energy sectors. One such approach is done by Tandem solar cells technology- i.e. Si-Tandem solar cells[50]. As aware, Si is abundantly available on earth and so it can be used in design and fabrication of multi junction solar cells with affordable making cost. The working of tandem solar cells is similar to that of a homojunction solar cell as discussed earlier. i.e. light falls on the metal grid and AR coated surface at the top N-type Si layer. This light energy gets converted into electrical form and a small voltage potential is generated by the solar cell. Further, when the light falls on the grid, metal blocks the light and due to it there's a large energy loss[50,53]. To overcome this problem, two or more solar cells are combined and structured such that, the light falls on the top cell first. This top cell consists of perovskite absorber layer due to which it absorbs the maximum light, and a very few amounts of photon energy reach the bottom cell. The bottom cell consists of Si layer This helps in reducing thermal loss as most of the energy is absorbed by the top cell. This can be understood from the fig. below; (a) Monolithic (2T) Tandem solar cells,[17] (as shown in Fig. 9a and 9b[32]). However, individual connections are required to be given to the additional contact layers for the bottom contact of the top cell surface and top contact of the bottom cell surface[17]. The layers can be of transparent conducting oxides (TCO)[50].



(a, b)

Figure 9: (a, b) Schematic diagram of Si-Tandem solar cells of two and four terminal (2T and 4T) systems[32] License: CC BY 4.0

Tandem solar cells consisting of multi-junctions are likely to achieve over 30% efficiency within a few years which shall lead PSCs materials towards large-scale productions[50].

Where there are benefits of hybrid PSCs, there are certain challenges that need to be overcome for their large-scale application and commercialization[52]. In order to do that, several methods are available by which it can be done; blade coating: the method used for thin film deposition at larger areas; slot-die coating: the roll-to-roll print of flexible PSCs to attain good PCE[52], etc. Here, first and the foremost concern in it is the "Large area fabrication of solar cells[5,41,52]". We know that the structure of hybrid PSCs plays a crucial role in determining stability and maintaining good PCE balance. In the real world, the solar cells are treated under extreme conditions like high humidity, temperature, and extreme solar illumination under severe weather conditions[52]. In these areas, PSCs tend to lack as they show shorter carrier lifetimes due to layer instability in perovskites when exposed to extreme environments. Due to this, maintaining good PCE in a large area is very challenging[52].

The stability and conversion efficiency of organic-inorganic hybrid perovskite solar cells depends on several parameters such as tolerance limit, carrier diffusion length, Energy gaps, etc. These parameters help tweak/tune the physical, light and electronic properties.

Tolerance factor: The tolerance factor (t) is a vital parameter used to express the stability of perovskite compounds[11] and is calculated using the Goldschmidt's[8] equation as;

$$t = (r_A + r_X)/\sqrt{2(r_B + r_X)} \qquad (1.6)$$

Wherein $r_A, r_{B,} r_X$, are the ionic radii of A, B and X-site atoms as shown in Fig.10. It is important for designing hybrid perovskite materials as it plays a crucial role in interpreting perovskite stability and device performance[11]. However, this equation is not enough for identifying stable perovskite-based halide materials especially iodide based as it showed only 33% tolerance accuracy. To overcome this, Scheffler and co-workers introduced a new factor in 2019[9,40]. Hence, the new equation is given by

$$t = \frac{r_X}{r_B} - n_A \left(n_A - \frac{r_A/r_B}{\ln \frac{(r_A)}{(r_B)}} \right) \quad (1.7)$$

Where n_A is the oxidation state of A site atoms. Apart from tolerance, the octahedral tilt factor μ[14], is calculated as the ratio of radii of B and X-site atoms as follows.

$$\mu = r_B / r_X \quad (1.8)$$

This is crucial for understanding the structural stability of perovskites. The t and μ values of mixed-cation perovskites can be calculated by considering the effective radius of A and X-site atoms. Generally, materials with t = 0.8–1.0[10,13] are considered to adopt a perovskite structure, while non-perovskite phases form at t < 0.8 and t > 1.0. It indicates a rather narrow region (t = 0.91–0.98)[18] for the formation of the single perovskite phase. Further, Mixed-cation hybrid perovskites are important for solar cell fabrication[10,16,18]. The t value guides the design of multi-cation perovskites. Guidelines are given for different alloys[11]. The selection of an ideal t can be achieved through the mixing of A-site cations. The r_A value governs the t value of the alloys. The incorporation of smaller MA+ moves towards the favourable value, generating a stable cubic perovskite phase. FAMAPb (I, Br)$_3$ absorbers are often made near the border of t = 0.98[20,40]. The Cs+ incorporation plays a key role in forming structurally stable perovskites, thereby reducing t = 0.85. Therefore, a small amount of Cs+ (doping) leads to the improvement in forming a suitable perovskite crystal[11].

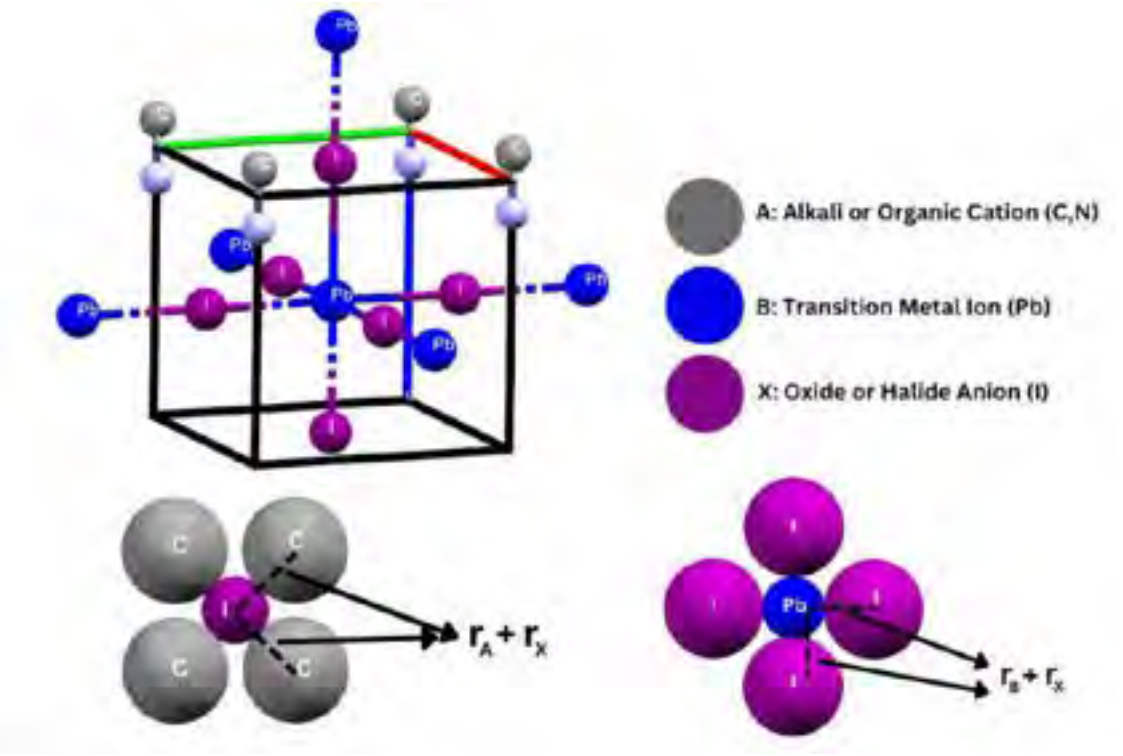


Figure 10: Calculation of Goldschmidt's factor (t) for perovskite structure CCDC No: 968125[31].

Carrier transport properties: The transport of photo-generated carriers is crucial for the operation of photovoltaic devices[21,23]. the average length of charge carrier movement between generation and recombination region is known as carrier diffusion length. In solar cells[21], the carrier *diffusion length* (L_D) is a key parameter[22,25,28]; determined by carrier mobility (μ*) and lifetime (τ). Hybrid perovskites, like $MAPbI_3$ and $FAPbI_3$, exhibit high (μ*, τ) resulting in large L_D due to the absence of deep defects[21,23]. The carrier lifetime for $MAPbI_3$ single crystals varies between 8 - 175 μm and for thin films, it varies between 0.1 - 23 μm[25]. The carrier transport characteristics of $MAPbI_3$ thin films contribute to the high efficiency of solar cells using $MAPbI_3$ as a light absorber[28]. The work of Bi.Y. et al also discussed various hybrid perovskite materials used in solar cells, their properties, crystallinity, and the effects of different cations and anions, as well as the relationship between carrier scattering and various parameters[25,28].

$$L_D = \sqrt{D.\tau} \tag{1.9}$$

$$D = \left(\frac{K_B * T}{q}\right) * \mu \tag{2.0}$$

In terms of light absorbing efficiency, the choice of A, B, and X-site species in perovskites and the variation of cations and anions lead to a large variation in light absorption characteristics[11,27]. Moreover, the light-matter interaction is described by two physical quantities; the refractive index (n) related to electromagnetic wavelength of radiation and the extinction coefficient (k) related to magnitude to electromagnetic wave[15] as shown in the equation below.

$$N = n - ik \tag{2.1}$$

Where N is the single complex number of refractive indices. Further, the stability is also dependent on the variation in the energy gap (Eg) of hybrid perovskites[29], which varies with measurements and analysis methods. This variation will influence the E_g values of A-site cation and X-site anions, thereby impacting the alloying as well as the band energy alignment of valence band maximum (VBM) and conduction band minimum (CBM)[29,30].

Solar Cells-Types	**Materials Type**	**Bandgap range (eV)**	**Tolerance factor (t)**	**Open Circuit Voltage (V_{OC})**	**Power Conversion Efficiency (PCE) (%)**	**Limitations/Challenges faced by Solar Cells**
Homo-junction (ABO_3)	Metals (Ca, Bi, Pb) + Oxides	1.5-2.9	>1.0	Low (<1V)	Lower (<1%)	Low light absorption capacity due to large bandgap, resulting to lower PCE
Homo-junction (ABX_3)	Metals + Inorganic metal Halides (Br, I)	1.23-2.5	>1.0	Low (<1V)	Lower (1-6%)	Moderate light absorption capacity with slightly lower band gap. But overall lower PCE
Hetero junction ($MAPbI_3$)	Organic cation + Inorganic	1.2-1.9	Between 0.9-0.98	Between 1-2.5V	High (12% to 30%)	Intense light absorption capacity with semiconductor like band gap value, resulting in

	metal + halides					significantly higher PCE compared to other solar cells.
Hetero junction (Cs, Rb doped $MAPbI_3$)	Organic-Inorganic metal + halides + (dopant metal like Cs, Rb)	Between 1.1-1.6	Between 0.8-0.9	Between 1-2.5	High (12% to 16.1%)	Intense light absorption capacity with good band gap range. Although slightly lower PCE than PSCs but with significant tolerance and V_{OC} limits.

Table 1: Representation of the comparison of Solar cells with solar and optical parameters.

Shockley-Queisser (SQ) Limit: The Shockley-Queisser (SQ) theory provides a straightforward method to calculate solar cell parameters based on the band gap (Eg) of a semiconductor light absorber[38]. Importantly, it should be noted that the SQ limit tends to overestimate the solar cell efficiency limit as it relies on simple assumptions[38].

Although, PSCs have reached the efficiency mark of 30% but it is also important to note that to achieve higher PCE several factors like tolerance limit, carrier transport properties, layer thickness, etc. needs to be considered to reproduce a solar cell/module that is viable for large scale area production and commercialization purpose. Here, the hybrid PSCs act as "saviour". The freedom to adjust the layer thickness of desired value in organic and inorganic part, one can tweak/tune the band-gap and achieve a solar cell of optimum efficiency along with tolerance factor lying in the region 0.8-.1.0.[10,33] As we know the correlation between thickness and efficiency[54], this work will be helpful to the researchers working in this field that can design and modify the cell structures, thickness, etc. which will provide a solar module/device with optimum stability, significant PCE value at the lower costs.

Recent Advancements/Progress carried out in Hybrid Perovskite Solar Cells (HPSCs)*:*

Research-based on HPSCs photovoltaics involves applications in various fields ranging from domestic to industrial scale. The process includes synthesizing materials using a solution-based

chemical process, characterizing perovskite semiconductors using physical methods, and fabricating devices using chemistry, physics, and electronics[17,52]. Progress in enhanced efficiency and stability depends on the development of new materials and the fostering of the connection between different disciplines. These materials can have a high tolerance factor[9,37] leading to a larger lifetime for photoexcited-free carriers required for achieving higher PCE[10,13]. This is especially useful for indoor power sources in IoT[43] applications, where high voltage is required to power devices and their secondary batteries under weak light. The goal of perovskite photovoltaics is to mimic the excellent photophysical properties of perovskite-halide materials having an open-circuit voltage and power conversion efficiency close to the Shockley-Queisser limits[38,41]. Perovskite modules are expected to practically achieve more than ~22% efficiency, making them suitable for commercial devices in terms of cost performance[50]. Additionally, research and development efforts are focused on enhancing the stability and durability of the modules and finding environmentally safe alternatives to lead, such as Sn, Bi, Sb, and Ag[36-44]. The field of perovskite science and engineering is anticipated to achieve notable progress in various applications, such as LED, photodetectors, and lasers, apart from photovoltaics[17]. Recently in 2020, New Energy and Industrial Technology Development Organization (NEDO) and Panasonic Corporation achieved an extraordinary PCE of 16.1% with hybrid PSCs thin film technology that opened up the potential capabilities and large-scale possibilities for industrial commercialization.[11,17,52] Therefore, looking at the potential capability of organic-inorganic HPSCs, the future of green and clean energy seems to be lying under their hood in the coming decades, wherein green energy shall be the need of an hour not just for running home/shop appliances, but it shall take up the place in the large scale manufacturing and production based industries to overcome the power consumption and fuel cost. Although the movement is in small steps, the steps taken in this field are guiding us towards the sustainability of green energy that shall assure the sustainability of humanity and the environment.

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Glossary

Junction- Meeting of two points or regions that creates an interface with each other

Diffusion- The physical or the biological process of spreading out or dispersing of the particles from the larger concentration (ratio) to the lower one.

Biasing- Electrical diode arrangement that allows uni-directional flow of the current after applying the external voltage.

Solar Cell- The electrical device that transforms the photo-energy (i.e. light energy) into heat energy.

Photovoltaics (PV)- The process of transforming the heat energy of the solar cell into the electrical form/ thermal energy with the help of semiconducting materials.

Perovskites- Material consisting of ABX_3 structure that is similar to that of minerals like calcium titanium oxide.

Hybrid Perovskites- It can be described as a semiconducting material of ABX_3 type that consists of organic as well as inorganic molecules like alkyls, aromatic ions, oxides and halides.

Homo junction- Semiconductor interface/layer created between the two identical material types. Homo- means "Single/One".

Heterojunction- Multiple layers/interfaces created between the two semiconducting materials but of different types. Hetero- means "Two or more/Multiple".

Mesoscopic- The size of materials lying between the range of nano meters (nm) to few micrometers (μm).

Tandem- Two or more groups/cells arranged one behind/below the other that can be used to generate power output in terms of voltage or current.

Sustainability- A continuous effort/ initiative to support and sustain the process/methods that are economically, socially and environmentally safe/reproducible for all. Example: Tree-plantation programme, Bio energy fuels, Electric vehicles, etc.

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Science, Art, and Spirituality: A Sustainable Approach

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Figure 1: Picture of Scientific Toy -2nd version from different angles

Figure 2: Picture of Scientific Toy -1st version as End Sem Project of Course : Designing Scientific Toys

Abstract

Science, art, and spirituality—often seen as distinct—are, in truth, three lenses to explore a single reality: Who are we, and what is our place in this cosmos? This paper presents a practical and philosophical journey that interweaves these realms through the creation of a sustainable, low-cost scientific toy. Developed initially as the End Semester Project of a Choice Based Course 'Designing Scientific Toys' at Navrachana University. It was born from the author's own lived experience as an Artist, Engineer, Educator, Seeker, a Lifelong Learner, and a B.Ed Student. Then it evolved to the current 2nd version with Mentor's Vision, guidance, and author's hard work. The author also as someone who has personally battled the depths of depression and survivor of dark suicidal phase is on a mission to save students from suicides. The inclusion of suicide prevention and mental well-being is not an academic formality, but a life-and-death necessity.

This is not a definitive claim, but a perspective—a reflection of insights gathered while building, teaching, meditating, and living. As the Tao of Physics beautifully reminds us, "Modern physics has come to take a radical turn toward mysticism when it enters the atomic

and subatomic domain" (Capra, 1975). Just as quantum theory reshaped the boundaries of logic, so too must education transcend rote learning to become an integrated experience of head, hand, and heart.

The toy integrates scientific principles such as the cam-shaft-follower mechanism, Newton's laws, torque, and energy transfer, hinge-based motion, moiré interference patterns, and surface tension through bubble formation. At a deeper level, it opens doors to questions of consciousness—symbolized by the pineal gland and the third eye, rooted in both neuroscience and Vedic symbolism.

The learning design follows a constructivist path, incorporating Piaget's theory of cognitive development, Skinner's reinforcement theory, Thorndike's law of effect, and the 8 Learning Events Model by Leclerq and Poumay. These are mapped onto Bloom's Taxonomy to move beyond memorization towards application, analysis, evaluation, and creation. The toy-building activity uses discarded and recycled materials—pen refills, gift boxes, cardboard, bottle caps—echoing the principles of SDG 4 (Quality Education), SDG 3 (Good Health and Well-being), and SDG 12 (Responsible Consumption and Production).

The spiritual dimension unfolds through themes of Karma (action and consequence), Maya (illusion), impermanence, and unity of Shiva-Shakti (balance of cosmic energies). These are not religious abstractions but psychological truths. As **Carl Jung wrote, "Who looks outside, dreams, who looks inside, awakens."** Students are invited to explore these layers through reflection questions, journaling, and dialogue—linking the mind's mechanisms with the mechanics of motion.

By weaving together scientific thinking, spiritual depth, and artistic expression, this project transforms learning from a task into a personal journey. It invites students not merely to memorize formulas but to create, question, and contemplate. Through hands-on engagement and reflective practice, learners begin to see science as alive, art as purposeful, and spirituality as a lived experience—not an abstract ideal. The use of recycled everyday materials does not just reduce environmental impact; it nurtures values like mindfulness, resourcefulness, and harmony with nature. Ultimately, this approach helps create a learning environment where knowledge is not just acquired but lived. **Aligning with the vision of the United Nations' Sustainable Development Goals: "peace and prosperity for people and the planet." It lays**

the foundation for a future that is not only sustainable, but also compassionate, creative, and deeply aware.

Keywords

Sustainability, STEAMS Education (Science, Technology, Engineering, Art, Mathematics, Spirituality), Spirituality in Education, Sustainable Pedagogy, Constructivist Approach, Hands-on Learning, Experiential Learning, NEP 2020, Critical Thinking, Higher Order Thinking Skills (HOTS), Scientific Toy Making, Upcycled Educational Tools, Sustainable Development Goals (SDGs).

Introduction

Can a toy made from scrap materials do more than demonstrate physics? Can it also help a learner discover the rhythm of life, the balance of mind, and the beauty of interconnectedness?

This paper emerged from such a possibility. The choice-based course ‘Designing Scientific Toys”, offered as part of all UG PG programs at Navrachana University, became the seed for a larger inquiry. It invited pre-service teachers and future educators, engineers, artists, architects, lawyers, and managers to connect scientific principles with creativity, sustainability, and deep pedagogical reflection. What began as an exercise in craft turned into a journey of integrating science, art, and spirituality. The Scientific Toy built in this project became not just a tool, but a metaphor—a bridge between Newton and the Upanishads, between mechanisms and meaning.

While traditionally seen as separate, science, art, and spirituality often seek the same truths through different paths. As the author reflected on the process, it became evident that creating a simple toy can reveal the interconnectedness of reality. The author echoes what Fritjof Capra described in The Tao of Physics—that the essence of the Eastern worldview is the awareness of unity and mutual interrelation of all things (Capra, 1975).

Modern physics, especially at the quantum level, has discovered a reality so subtle, interconnected, and mysterious that it begins to sound strikingly like the language of mystics. As Capra noted, When the concepts of space, time, and matter break down, we are left with relationships, with movement, with flow—a Tao. This realization mirrors the author's

experience through this case study: true knowledge comes not only through reason, but also through intuition, contemplation, and engagement.

This work is not definitive proof, but a perspective. The author's intent is to reach fellow educators, students, parents, scientists, and mystics alike—those who may never have considered the overlap between quantum mechanics and Vedantic philosophy, between wave interference and Maya. And just as Capra cautioned that mysticism is ultimately an experience beyond words, so too is the transformative potential of education. One must build, reflect, and experience.

Aligned with India's National Education Policy (NEP) 2020 and National Curriculum Framework (NCF) 2023, this paper advocates a shift from rote learning to constructivist, holistic education. Ancient Indian thought encapsulated this through Apara Vidya—worldly knowledge—and Para Vidya—inner wisdom. When learners apply both, they don't just solve problems; they begin to understand themselves (Radhakrishnan, 1953; Vivekananda, 1896).

In the hands-on act of making, theory meets experience. A rotating cam becomes a model of karma—action setting changes into motion. Moiré patterns from plastic sheets echo the illusion of perception. A shimmering bubble becomes a silent teacher of impermanence. These aren't just craft ideas; they are philosophical gateways.

Modern learning theories validate this method. Piaget emphasized active learning to construct mental models. Skinner highlighted the role of feedback and reinforcement. Thorndike's law of effect pointed to satisfaction as the driver of habit. The 8 Learning Events Model by Leclerq and Poumay ensures exploration, experimentation, and expression. Bloom's Taxonomy moves the learner from recall to creation—exactly what happens when a child designs, tests, and refines a working model.

The toys themselves demonstrate powerful scientific principles: Newton laws, torque, mechanical motion transfer, wave interference, and surface tension (Norton, 2009; NCERT, 2023; Adamson & Gast, 1997). But more importantly, the way they are built—using discarded pen refills, old cardboard, and reused plastic—promotes sustainability and resourcefulness. This supports United Nations Sustainable Development Goals Like SDG 4 (Quality Education), SDG 3 (Good Health and Well-being), and SDG 12 (Responsible Consumption).

The spiritual dimension comes alive through reflection. From Bhagavad Gita principle of selfless action (Ch. 2, V. 47) to the Mandukya Upanishads map of consciousness, to the symbolic Third Eye—these timeless ideas find space in this learning journey. Echoes of this integration can even be found in modern physics. Heisenberg spoke of physics losing its solid ground. Einstein said, it was as if the ground had been pulled out from under one… (Capra, 1975).

This paper is not presented as absolute truth. It is a perspective, shaped by lived experience and educational exploration. It is the author's attempt to ask—not just how we teach science—but why, and with what impact. It is a call to teach not just to the mind, but also to the soul.

So now let us dive deeper. This exploration will follow a unique outline: #***Experience and Learning of the Author, #Need of Art, and Spirituality in Modern Education: Path to Holistic Learning, #Narrative of Story—From Scientific and Spiritual Perspectives, #Methodology and Mechanism, #Reflective Exercises, #Scope of Improvement, #What Students May Learn ending with Conclusion.***

Experience and Learning of the Author

Since this is a case study cum perspective, it's vital to know the background of the author. The author’s journey into the intersection of science, art, and spirituality began not in a classroom but in the coastal town of Veraval–Somnath (Prabhas Kshetra): a land known as much for ancient temples as for crashing waves and whispered myths. Raised in a home shaped by three powerful influences: a deeply spiritual father, a devout yet flexible mother, and a strictly religious grandmother, the dinner table often became a battleground of ideas: ritual versus reflection, belief versus experience. These early dialogues planted the seeds of curiosity that would later shape the author’s unique pedagogical path.

Over time, the author’s professional experiences as an engineer, creative artist, a B.Ed student, and later as a STEAMS educator were all colored by this early exposure to philosophical debates. The course Designing Scientific Toys, undertaken during the B.Ed. program at Navrachana University, became a turning point. It provided not just tools for teaching science but a canvas for exploring consciousness.

Through toy-making, the author witnessed how something as simple as a discarded pen refill or a bottle cap could be transformed into a tool of learning. It was not about physics anymore. It was about perception. Students, when invited to work with recycled materials, did not just build toys; they built insight. They began to question waste, value, and the meaning of creation itself. This hands-on process teaches critical thinking, design thinking, and ecological thinking—not in isolation, but in harmony.

Incorporating art and spirituality deepened this experience. When toys were used to illustrate abstract spiritual ideas—karma as motion, illusion as Moiré patterns, consciousness as wave collapse—the classroom turned into a living laboratory of inner and outer worlds. Meditation activities and creative reflection helped students slow down, look within, and connect ideas beyond the syllabus. The blend of artful learning and mindful inquiry created a rare, healing space—one where logic met silence.

The author's exploration was enriched by reading works like The Tao of Physics, which echoed the same vision: that science and spirituality are not two paths, but two languages speaking the same truth. As Capra writes, **"The mystic and the physicist arrive at the same conclusion; one starting from the inner realm, the other from the outer world" (Capra, 1975).**

This belief was reinforced by the legacies of great thinkers—Nikola Tesla, who was inspired by the Vedas; Heisenberg, who acknowledged the limits of objective science; and Schrödinger, who turned to Vedanta to understand consciousness. Their lives are a reminder that true knowledge transcends the textbook.

The author has learned that sustainability is not only a scientific challenge but also a spiritual responsibility. It asks us to see the earth not as a warehouse of resources but as a shared home. And education, to be complete, must teach students how to care—not just calculate; how to observe—not just obey.

This journey continues—not as a finished method, but as a living inquiry. The author no longer sees science, art, and spirituality as subjects to be taught separately, but as streams of the same river, flowing toward one ocean: wisdom.

Need for Art and Spirituality in Modern Education: Path+ to Holistic Learning

Modern education tends to prioritize Science, Technology, Engineering, and Mathematics (STEM), aiming to build logical reasoning, analytical thinking, and technical skills. However, this focus often neglects other vital aspects of human development, such as emotional intelligence, creativity, and inner awareness. To bridge this gap, the author proposes a more inclusive approach called **STEAMS**—which adds **Art and Spirituality To** STEM. This model addresses the need to educate not only intellect but also the heart and soul.

Art provides an outlet for expression, creativity, and emotional connection. Research shows that artistic activities can significantly reduce stress, improve emotional balance, and support mental health (Stuckey & Nobel, 2010). Similarly, incorporating spirituality through mindfulness, meditation, and quiet reflection has been linked to better focus, lower anxiety, and greater resilience (Davidson et al., 2003). Students equipped with these inner skills are more likely to handle academic challenges without internalizing failure as personal defeat. Instead, they develop perseverance, patience, and a healthier m+indset toward growth.

What if students are unable to accept failures and rejections as part of growth and see them instead as a dead end? An untrained mind, under pressure, can collapse—and tragically, many do. When the author began researching this topic, he came across data that was deeply disturbing. According to the **Accidental Deaths and Suicides in India (ADSI) 2022**report by the National Crime Records Bureau, **13,044 students died by suicide in 2022**—almost double the number from 2012. Thats an average of about **38 student suicides per day**. Assuming the same trend continues, between December and May—the period during which this paper was written and revised—over **6,522 students may** have lost their lives to suicide in India alone.

Social media, academic pressure, and family expectations create a perfect storm for mental strain. Students often compare themselves with curated versions of others' lives. Their self-worth becomes entangled with digital validation and external opinions. When life doesn't align with their expectations, and there are no tools to cope, the mind spirals.

The author himself experienced such a spiral. Once joyful and motivational, he sank into silence and isolation, losing the ability to feel happiness or hope. After repeated setbacks, he began considering suicide—not out of weakness, but from a desire to escape overwhelming

pain. A suicide note was drafted. But then a different question arose: *What happens after death? Does suffering end—or start again in a different form?*

These questions led him to ancient Indian wisdom. He turned to the **Vedas and** later to the **Upanishads**, which explore life, death, and consciousness through a dialogue between teacher and student. He began with the **Mandukya Upanishad**, which explains four levels of consciousness, and continued with the **Brihadaranyaka Upanishad**, gradually discovering clarity and hope. He found profound support in the **Bhagavad Gita**, where Arjuna—representing the modern confused and disheartened youth—is on the verge of giving up. In Chapter 2, verses 62–63, Lord Krishna outlines a psychological chain reaction:

Bhagavad Gita – Chapter 2, Verses 62–63

Sanskrit:

ध्यायतो विषयान्पुंसः सङ्गस्तेषूपजायते। सङ्गात् संजायते कामः कामात्क्रोधोऽभिजायते॥ 2.62॥
क्रोधाद्भवति सम्मोहः सम्मोहात्स्मृतिविभ्रमः। स्मृतिभ्रंशाद् बुद्धिनाशो बुद्धिनाशात्प्रणश्यति॥ 2.63॥

Translation:

While thinking about sense objects, a person gets attached to them. From attachment comes desire (*kāma*), and from unfulfilled desire comes anger (*krodha*). From anger arises confusion, from confusion comes loss of memory. When memory is lost, intelligence is destroyed—and when intelligence is lost, the person falls into ruin.

"While contemplating the objects of the senses, one develops attachment. From attachment comes desire, from desire arises anger. From anger comes delusion; from delusion, loss of memory; from loss of memory, destruction of intelligence; and from destruction of intelligence, one perishes. (Bhagavad Gita 2.62–63)

This chain reflects both ancient wisdom and modern psychology: **Attention → Attachment → Desire → Frustration → Anger → Confusion → Memory Loss → Collapse.**

Spirituality is not about rituals or religion. It is about understanding one's own mind, thoughts, and emotional patterns. In truth, **spirituality is the science of the mind**. Swami Vivekananda once said, *Education is the manifestation of perfection already in man.* Adi Shankaracharya

echoed this in *Vivekachudamani*: *The mind is the root of bondage and liberation. Even* Carl Jung, the pioneering psychologist, asserted, *"Who looks outside, dreams, who looks inside, awakens."*

The wisdom of **Stoicism**, followed by thinkers like Marcus Aurelius and Epictetus, aligns with this view. Stoicism teaches that happiness is not based on external events, but on our internal state. *You have power over your mind—not outside events. Realize this, and you will find strength, wrote* Aurelius. Stoicism is spirituality in action: a disciplined mind meeting a chaotic world with calmness. Its core idea is simple yet profound—**focus only on what you can control and let go of the rest**. This mirrors the **Taoist principle of Wu Wei**, or effortless action. It emphasizes inner stillness and flowing with the natural rhythm of life, making decisions with clarity instead of resistance.

Science, too, reaches similar conclusions. **Albert Einstein said**, "*The most beautiful experience we can have is the mysterious." Werner* **Heisenberg**, father of quantum mechanics, admitted, *the first gulp from the glass of natural sciences will turn you into an atheist, but at the bottom of the glass, God is waiting. And* **Max Planck**, founder of quantum theory, observed, *all matter originates and exists only by virtue of a conscious and intelligent Mind.*

These voices—from Vedanta to Stoicism, from psychology to quantum physics—point to a single truth: **education must nurture the whole being**. From personal experience, the author strongly believes that schools and colleges need to create space for **mental and spiritual training**. Just as physical education builds strength and stamina, inner training develops emotional resilience and clarity. Meditation corners, reflective journaling, storytelling through ancient texts, or expressive art sessions can all be valuable tools.

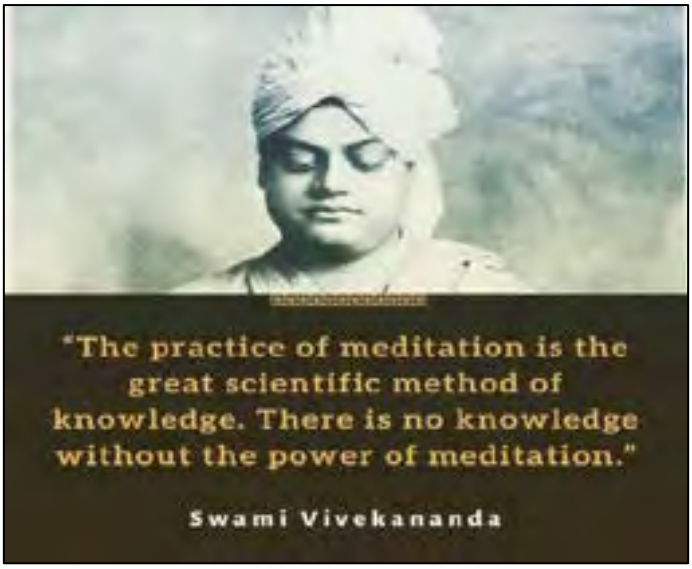

Figure 3: Swami-Vivekananda quote on meditation and knowledge

Retrieved from https://vivekavani.com/swami-vivekananda-quotes-meditation/ Quote is an excerpt from lecture *Delivered at the Washington Hall, San Francisco, April 3,1900*

Figure 4: Swami Vivekanand and Nikola Tesla connection

Retrieved from https://www.facebook.com/sagarworldmultimedia/posts/did-you-know-swami-vivekananda-inspired-nikola-tesla-with-vedasnikola-tesla-and-/3718381091554376/

We all know Swami Vivekanand and Nikola Tesla, but how many of us know that they both met, and Swami Vivekanand and his teachings greatly influenced Nikola Tesla? Very few. The author found this link while doing research on Swami Vivekanand's influence on education and modern science.

Moreover, as outlined in the National Education Policy (NEP) 2020 and2020and the National Curriculum Framework (NCF) 2023, there is a clear push toward holistic education. These policy documents emphasize not just academic knowledge but also the development of life skills, ethical values, emotional well-being, and creativity. The NEP 2020 calls for education that nurtures the whole individual, while the NCF 2023 encourages schools to focus on experiential learning, mindfulness, critical thinking, and socio-emotional growth.

This means that spiritual education is not a luxury, it is a necessity. Integrating it with art and science through the STEAMS model could equip learners not just to succeed in careers but to lead balanced, meaningful, and resilient lives.

Education should not only prepare students for careers and exams should prepare them for the most precious gift: life itself. And life deserves awareness, attention, and care—from within.

Narrative of the Story - From a Scientific and Spiritual Perspective

In Navrachana University, focused on holistic development, an elective course titled *"Designing Scientific Toys"* offered a transformative learning experience. The course encouraged learners to move beyond traditional textbook knowledge and engage in experiential, hands-on exploration of scientific principles. It emphasized creativity, sustainability, and deeper reflection, creating a space where science education could transcend its conventional boundaries. While designing toys that embodied concepts such as energy transformation, motion, and balance, participants began to see parallels between scientific mechanisms and philosophical insights. The construction of a single toy often involves multiple interconnected scientific principles—such as torque, motion conversion, and wave interference—mirroring the interconnectedness of life itself.

These realizations prompted deeper contemplation about the nature of existence, leading to spiritual insights grounded in ancient Indian wisdom, such as the ideas of *Apara Vidya* (practical knowledge) and *Para Vidya* (inner wisdom). This journey culminated in the creation

of a toy that not only demonstrated mechanical and physical concepts but also served as a metaphor for consciousness, duality, and the cyclical nature of life. Inspired by texts like the *Bhagavad Gita*, the *Upanishads*, and the philosophies of Advaita Vedanta, the project evolved into more than just a teaching tool—it became a symbol of the fusion between scientific inquiry and spiritual understanding. The toy invited reflection on themes like balance, cause and effect, illusion and reality, and the unseen forces that govern motion, both in matter and in the mind.

Here we will first see the scientific principle, then see its spiritual perspective.

1. Cam-Shaft-Follower Mechanism: From Motion to Meaning

Scientific Principles

A **cam-shaft-follower mechanism converts rotational motion into reciprocating motion**. The **cam rotates**, and its shape controls how the **follower moves**—either smoothly or in jerks. This setup is common in internal combustion engines, automatic machines, and textile looms (Norton, 2009).

The principle follows **Newton's First Law of Motion**: an object continues in its state unless acted upon by an external force (NCERT, 2023). In rotational terms, **torque (τ)** creates **angular acceleration.** More precisely, torque is a measure of the force that causes an object to rotate around an axis, and its magnitude can be calculated using the formula $\vec{\tau} = \vec{r} \times \overrightarrow{F}$. This is a **vector cross product**, which means torque has both **magnitude** and **direction. $\vec{\tau}$ (Torque vector):** This tells us *how much* rotational force is being applied and *in what direction.* **$\vec{r}$ (Position vector)**: This is a vector from the **axis of rotation (pivot point)** to the **point where the force is applied**. **$\vec{F}$ (Force vector)**: This is the **force being applied** at that point, its magnitude and direction matter. (often called the lever arm or moment arm).

A simple analogy? Try opening a stuck door. If you push near the hinge, it hardly moves. But the farther your hand is from the hinge, the less effort you need. That's **torque in action**: *more distance, less force*. Engineers design cams with this idea in mind, using motion to control timing and efficiency with minimal energy.

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Figure 5: Shaft Handle

Figure 6: Cam , Shaft and Follower

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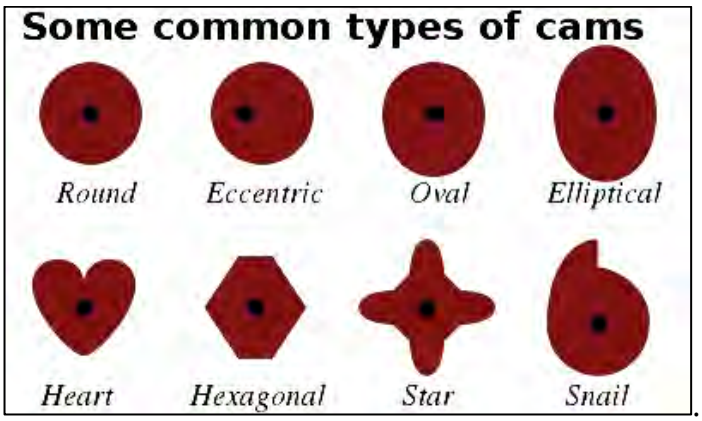

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Figure 7: Common Types of Cam

Retrieved from https://www.explainthatstuff.com/cranks-and-cams.html

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Spiritual Perspective

What if life, too, had a cam guiding our motion?

Imagine the **handle** as our **mind**—where thoughts begin. **Desire** turns the cam; **thoughts become actions**—our **karma**. The **shaft** carries this energy outward, shaping our experiences.

Just as each type of cam shape creates a unique pattern, when rotated, every person's spiritual journey has its own rhythm—some steady, others unpredictable.

When life jerks or flows, do we resist—or trust the design?

In Hindu and Buddhist philosophy, this mirrors the law of **karma**—our actions shape our path. The cam doesn't choose the followers response; it sets the rhythm. We choose how to walk it—with confusion or clarity, fear or faith.

So next time something in life feels off-track, ask:

Am I pushing too close to the hinge?
Do I need to step back to gain strength?

Mechanics teach motion. **Spirituality teaches meaning**. Together, they remind us: while we may not control the cam, we can always choose how we follow.

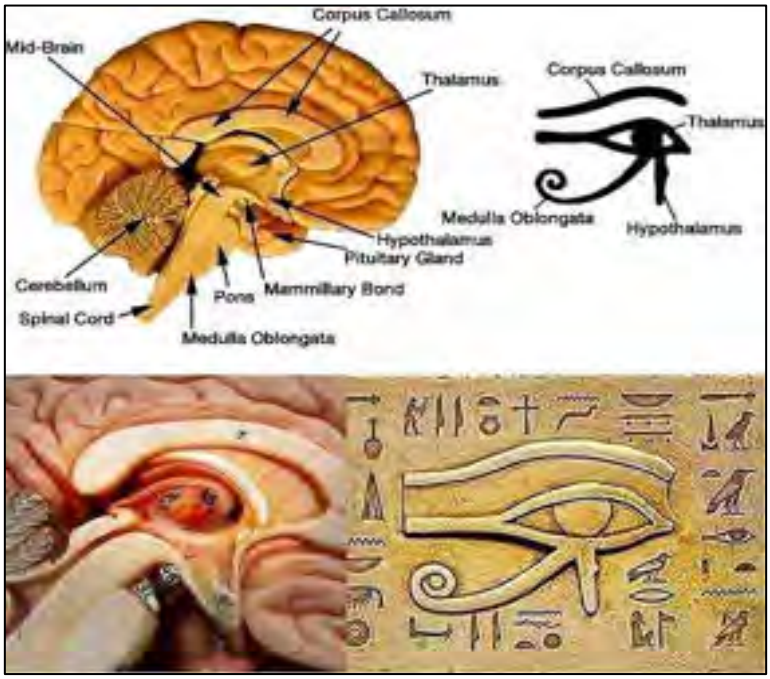

Figure 8: Pineal Gland in Brain and Egyptian Culture

Retrieved from https://en.wikipedia.org/wiki/Pineal_gland

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2.2 Moiré Pattern, Constructive and destructive - graphene interference patterns

Scientific Principles

A **Moiré pattern** appears when two grids or patterns are overlaid with a slight twist. The result? A new, often beautiful pattern emerges—seemingly complex but born of simple structures (Hecht, 2017).

Graphene is a two-dimensional allotrope of carbon showing unique properties like high tensile strength and very high electron mobility. When two Graphene sheets, each having a honeycomb lattice of carbon atoms, are twisted against each other, beautiful Moiré patterns are generated. It was shown that one graphene sheet overlaid above the other with a twisted magic angle of 1.1° graphene becomes a superconductor.

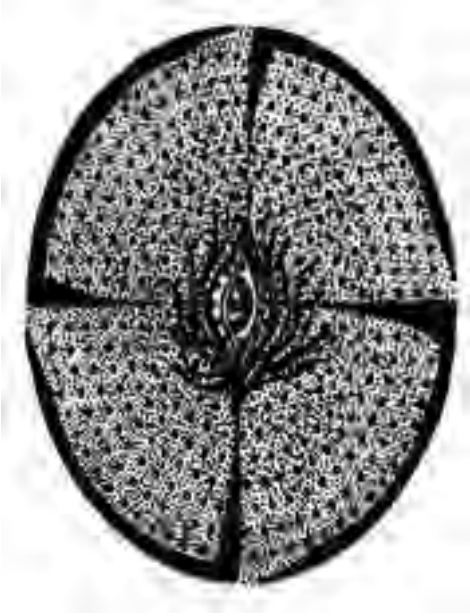

Figure 9: Third Eye with Peacock Feathers

Figure 10: Moiré-Graphene interference pattern

Spiritual Perspective

Life is like a Moiré pattern.

We look at the world through layers of belief, desire, and emotion. What we see is not always what it is, but what appears. Vedanta calls this Mithya—illusion. The Brahman, or the ultimate reality, lies beyond the shifting patterns of perception.

Graphene's twisted symmetry reminds us: simple truths, when layered and rotated, create beauty—and sometimes confusion. What if the mind's restlessness is just misalignment? What if a small shift in attitude, awareness, or attention—can reveal a higher pattern?

The Moiré toy becomes a metaphor. As students rotate layers, they observe how new forms emerge. With mindfulness, they begin to understand: What looks complex may come from something very simple.

And just like that, physics becomes philosophy. A toy becomes a teacher.

3. Hinge Mechanism and the Dancing Monkey: Unlocking Movement and Mind

Figure 11: Hinge mechanism : Dancing Monkey

Scientific Principles

A **hinge** is one of the simplest mechanical systems—yet its applications are everywhere, from doors and boxes to robotics and toys. It allows two connected parts to **pivot** around a common axis, enabling controlled motion in a single plane.

In this toy, **toothpicks and thread knots** are cleverly used as makeshift hinges to give movement to the monkey's limbs. These joints offer **degrees of freedom**, making the monkey appear playful, animated, and lifelike.

From a physics perspective, hinges are about **constraint and flow**—permitting motion, but within limits. They are essential in building systems that mimic natural movement while maintaining structure.

Spiritual Perspective

But what does a **dancing monkey have** to do with the mind?

In the **Upanishads**, the mind is described as *Markatasya Manah*—like a monkey. It **leaps from one thought to another**, rarely still, easily distracted, never satisfied. This restless mind, if left unchecked, becomes the biggest hurdle in learning, focus, and self-growth.

Just like a monkey swinging through trees, our untrained mind jumps from **desire to fear**, **past to future**, rarely pausing in the present.

Now imagine the monkey's joints held together by **hinges**. Each hinge limits chaotic motion and brings **grace to its movements**. Similarly, when we **tie our thoughts to awareness**—through mindfulness, meditation, or deep focus—we begin to dance with clarity, not chaos.

Ask yourself:

- What hinges have I built in my own mind?
- Do my thoughts swing wildly, or do they flow with rhythm and control?
- What holds me together when everything feels scattered?

This toy teaches more than mechanics. It reminds us: **freedom without structure leads to frenzy**, but freedom with awareness becomes a dance.

4. Surface Tension and Bubbles: Seeing the World in a Drop

Scientific Principles

What keeps a bubble from bursting instantly? **Surface tension**—a subtle, invisible force acting like a stretched skin across the surface of a liquid. Molecules at the surface experience a cohesive pull inward, minimizing area and forming the most efficient shape possible: a **sphere**.

This is why soap bubbles always round out, regardless of their initial shape. The force balances inner air pressure with external atmospheric pressure, creating delicate, iridescent forms that float and shimmer… for a moment.

But science doesn't stop at the *how*. It's in the *why* that wonder truly begins. The world thus appears to be a complicated tissue of events, in which connections of different kinds alternate or overlap or combine and thereby determine the texture of the whole. *Werner Heisenberg*, as quoted in *The Tao of Physics* (Capra, 1975)

Figure 12: Soap bubble mechanism

A Wire is rolled into a loop, so it creates a closed boundary for soap film. The wire is attached to the shaft

Figure 13: Colorful Soap bubbles

Retrieved from https://pikbest.com/backgrounds/soap-bubbles-three-small-placed-in-black-background_9473549.html

Spiritual Perspective

A bubble is a **miracle** in midair—a translucent, temporary universe. It lives briefly, reflects light beautifully, and then... *pop*. Gone.

Isn't that also life?

The **Bhaja Govindam**, composed by *Adi Shankaracharya*, says:

Punarapi jananam punarapi maranam, punarapi jananī jaṭhare śayanam... Again birth, again death, again lying in the mother's womb—this cycle is endless unless one seeks liberation.

Just as a bubble arises from still water and vanishes into air, so too do we emerge, shine briefly, and dissolve back into the cosmic flow. Life is fragile, vibrant, and short—and that is precisely what makes it meaningful.

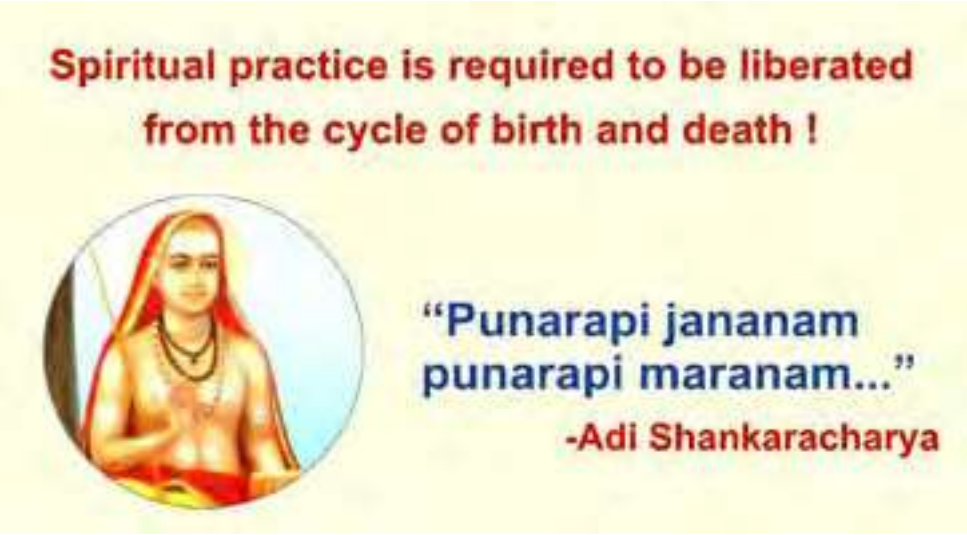

Figure 14: Adi Shankaracharya's Thoughts on Life

Retrieved from www.sanatan.org/en/a/110659.html/englishpravachan_part2_12

In **Vedanta**, the world is often described as *Maya*—a constantly shifting illusion, never permanent. A bubble teaches the same: *do not cling*. Enjoy the play of light, the color, the motion—without losing yourself in it.

What we observe is not nature itself, but nature exposed to our method of questioning. — *Werner Heisenberg*(Capra, 1975)

Physics teaches form, but *spirituality teaches impermanence*. Together, they reveal a truth we often miss: reality is always in motion, held briefly by forces we barely understand.

Figure 15: Artistic Representation of Life Cycle and Rebirth

Retrieved from https://www.bvashram.org/from-death-to-immortality/

So, ask yourself:

- What bubbles am I chasing? Can I find joy even in what is short-lived?
- Am I clinging to form, or am I watching the dance?

Life, like a bubble, is not meant to last—but it is meant to shine.

As C. Rajagopalachari beautifully wrote in his commentary on *Bhaja Govindam*: When intelligence matures and lodges securely in the heart, it becomes wisdom. When that wisdom is integrated with life and issues out in action, it becomes devotion.

In this toy, children blow bubbles, watch them float, and then disappear. But in that play, a quiet lesson unfolds: **everything beautiful must pass, and that's what makes it sacred**.

5. Consciousness and Energy : Shiva Shakti Dance and the Cosmic Rhythm (Taal)

Figure 16: Shiva-Shakti, Consciousness and Energy

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Scientific Principles

Outside CERN—the world's leading particle physics laboratory—stands a statue of **Lord Nataraja**, symbolizing the **cosmic dance of creation, preservation, and destruction**. This is not merely an artistic display; it is a conscious acknowledgment that **science and spirituality together help us understand the deeper patterns of reality**. As stated by CERN, the dance of Nataraja is a beautiful metaphor for the rhythms of the universe observed in particle physics (CERN, 2004).

Fritjof Capra, in *The Tao of Physics Book* (1975), explains that the **dynamic dance of subatomic particles is** remarkably similar to the Tandava dance of Nataraja. In both cases, movement is fundamental—not just to existence but to creation itself. Nataraja's form,

encircled by a ring of fire, represents **energy in perpetual motion**, and his posture symbolizes **balance amidst chaos**—an image mirrored in the behavior of particles in quantum fields.

This imagery becomes even more relevant when seen through the lens of Einstein's **theory of relativity**, which radically changed how we understand **space, time, and mass**. In relativity, the absolute space and time are no longer constants; they are dependent on the observer. The realization that **mass is a form of energy**, summarized by the famous equation $\mathbf{E = mc^2}$, echoes the Shiva-Shakti Principle. In Indian philosophy, Shiva represents stillness or pure consciousness (mass or potential), and Shakti represents energy and motion (dynamic creation). Together, they form the **cosmic balance of being and becoming**—just as mass and Energy is not separate, but deeply interconnected aspects of reality.

Figure 17 : Art made by author with white paint on black paper, representing dance of particles. Inspired from an image of bubble chamber, pg 236 Tao of Physics book. Image captured a shower of about 100 particles produced by a cosmic ray which found its way into a bubble chamber by accident. The roughly horizontal tracks in the picture belong to the particles coming out of the accelerator

.

An unexpected cosmic-ray shower, accidentally captured in a bubble chamber at CERN during an experiment, provided a magnificent visual of this energy dance.

For modern physicists, Shiva's dance represents the dance of subatomic matter. This continual cosmic dance of creation and destruction, mirroring Hindu mythology, underpins all existence and natural phenomena. Centuries ago, Indian artists beautifully depicted dancing Shiva in bronze. Today, physicists use advanced technology to visualize these cosmic patterns. Bubble-chamber photographs of interacting particles, testaments to the universe's constant rhythm of creation and destruction, are as beautiful and profoundly significant as the ancient Indian artworks. Thus, the metaphor of the cosmic dance seamlessly unites ancient mythology, religious art, and modern physics, proving, as Coomaraswamy noted, to be "poetry, but nonetheless science."

Spiritual Perspective: The Cosmic Dance

In Indian philosophy, Shiva’s Tandava is the dance of cosmic cycles—creation, preservation, and destruction—while Shakti’s Lasya is the dance of grace, nurturing, and renewal. Together, they create **Taal—the eternal rhythm of existence.**

The ancient image of Shiva Nataraja—the Lord of the Dance—is not merely artistic; it is deeply philosophical and uncannily aligned with modern scientific understanding of reality. In Hindu thought, Shiva’s cosmic dance is the eternal rhythm of creation, preservation, and destruction—the pulse of the universe itself.

Ananda Coomaraswamy described it powerfully:

“Dancing, He sustains its manifold phenomena… This is poetry, but nonetheless science.”

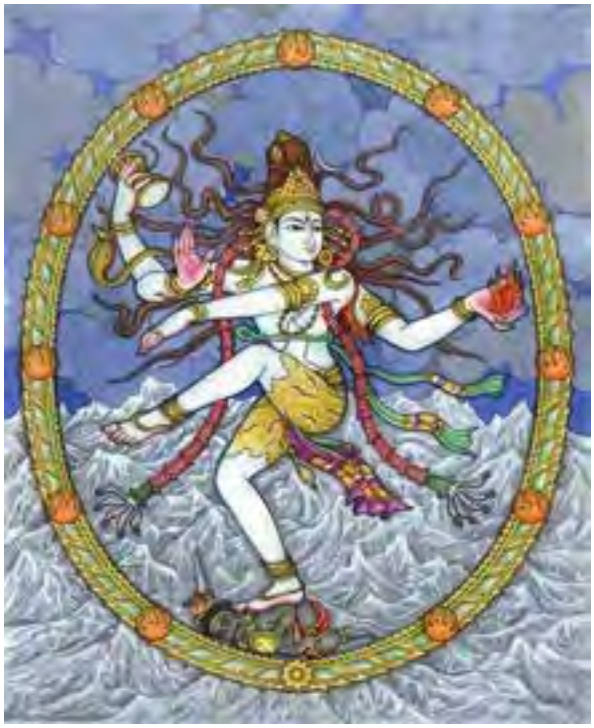

Figure 18: Shiva in Nataraja pose Retrieved from https://www.wikiwand.com/fr/articles/Tandava

Figure 19 : The statue of Nataraja at CERN

Retrieved from https://cds.cern.ch/record/768796 CERN provides the image free of charge for educational and informational use.

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Heinrich Zimmer echoed this sentiment, writing:

"His gestures… are the continuous creation-destruction of the universe, death exactly balancing birth, annihilation the end of every coming-forth."

Bronze sculptures from 10th–12th century South India bring this symbolism to life. Shiva's upper right hand holds a drum—the primal sound of creation. His upper left bears fire—symbol of destruction. The balance of these opposites is reflected in the serene, detached face at the center: calm amid chaos.

His lower right hand, raised in the abhaya mudra (fearlessness), represents protection and reassurance. The left-hand gestures toward the lifted foot—liberation from illusion (maya).

Underfoot, the god dances upon a demon, symbolizing ignorance. Only by transcending this ignorance can one be free.

In this image, spirituality meets science. As Capra (1975) notes in The Tao of Physics, the dynamic balance of Shiva's dance parallels the quantum world's fluctuations: "The dance of Shiva is the dance of subatomic matter… the rhythm of creation and destruction, of energy and form."

Shiva's dance, then, becomes a universal metaphor—bridging mysticism, cosmology, and art. It invites learners not only to observe the world, but to feel its rhythm. Through this lens, education expands—beyond information—toward awareness.

This perspective is not evidential—it is experiential. It reflects the author's learning journey within the *Designing Scientific Toys course*, where **spiritual understanding emerged naturally through scientific creation**.

Methodology and Mechanism - Educational Theories

Educational theories help us understand how people learn—not just what they learn. In this project, the author explored how key theories by Piaget, Skinner, Thorndike, Bloom, and the 8 Learning Events Model could be naturally integrated into the toy-making process. These theories not only supported the construction of toys but also made the entire learning journey more thoughtful, engaging, and reflective.

Jean Piaget's cognitive development theory states that learners, especially during the concrete operational stage, understand concepts best through direct interaction with physical objects. In this project, building the **cam-shaft-follower mechanism helped** the author visualize Newton's laws and torque by observing how rotary motion transformed into vertical motion (Norton, 2009; NCERT, 2023). Physical experience made abstract concepts more real and memorable.

Application: In schools, this model can help middle-grade students grasp motion through manipulation. In colleges, it can aid pre-service teachers in learning pedagogy through STEAM. At home, parents can use it as a DIY physics model with storytelling.

B.F. Skinner's reinforcement theory suggests that behaviors followed by positive outcomes are more likely to be repeated. During the iterative toy-making process, every time a model worked as intended—like the **hinge-based monkeys swinging** smoothly—it provided a sense of achievement. This success reinforced accurate understanding and encouraged further experimentation (Halliday et al., 2013).

Application: In classrooms, teachers can use small toy successes as immediate reinforcement tools. In colleges, it encourages project-based learning. At home, children can be motivated to build and improve through small wins.

Edward Thorndike's Law of Effect states that actions leading to satisfying outcomes are remembered and repeated. This was experienced while aligning patterns in the **Moiré interference model**. After repeated trial and error, the correct visual effect appeared, making the principle of constructive and destructive interference clearer (Hecht, 2017; NCERT, 2023). The joy of seeing it work encouraged repeated attempts, leading to mastery.

Application: In schools, it can support science labs and design thinking tasks. In colleges, it is useful in teacher education for reflecting on learner behavior. At home, it promotes persistence through trial-based learning.

Bloom's **Taxonomy Provides** a layered model for learning—starting from remembering and understanding, and moving towards applying, analyzing, evaluating, and creating. This process was clearly seen as the author recalled scientific principles, applied them to build toy prototypes, analyzed mechanical failures, and ultimately created new designs. Each toy-making step involves a higher level of thinking and problem-solving.

Application: In classrooms, it can guide lesson planning and assessment. In colleges, it provides a structure for inquiry-based or STEAM learning. At home, parents can use it to encourage creativity in children by letting them invent their own toys.

The 8 Learning Events Model (Leclercq & Poumay) outlines a full cycle of learning: receiving knowledge, exploring it, practicing skills, getting feedback, and creating something new. It reminds us that real learning happens when learners are active participants, not just listeners. *Making the toy*: This entire model unfolded naturally during the toy-making process. First came the intake of knowledge (receiving), followed by trying out materials (exploration),

assembling parts (practice), testing and reflection (feedback), and finally, creating a functional, meaningful learning toy. These stages were not only academic, but they were also emotional and philosophical too.

Application: In school or home environments, this model promotes deep learning through doing. In colleges, it supports reflective teacher training through making and critique.

These theories naturally came alive during the creation of the toy. This toy-making journey was more than just a task or assignment, it became a space for thinking, feeling, and exploring. The educational theories provided a kind of scaffolding; they helped make sense of each step. Scientific principles acted as tools—guiding how things move, react, or connect. But it was the process of making, failing, adjusting, and creating that brought everything together. It was not just about understanding a mechanism; it was about seeing how an idea becomes real, how a motion mirrors a thought, or how a pattern reveals something deeper. In this quiet space of hands-on learning, the author found a way to connect classroom ideas to life, and perhaps more importantly, to the self. In short, Pedagogical theories shaped how the toy was built. Science explained how it worked. Reflection gave it depth. And spirituality gave it meaning.

Methodology and Mechanism - Build, Observe, Reflect

This model brings science alive through hands-on exploration. Instead of ready-made kits, the entire system is built using upcycled materials—an approach that mirrors both *engineering ingenuity and spiritual mindfulness*. Below are step-by-step guides for creating the models using basic household waste. Each activity is paired with reflective prompts to deepen understanding.

1.Cam-shaft-follower mechanism*:*

Scientific Concept: Converts rotary motion into up down or back-and-forth motion using offset cams and followers.
Theme: *Cause and Effect, Motion and Karma*

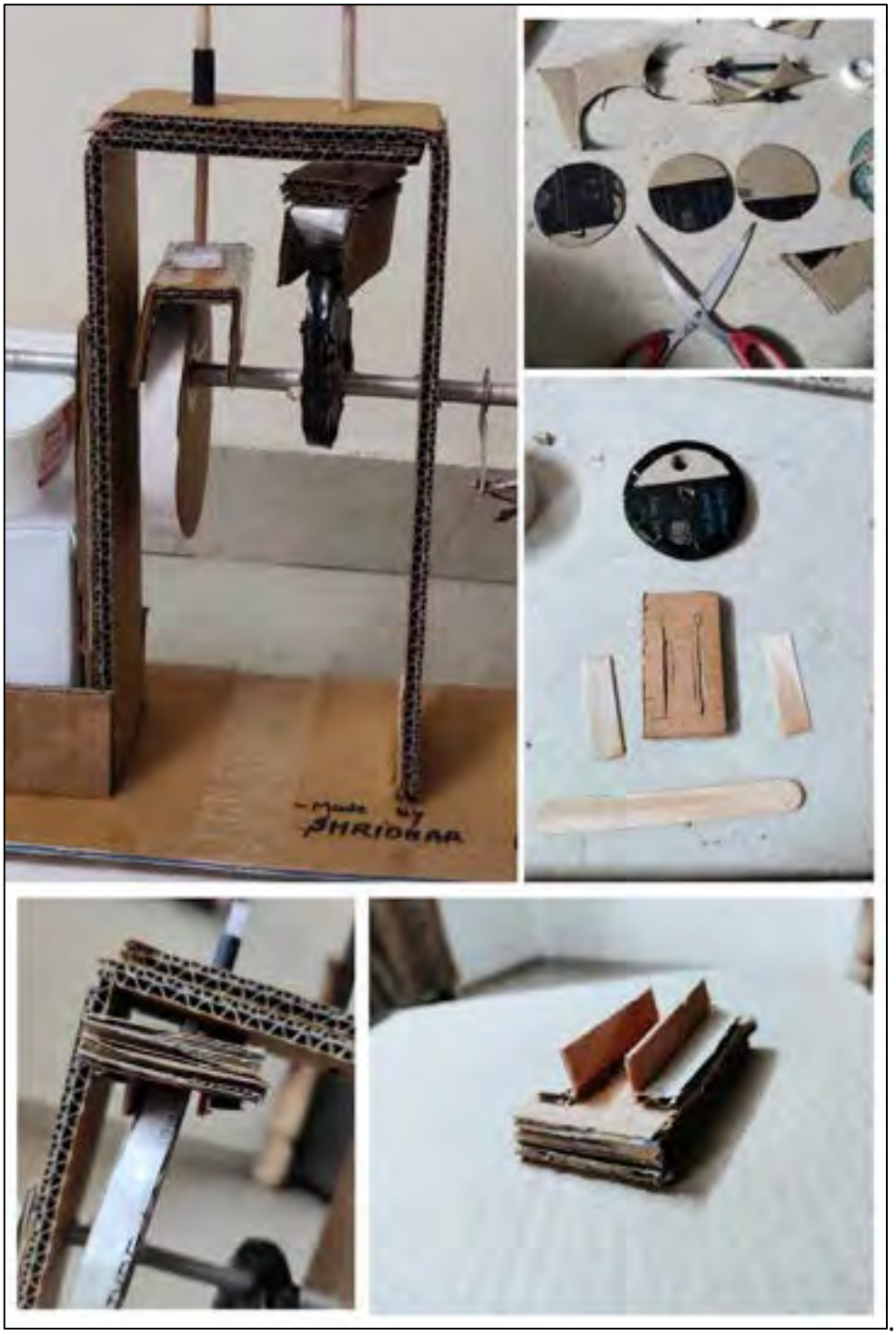

Figure 20: Cam-shaft-follower mechanism

Materials Needed:

- Cardboard (repurposed boxes) ,Scissors or craft knife, Pen refills or skewers (as camshaft), Glue or tape, Thermocol / bottle caps (to create a frame), Scrap paper, markers

Steps:

1. Cut out 2–3 circles from cardboard. Stack and glue them to make a **cam**.
2. Skew the circles slightly while stacking to create an *offset cam*.
3. Insert a pen refill through the center to make a **shaft.**
4. Mount the shaft on a frame (thermocol or reused plastic tray) so it rotates freely.
5. Cut a rectangular strip from thick paper or cardboard to act as the **follower**.
6. Position the follower vertically so it rests on the cam.
7. Rotate the shaft and observe how the follower rises and falls.

Reflective Prompts:

- What determines the height and rhythm of the follower's motion?
- In your life, what cam patterns—habits or desires—guide your actions?
- Can adjusting your routine (cam profile) lead to smoother outcomes?

2. Moiré Pattern - graphene interference pattern

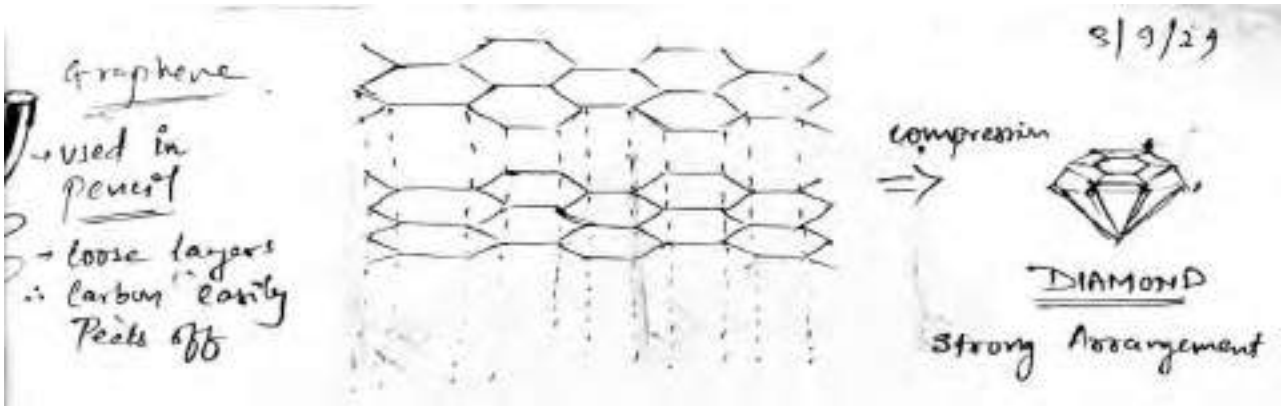

Figure 21: Author's Sketch , Class Notes - Course: Designing Scientific Toys

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Scientific Concept: Overlapping grids or patterns create visual interference—like in twisted bilayer graphene.

Theme: *Perception vs. Reality*

Figure 22: Making of Moiré interference patterns

Materials Needed:

- Transparent plastic sheets (used wrappers, folders), Permanent marker, Ruler, Stapler or thread

Steps:

1. On two plastic sheets, draw identical sets of parallel lines spaced evenly (around 5 mm apart).
2. Overlay one sheet on top of the other.
3. Slowly rotate the top sheet.
4. Watch as flower-like or wave patterns emerge and shift.

Reflective Prompts:

- How does slight rotation change what you see?
- What patterns in life change with just a small shift in perspective?
- What does this say about illusion (*Maya*) and perception?

3.Hinge-Based Motion (The Dancing Monkey)

Scientific Concept: Hinges add flexibility and degrees of freedom to systems.

Theme: *Discipline vs. Distraction – The Mind as a Monkey*

Materials: Needle and threads, thick cardboard, stick or toothpick, colors.

Steps:

- Attach the hinge to the fixed support and the movable panel/thick paper using thread knots or screws.
- Move the two pieces to observe the movement.
- Measure the rotation angle and analyze force distribution at the hinge.

Figure 23: Up cycle: Dancing Hinge based Monkey

Photographed by Author . Made using old garment cardboard box, toothpick and threads to teach science!

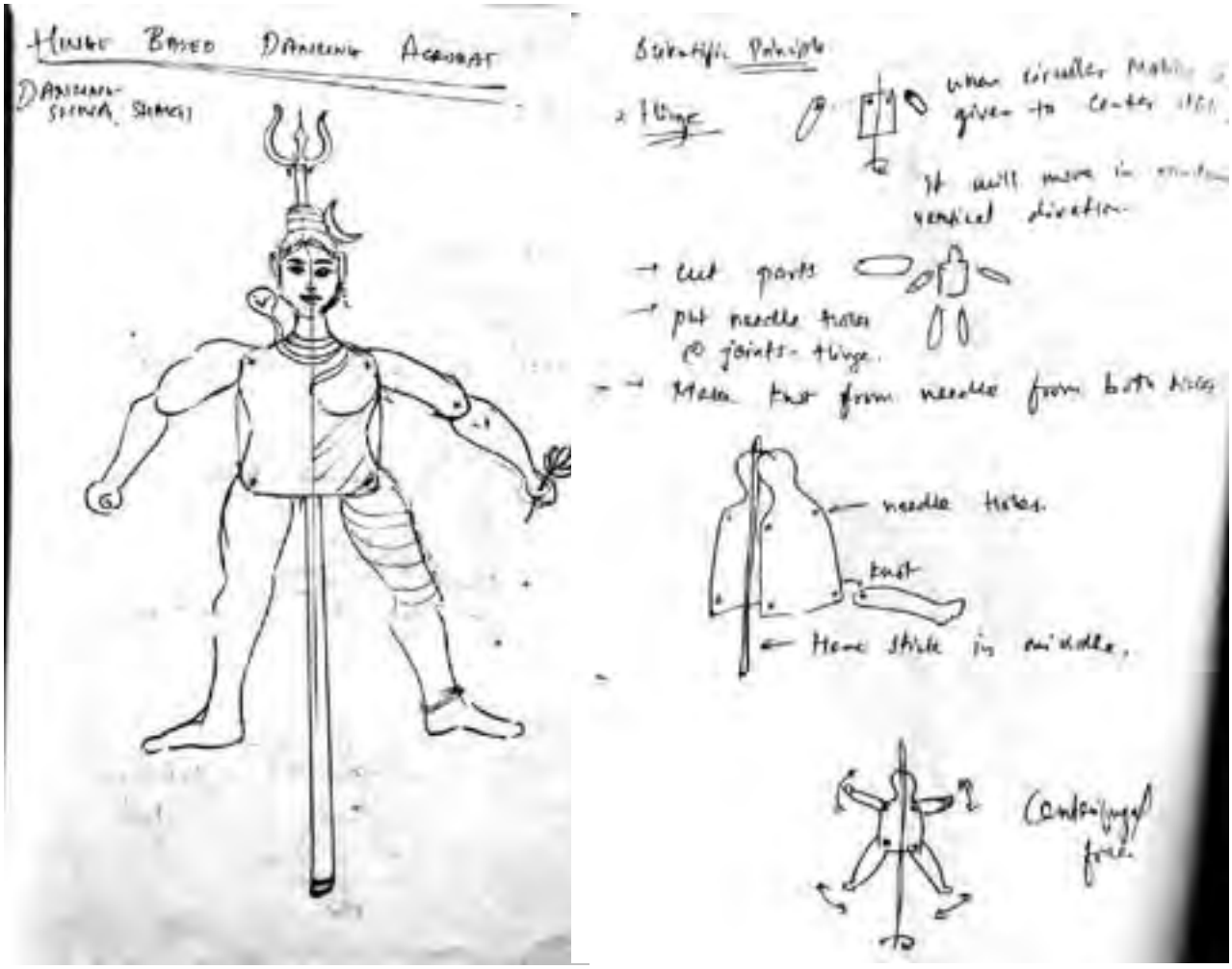

Figure 24: Hinge based mechanism Designing in process - Sketches and notes

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Reflective Prompts:

- How do the hinges allow movement?
- What makes your thoughts swing back and forth like a monkey?

What practices help train the mind and bring it to stillness?

4. Surface tension and bubbles formation:

Scientific Concept: Molecules at the surface of water experience cohesive force, forming bubbles.
Theme: *Impermanence and the Beauty of Now*

Materials: Water (300 ml), soap or detergent (100 ml), glycerin (200 ml), plastic container and wire in a closed loop.

Steps:

1. Mix water with soap and glycerin to reduce surface tension.

2. Dip the straw or wand into the solution and blow gently to form bubbles. Here the wire loop is joined at the end of the shaft such that it rotates when rotating the handle. 3. Observe the shape, size, and lifespan of bubbles.

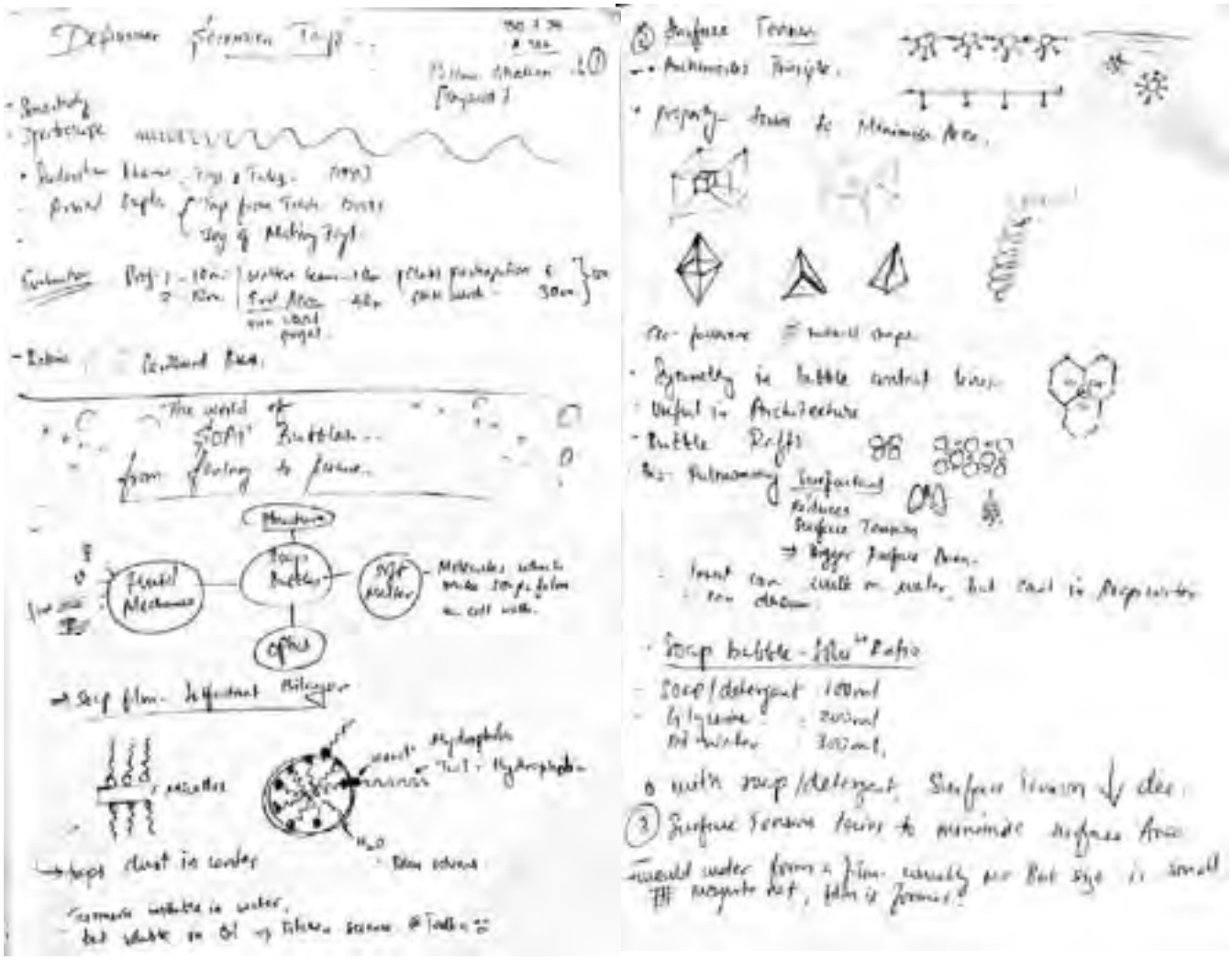

Figure 25 : Author's Class Notes - Course: Designing Scientific Toys

Figure 26: Upcycle: Soap solution Tray made from Amul Cheese container.

Photographed by Author . Small grooves made for shaft support. Instead of going into Trash, now it will be a tool to teach science!

Figure 27:Soap Bubble formation Mechanism

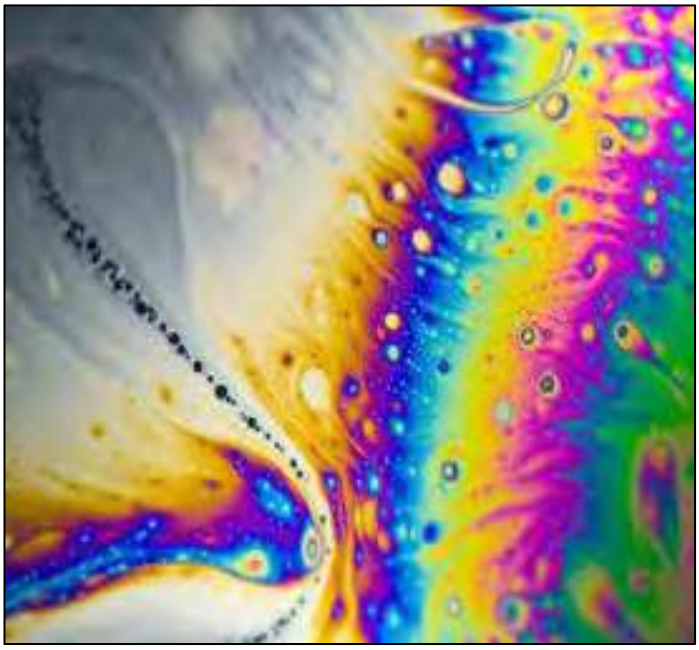

Figure 28: Soap Bubbles Iridescent rainbows

Retrieved from : https://www.wired.com/story/the-secret-to-soap-bubbles-iridescent-rainbows/

Reflective Prompts:

- Why do bubbles pop even when they seem perfect?
- What in life is short-lived yet beautiful?
- Can we love something without holding on to it?

In Summary

Each mechanism is more than an engineering concept, it's a metaphor. Each toy invites not just to play, but presence. And each recycled part teaches not only physics, but values—care, creativity, and curiosity.

Application and Exercises :

A Hands-On Way to Learn Science (and more)

Imagine starting the semester with a cool science toy or model—something students can touch, play with, and take part in. Along with it, they would get a simple DIY kit to build their own version. Here is how it could work:

First, students explore a ready-made model. They tinker with it, watch how it moves, and talk about what makes it work. They jot down the science behind it—laws of motion, energy transfer, whatever applies—and even reflect on how it connects to bigger ideas (like balance in nature or cause-and-effect in life).

Then, they get their hands dirty. Using the DIY kit, they rebuild the model themselves. This time, they'll notice details they missed before—why a certain part rotates this way, how friction changes the motion. The best part? Each group can add their own twist—maybe tweak the design, throw in extra gear, or even mix in some art. It is not just copying; it is creating.

Make It a Cross-Campus Project

Take it further by turning it into a collaborative, interdisciplinary effort:

- **B.Ed students** identify difficult science concepts students struggle with.
- **Science majors** design physical models to illustrate those concepts.
- **Engineering students** contribute mechanics, levers, lights, or sensors.
- **Art and Design students** create visual impact and narrative meaning.

The result? A mini-innovation lab where creativity meets critical thinking, and theory meets hands, heart, and imagination.

Glimpses of Exercises Inspired by Physics, Mysticism, and Mindfulness

This is just a glimpse. The author, a lifelong seeker, hopes one day to compile a full workbook of interdisciplinary exercises. For now, let this be a beginning.

"Imagination is more important than knowledge."
"The most beautiful experience we can have is the mysterious." — Albert Einstein

Set 1: Quantum Curiosity – The Mind as Observer

1. Wave or Particle?

- Watch a double-slit experiment video.
- **Art Task:** Paint what you feel—dots, waves, or both.
- **Reflective Question:** When no one is watching, light behaves like a wave. But when observed, it becomes a particle. *What does that say about how your attention shapes reality?*
- **Spiritual Link:** In the Upanishads, the seer and the seen are one. Is observation itself a form of creation?

2. Entangled Twins

- Simulate entanglement with two similar coins.
- **Creative Task:** Write a dialogue between two twins who feel each other's emotions across continents.
- **Vedic Link:** Indra's Net—each jewel reflects all others. *How interconnected are we really?*

Set 2: Cosmic Labs – Playing with Time and Space

3. Black Hole Mandala

- Watch a black hole visualization. Watch the Interstellar movie by Christopher Nolan. Discuss The Black Hole, time travel and relativity.
- **Art Task:** Create a mandala. Outer ring: collapsing stars. Center: unknown.

- **Philosophical Prompt:** Is consciousness like a black hole—drawing in all thought until only stillness remains?

4. Time Dilation Journal

- For one week: Log all day, phone use time, sleep, break, study, work etc.
- Record "heart time"—moments of joy or flow.
- Lay down on the terrace at night, or near a river or seashore, on a park bench… stargaze or sky gaze and write about cosmic time.

Final Question: Which one felt most real? Short or stretched? Why? Describe.

Consciousness Experiments

5. Observer Effect Diary

Quantum Prep: Read about Schrödinger's cat .

Campus Activity: For 3 days: Morning: Predict how many people will smile back. Evening: Record actual smiles when you initiate.

Bhagavad Gita Link: "Does seeing require a seer? Can there be light without your eyes?" Who

Why This Works:

True Interdisciplinary: science "and" spirituality - shows they're two languages describing one reality. Cognitive Friction: Creates productive discomfort ("Wait, how can light be both?") Embodied Learning: Uses body (art), mind (science), and gut (philosophy)

Teacher Tips:

Start sessions with 3 minutes of Mindfulness Meditation (calibrate "observation instruments", *Already in practice at Bachelor of Education program, Navrachana University*). Use "What if…" questions more than "What is…". Celebrate wrong answers that show deep thinking

Exercises set 2

3-Minute Meditations for Online Classes/Home Practice

(Based on Vigyan Bhairav Tantra, Zen & Taoist Masters)

A. "Breath Gap" Meditation (Vigyan Bhairav Tantra#15)

Practice: At the start of class, the teacher says: "Notice the tiny pause after exhaling… wait there for 3 breaths." Students observe the natural stillness between breaths.

Art: While taking deep breaths, make an artwork which shows art, science and spirituality. Example:

Figure 29: Art as Bridge between Science and Spirituality

Illustration generated using ChatGPT (GPT-4o), OpenAI, 2025, based on conceptual input and design by the author.

Why It Works:

Science: Activates parasympathetic nervous system (Frontiers in Human Neuroscience, 2018)

Tantra: "In the gap between thoughts, taste infinity."

B. "Hand Awareness" (Zen & Taoist Embodiment)

Practice: Rub palms vigorously for 10 seconds until warm. Freeze motion but keep feeling the tingling energy. Ask: "Where does the 'aliveness' in your hands come from?"

Scientific Twist: Maps to homunculus brain model (hands occupy large portion of somato-sensory cortex)

C. "Sound Vortex" (Vigyan Bhairav TantraTantra#33)

Practice: Play a singing bowl, tuning fork, or app sound. Students close their eyes and raise their hands when the sound fades completely. Notice the silence afterward.

Neuroscience Link: Trains attention like fMRI neurofeedback (Nature Scientific Reports, 2020)

Research: Why are Bells placed in religious gathering spaces of Hinduism, Buddhism, Christianity, Jainism and other world religions?

5-Minute Home Practices

D. "Third Eye Flashlight" (Tantric/Taoist Hybrid)

Practice: Sit in dim light. Hold the flashlight against closed eyelids. Move light slowly left-right while chanting "AUM" softly. After 2 minutes, turn off the light but observe the inner glow.

Science Connection: Stimulates pineal gland (melatonin release) via retinal exposure

E. Difference between Religion and Spirituality.

Debate: Share views and do research.

Practice: Explain how both are different in practice.

Art: Draw a painting which shows Science, Religion and spirituality

Example: Figure 28

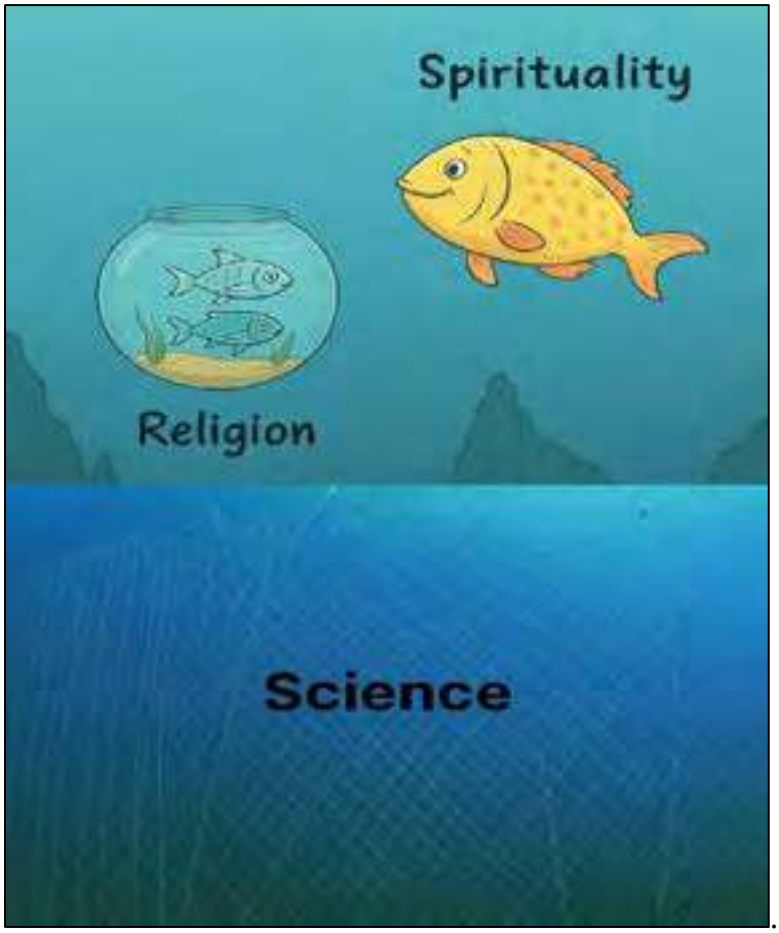

Figure 30 Artistic Representation of Religion, Science and Spirituality. *Science is a net to grasp nature and reality, the size of net varies to grasp life in ocean .Still one needs to take a deep dive in ocean to understand and feel the ocean life.*

Illustration generated using ChatGPT (GPT-4o), OpenAI, 2025, based on conceptual input and

Why Practice Beats Theory: Neurological Rewiring

Meditation grows the prefrontal cortex (Harvard, 2011) Reading about meditation activates only language centers

Para Vidhya (Higher Knowledge) Requires: Direct Experience: Like tasting chocolate vs reading about it. Embodied Insight: Buddha attained awakening through practice, not scrolls

Modern Proof:

MRI scans of monks reveal gamma waves during compassion meditation (Prof. Richard Davidson, UW-Madison)

Student-Friendly Explanation

"Imagine trying to learn swimming by only reading books. You might understand buoyancy, but you will still sink. Real wisdom—in physics or self-awareness—comes from doing, failing, and feeling. These mini meditations are like mental push-ups for your inner scientist."

Scope of Improvement/Evolution:

Electromagnetic Induction Demonstration

Enhancement: Attach a set of magnets and copper wire to the rotating shaft, causing a bulb to light up. Teaching Principle: Demonstrates how a changing magnetic field (from the spinning shaft) induces electron flow in the wire—the core concept behind generators and electricity.

Gear Systems & Energy Centers

Enhancement: Introduce a 7-gear mechanism to teach gear ratios and mechanical advantage. Interdisciplinary Link: Connect each gear to one of the 7 chakras (energy centers in yogic philosophy), merging physics with mindfulness. For example:

Gear 1 (Base): Stability and foundational motion (like the Muladhara chakra). Gear 7 (Crown): Precision and harmony (Sahastrara chakra).

IoT/AI Integration (University Level)

Advanced Model: Design a robotic prototype incorporating:

Microcontrollers (Arduino/Raspberry Pi) and sensors (ultrasonic, IR, temperature/humidity) mimic human senses. Spiritual Link: Map sensors to the Pancha Indriyas (five senses in Ayurveda), e.g.: Ultrasonic sensor ≈ Hearing (Shrotrendriya). Temperature sensor ≈ Touch (Sparshanendriya).

AI Layer: Use machine learning to analyze sensor data, prompting discussions on consciousness (e.g., how the "robot mind" processes inputs vs. human intuition).

Why It Works:

- **Hands-on Physics**: From Faraday's law to gear mechanics, grounded in real-world applications.
- Holistic Learning: Bridges STEM with self-awareness (chakras, senses).
- Scalable Complexity: Adaptable for schools (basic models) or universities (AI/robotics).

- **Integrated Learning:** Science will merge with vital sustainability lessons and ethical thinking.

What Students may Learn

This project opens the door to a kind of learning that engages the whole being—hands, head, and heart. Students do not merely absorb information; they interact with it, reflect on it, and question it.

- They build, break, and rebuild—developing problem-solving skills not by memorizing steps but by navigating real constraints, like material limitations or design flaws. Trial becomes their teacher.
- They learn science by doing. Concepts like torque, motion, and wave interference become more than textbook terms—they are seen, touched, and felt. A cam mechanism no longer exists only on a page; it becomes a rotating truth about how action creates movement.
- They see waste differently. By using recycled materials—pen refills, bottle caps, cardboard—they realize that sustainability is not a theory but a habit. What we throw away has value. So does what we ignore.
- They make sense. Through integration with spiritual ideas—karma, illusion, stillness, balance—students begin to reflect: What powers this motion? What lies in the gap between breaths? What does this pattern remind me of in life?

- They feel the beauty of learning. Art transforms the process into play. Creativity becomes the paintbrush that colors even the most logical of lessons. Science becomes poetic; spirituality becomes practical.
- They ask better questions. Not just What is the answer? But What does this mean to me? What am I missing? Who am I, beyond grades and goals?
- Each toy becomes a mirror. Each meditation becomes a doorway. Students begin to grasp not only the laws of the physical world, but the inner laws of attention, intention, and presence.

In the long run, such learning plants quiet seeds—of resilience, of curiosity, of conscious living. Because the real test is not just how much we know—but how deeply we live what we learn.

Conclusion

What if science could feel like poetry? What if learning physics could also open a door to the soul?

This case study is a perspective. One that suggests we do not need to separate equations from emotion or discard inner exploration in pursuit of external results. When science, art, and spirituality are allowed to meet—through a humble scientific toy, made from scrap—they begin to speak a common language.

The Tao of Physics reminds us:

"Every particle in the universe is in constant dance with others; nothing exists in isolation. What we call reality is a flow, a relationship, a process." (Capra, 1975)

Education, too, must reflect this. It must become a dance—not a drill. A co-creation between knowing and wondering. Between doing and being. Scientific toy-making becomes more than a project; it becomes a mirror for motion, cause, and consequence—a live demonstration of Newton and karma, of gears and choices. A Moiré pattern made with old plastic reveals the illusion of perception. A soap bubble becomes a reminder: all beautiful things are also fragile.

And somewhere in this process, students begin to pause—not just between tasks, but between thoughts. They begin to ask better questions—not just "how does it work?" but "why does it matter?" They begin to listen—not just to the teacher, but to their own inner voice.

In a time when 13,044 students in India took their own lives in a single year (ADSI, 2022), this shift matters. When self-worth hinges on marks and likes, and failure feels fatal, we need education that strengthens the mind as much as it trains the brain. This paper does not claim to have answers. It simply holds space for a different way—where doing meets being, recycling meets sacred, and STEM becomes STEAMS by welcoming Art and Spirituality into the equation.

Inspired by India's **NEP 2020** and **NCF 2023**, this approach aligns with global goals too. **It directly addresses SDG 3 (Good Health and Well-being), SDG 4 (Quality Education), and**

SDG 12 (Responsible Consumption). But more than checkboxes, it aims to light a spark—a deeper way of knowing and growing.

As the author reflects, this project was not merely a pedagogical experiment, it was a deeply personal journey. From confusion to clarity, from despair to design, each step revealed that the most valuable insight is not always what you teach, but how you live.

Nothing must be done. But something can begin. May that beginning be mindful, creative, and courageous.

The author, a believer in **Vasudhaiva Kutumbakam**—the ancient Indian ideal that "the world is one family"—prays for love, peace, and unity among all members of this shared global home.

He closes this case study—part perspective, part self-inquiry—with a timeless prayer from the **Brihadaranyaka Upanishad**, echoing a universal yearning for truth, light, and liberation:

ॐ असतो मा सद्गमय ।
तमसो मा ज्योतिर्गमय ।
मृत्योर्मा अमृतं गमय ।

Aum, lead me from the unreal to the real!
Lead me from darkness to light!
Lead me from death to immortality!

Let learning be an offering. Let inquiry be sacred. Let Life itself be the curriculum!

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Nitrosamine Impurities in Pharmaceuticals – An Awareness to enhance its Sustainability

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Abstract

The *N*-Nitrosoamines are the concerning class of genotoxic impurities with higher mutagenic potency that leads to carcinogenesis. These impurities are found in different types of Active pharmaceutical ingredients (APIs) and formulations were reminiscing from the market as soon as they were assessed. The present review represents the formation of nitrosamines by nitrosation reaction. Nitrosamines were classified into three groups according to their carcinogenic potential. The bioactivation of nitrosamines were undergone by two mechanisms i.e., by α- hydroxylation and by Cytochrome P450 Monooxygenase pathway. The methyldiazonium ion and formaldehyde, two reactive intermediates of nitrosamines alkylate the DNA to mutate it. The Acceptable intake (AI) was established with the help of the International Council for Harmonization (ICH) M7 (R1) guideline, using Tumorigenic dose 50 (TD_{50}) data with substance specific animal carcinogenicity data and using Carcinogenic potency categorization approach (CPCA) with no substance specific data. The CPCA approach establishes the five different categories and related specified AI limits for Nitrosamine Drug Substance Related Impurities (NDSRI's). To make drug and drug products sustainable, there is a need to bypass the threat of API scarcities or absolute loss of medicinal choices due to impurities like *N*-nitrosamines, which requires cooperation of Regulatory Authorities with Pharmaceutical industries is of greater importance to prevent economical as well as resources deprivation. Green synthesis of APIs by replacing the use of nitrating reagents with other most suitable green reagents might prevent the formation of nitrosamine impurities.

Keywords

N-Nitrosamines, Genotoxic Impurity, Risk assessment, CPCA approach.

Introduction

The *N*-nitrosamines, also mentioned as nitrosamines, which belong to the category which have nitroso group in its chemical structure. The present nitrosamine compounds have higher mutagenic potential and leads to cancer. Nitrosamines were previously detected in drinking water supplies, tobacco smoke, cosmetic products, beverages, grilled and cured meats, dairy products, and vegetables[1, 2, 3].

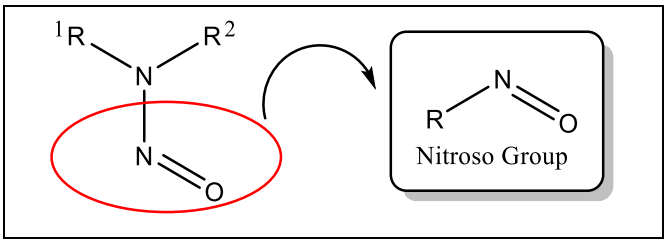

Figure 1: Structure of *N*-nitrosamine

Otto N. Witt the German chemist in 1874, conducted reaction between nitrous acid with secondary and tertiary amines the product formed is called “Nitrosamine”. Since 1954, nitrosamines didn’t get significant attention from the science communities.

In 1954, Peter Magee and John Barnes specified the *N*-nitrosodimethylamine (NDMA) as hepatoxic agent (The chemical which may damage the liver) in a study they found, two out of three men got liver cirrhosis working in laboratories in which the NDMA was used as solvent. They also reported carcinogenicity of NDMA in liver of rats in 1956. Due to this invention the rapid rise in interest of toxicology’s of *N*-nitroso substituents were developed.

In 1960, many farm animals fed with herring preserved in high amounts of sodium nitrite were suffering from liver disorders. The substance responsible for disorders were identified as NDMA. The present contaminant NDMA which might form due to reaction between dimethylamine from fish and nitrosating agent generated due to sodium nitrite.

12 Japanese patients found with hepatic injury because of intake of herbal Chinese dietary supplements in 2002. A hepatotoxic *N*-Nitrosofenfluramine was found in dietary supplement after analytical investigation [4, 5].

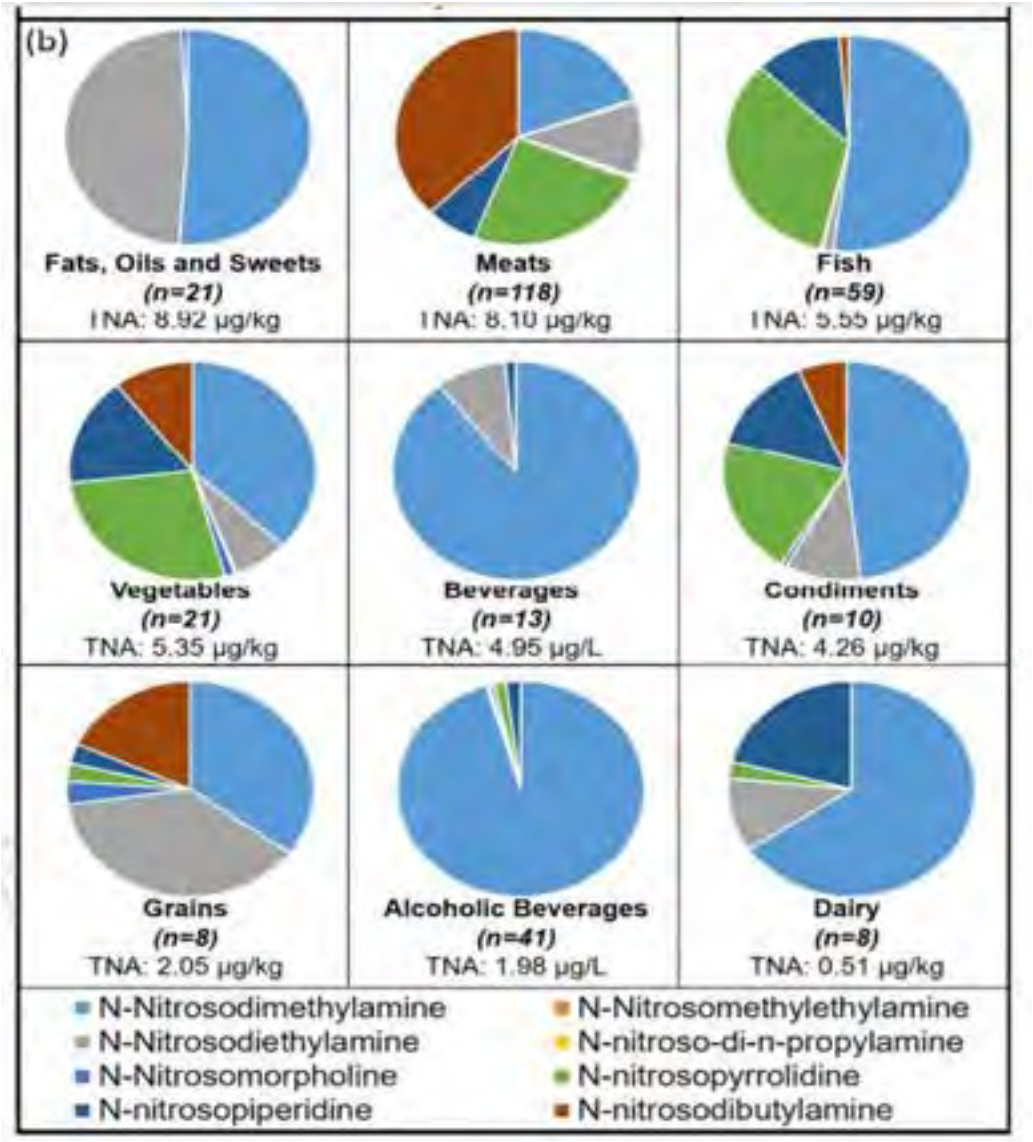

Figure 2: *N*-nitrosamine levels in different food categories.

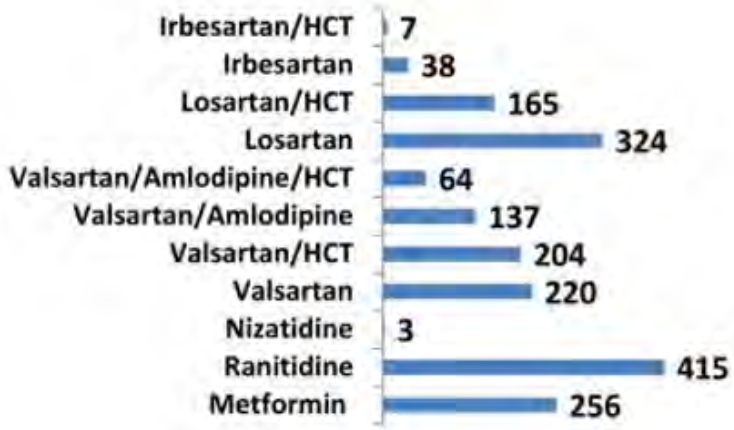

Figure 3: Batches recalled due to the presence of nitrosamines.

Since last 5 years starting from June 2018 the pharmaceuticals have been perceiving the crisis due to Nitrosamines. The Chinese manufacturer reported occurrence of NDMA in Valsartan API. The NDMA, *N*-nitroso-*N*-methyl-4-aminobutyric acid (NMBA), and/or *N*-nitrosodiethylamine (NDEA), as an impurity was established above acceptable limits within API and drug formulations with 22% as well as 18% respectively containing valsartan, losartan and irbesartan. About 1800 formulation batches containing antihistamines, sartans, antidiabetic drugs, and antibiotics were withdrawn from US market because of the presence of Nitrosamine impurities. This makes a compulsion of qualitative evaluation of nitrosamines in API's and medicinal products. The scenario has been changed after recollection of varenicline batches in various countries like Canada, USA and European union in 2021 because of existence of nitrosovarenicline as NDSRIs. The present case is further extended by recollection of various other APIs like quinapril, propranolol and orphenadrine due to their respective NDSRIs. The studies further reported that approximately 40% of common drug substances and 30% of their impurities are the potent precursors for nitrosamine synthesis because of amino functional groups in their structures out of which if we only consider most active secondary amines still 13-15% of drug substances are at potential risk. Therefore, the NDSRIs requires more attention in regulatory as well as industrial approach [6, 7].

1. Formation of Nitrosamines

The basic needs for synthesis of nitrosamines are acid, amine and inorganic nitrite. These requirements are necessary because the nitrite ion (NO_2^-) itself is not effective, therefore it should first react with the acid proton to form nitrous acid (HNO_2). Still HNO_2 is an intermediate for the generation of nitrosating agent dinitrogen trioxide (N_2O_3). The fact taken in consideration that other nitrosating agents were also formed like; nitrosonium ion and nitrous acidium $(H_2NO_2)^+$ ion [8].

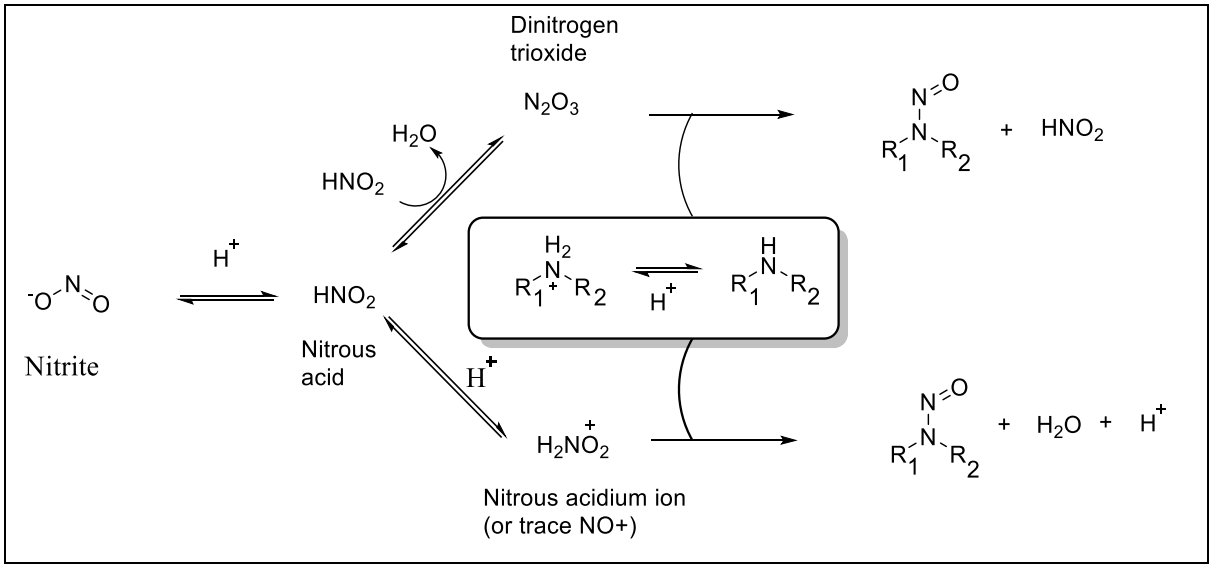

Figure 4: Formation of Nitrosamines

In strong acidic condition the reactivity of amines was reduced due to which nitrosamines formation gets minimized despite that at acidic pH the nitrosation process is enhanced and less reactive in low pH because of amines protonation. The most favored step of nitrosation is to balance pH of the amine basic reagent. The kinetics of nitrosation process rely on formation, reaction conditions as well as nature of [NO^+] carrier. Commonly, the nitrosation is effectively induced by the more electrophilic the [NO^+] carrier. The Secondary amines are easily nitrosated under milder reaction conditions, while tertiary amines demand extreme conditions or use of most active [NO^+] carriers[9].

Nitrosation of different types of Amines

The nitrosating agents can easily nitrosate the primary amines, which generate the nitrosamine products that spontaneously change into diazonium salts. Further, this releases nitrogen to generate carbonium ions that react with water to form compound containing hydroxyl compound. In contrast, secondary amine is more active towards nitrosating agents and forms more stable nitrosamines. Thus, compounds with secondary amines are more prone to generate nitrosamines.

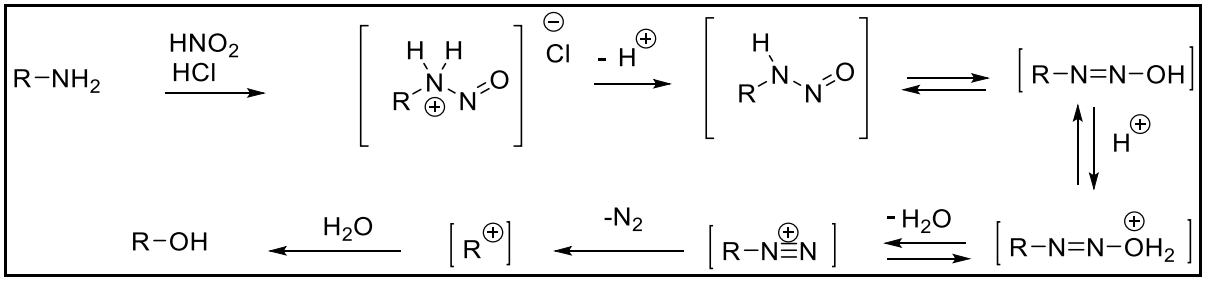

Figure 5: Nitrosation of primary amine

The nitrosation was also possible with tertiary amines and it is known as nitrosative dealkylation or nitrosative cleavage. For generation of nitrosamines the tertiary amines have to release one alkyl group to form secondary amine which further after nitrosation forms its corresponding nitrosamine. The tertiary amines are less reactive to the extent of <1000-fold as compared to secondary amines because of additional dealkylation process. Tertiary amines generally need reaction conditions (higher molar ratios of nitrosating agent, high temperature and more reaction time) and stronger nitrosating agents compared to secondary amines. Concerning the quaternary ammonium compounds, nitrosamines are formed in rather low yield because they undergo indirect non-nitrosative dealkylation to form tertiary amines which further undergo nitrosation to form nitrosamines.

The rate of nitrosation reaction depends on the nucleophilicity of nitrogen, nitrosonium ion reactivity and conditions such as temperature, pH and solvents used. The basicity of the secondary amines contributes to its reactivity. The nitrosation in simple aliphatic amines, includes nucleophilic attack by the amine on the electrophilic nitrosating agent, which forms the amines free base nature which allows nitrosation process to occur, the present scenario is not possible if the lone pair is unavailable due to protonation of secondary amine. As compared to more basic amines, less basic amines are lesser protonated in acidic or neutral pH which tends to easier nitrosation. Secondary aromatic amines give *N*-Nitrosamine derivatives, while tertiary aromatic amines might give ortho or para nitrosamines derivatives due to nitrosation in aromatic ring[10, 11].

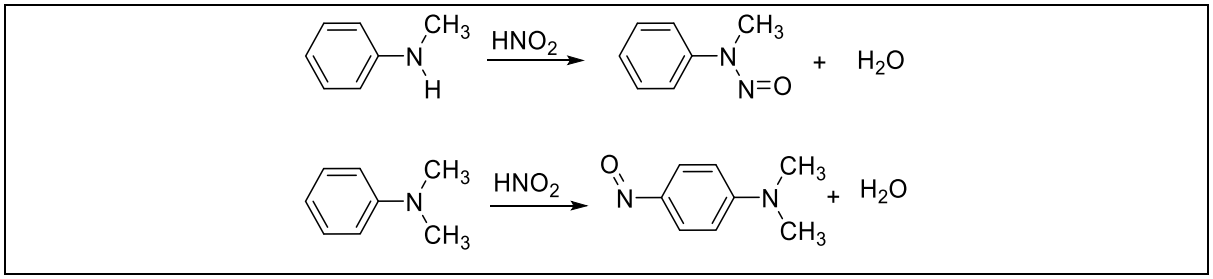

Figure 6: Nitrosation of secondary and tertiary aromatic amines.

The nitrosation process is majorly relied on pH. The rate of nitrosation reaction also depends on the other parameters such as unprotonated amine concentration which reduces with lowering pH. At lower pH the yield of nitrosamines is effectively dependent on the basicity of amino functional group. Therefore, the probability of nitrosation increases with the lower basicity. The free electron pair easily accepts the proton in higher basicity which prevents the

nitrosation. The lower pKa, the stronger acid and the weaker conjugate amine base, i.e., the higher susceptibility to nitrosation.

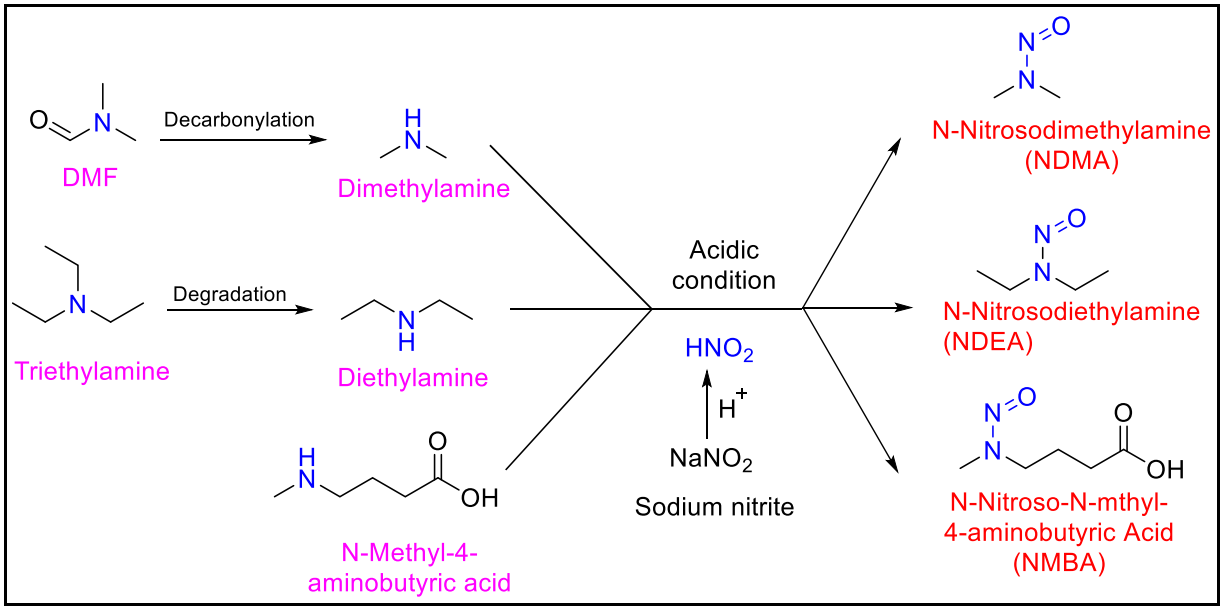

Figure 7: Principal sources for generation of *N*-Nitrosamines

Nitrosamine	**Amine and Amide Precursors**
N-nitroso-dimethylamine (NDMA)	*N*-*N*-dimethyl formamide (DMF) Dimethyl amine (DMA)
N-nitroso-diethylamine (NDEA)	*N*-*N*-dimethyl amine (DEA) Triethylamine (TEA)
N-nitroso-*N*-methyl-4-aminobutyric acid (NMBA)	*N*-methylamino-*N*-butyric acid (MBA) *N*-methyl pyrrolidinone (NMP)
N-nitroso-diisopropylamine (NDIPA)	*N, N*-diisopropylethylamine (DIPEA)
N-ethyl-*N*-nitroso-2-propanamine (NEIPA)	*N, N*-diisopropylethylamine (DIPEA)
N-nitroso-di-n-butylamine (NDBA)	*N,N*-dibutylamine (DBA)
1-methyl-4-nitrosopiperazine (MNP)	1-methyl piperazine
1-Cyclopentyl-4- nitrosopiperazine (CPNP)	1-Cyclopentyl piperazine

Table 1: Amines and amides progenitor of Nitrosamines in API

2. Classification of Nitrosamines

Based on their mutagenic potency the International Agency for Research on Cancer (IARC) categorized the nitrosamines in four different groups. The agents with sufficient evidence to prove it as cancerous to humans are categorized in Group 1. The agents having restricted proofs in humans but adequate proofs in animal study and apparently cancerous to humans are classified in Group 2A. The agents having restricted proofs in humans and animals too with possible carcinogenicity in humans are categorized in Group 2B. The agents with inadequate evidence of carcinogenicity data in humans as well as animals with non-classifiable carcinogenicity in humans are categorized in Group 3[12, 13].

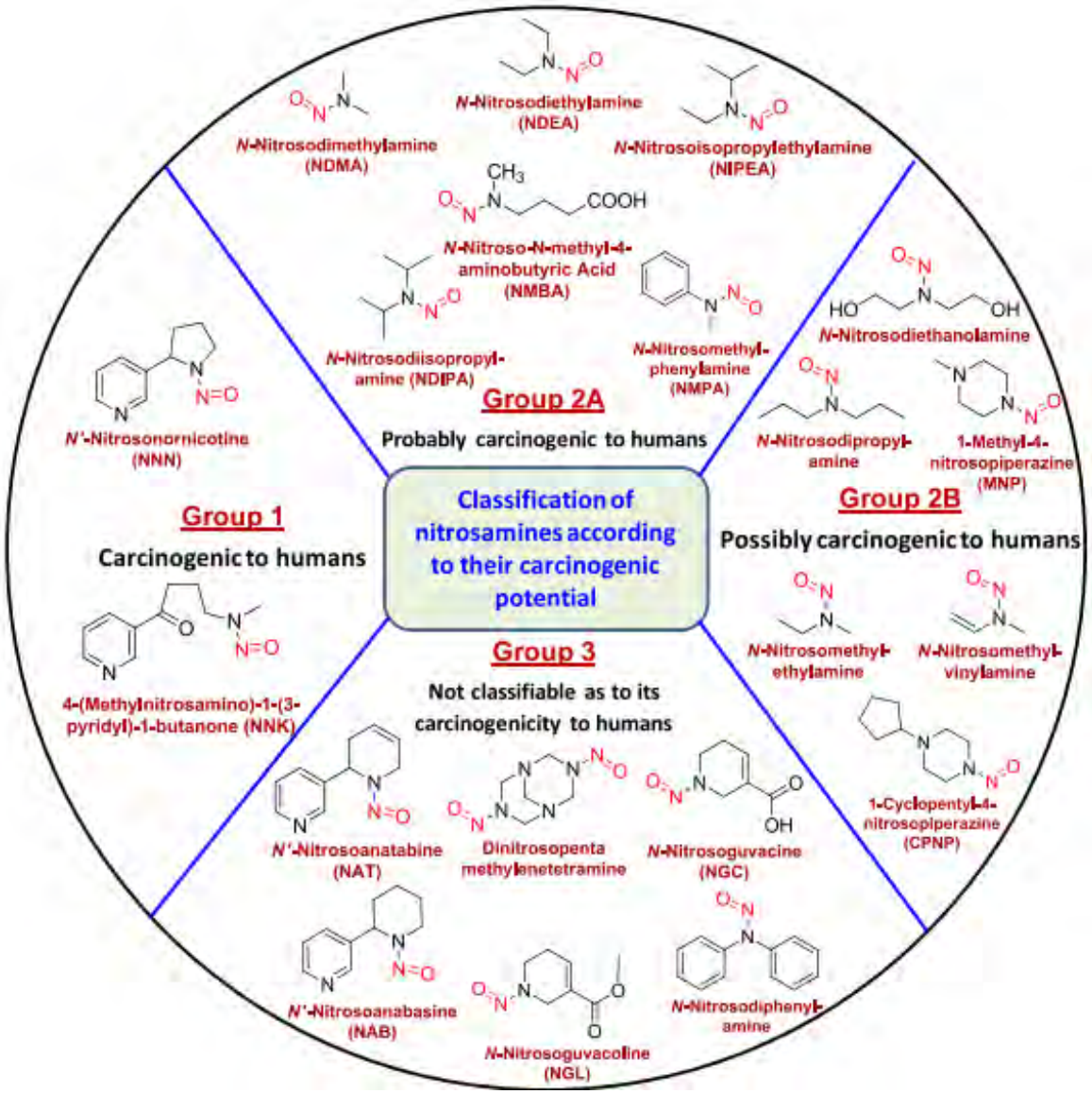

Figure 8: Classification of Nitrosamines

3. Sources of Nitrosamines

1. Sources of Nitrosamines in formulations[14]:

Important Sources of Nitrosamines	**Risks observed**
Carriers (Solvents)	➢ Existence of leftover Tri-substituted amines or dialkyl amines, nitrites, nitrosating agents and acids. ➢ Inferior quality of solvents
Pharmaceutical aids	➢ Existence of nitrosating agents or nitrites or nitrosamine impurities. (if applicable)
Water	➢ Existence of dialkyl amine or the substituents which after degradation forms dialkyl amines. ➢ Existence of nitrosating agents and acids.
Formulations (inclusive of stability)	➢ Presence of quaternary, tertiary or secondary amine group in the API molecule. ➢ Existence of nitrite as impurity in nitrate counter ion. ➢ Implicit reactions in formulation during storage.
Manufacturing process	➢ Presence of contaminants ➢ Utilization of bad quality or reprocessed solvents which might have nitrosamines or their precursors ➢ Contamination of drug substance or product by nitrous oxide present in drying air. ➢ Relative reactive substance carry forwarded to subsequent processes.
Container-closures	➢ Presence of nitrosating agents in packaging material reacts with the amines. Like; amines from ink reacts with nitrocellulose.

Table 2: Sources of Nitrosamines in drug products

2. Sources of Nitrosamines in drug substances[15]

Potential Source of Nitrosamines	**Observed Risk**

API	➢ In acidic conditions existence of quaternary, tertiary or secondary amines as well as nitrites. ➢ Presence of secondary and tertiary amines in API, their intermediates, and/or reactants. The Tertiary and quaternary amine reagents were added into process voluntarily. ➢ Utilization of di- or tri-alkylamines and amides (e.g., dimethylformamide [DMF], dimethylamine [DMA], triethylamine [TEA], *N*-methylpyrrolidone [NMP]) in the acid media containing nitrites. ➢ The raw materials purchased from vendor has been contaminated. ➢ Recycled material like reagents, catalysts and solvents might have nitrosamine impurities. ➢ Inappropriate cleansing of instruments ➢ The Quenching process was directly performed on principal reaction mixture. E.g. Nitrous acid added to mixture to degrade residual azide. ➢ Poor manufacturing process optimization of APIs ➢ Application of disinfected water ➢ Deterioration of API having functional groups which further engage in nitrosation process

Table 3: Sources of Nitrosamines in drug substances

4. Bioactivation of *N*-Nitrosamines

1. Bioactivation of *N*-Nitrosamines via α- hydroxylation mechanism:

Nitrosamines require the α-carbon hydroxylation step for its metabolic activation which leads to carcinogenicity. Cytochrome P450 primarily catalyzes the bioactivation of NDMA to reactive intermediates in human liver microsomes. The oxidation of the methyl group (α-methyl hydroxylation) leads to α-hydroxy NDMA, an unstable and mutagenic intermediate that spontaneously decomposes, generating two reactive species—formaldehyde and methyl diazohydroxide. Methyl diazohydroxide will spontaneously form the highly electrophilic methyl diazonium ion, which alkylates DNA.

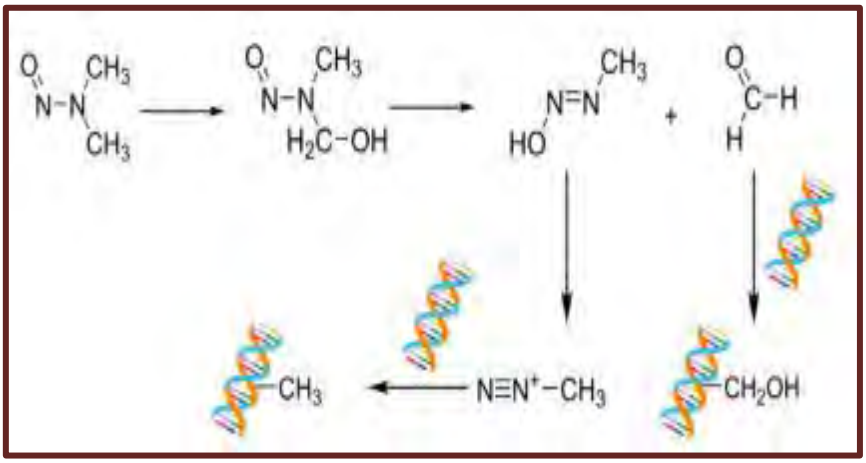

Figure 9: α- hydroxylation mechanism

2. Bioactivation of *N*-Nitrosamines via Cytochrome P450 Monooxygenase mechanism

Cytochrome P450 commonly catalyses the monooxygenase reaction. e.g., one oxygen atom added in aliphatic side chain of organic compound (RH), and reduction of another oxygen atom to water[16].

$RH + O_2 + NADPH + H^+ \rightarrow ROH + H_2O + NADP^+$

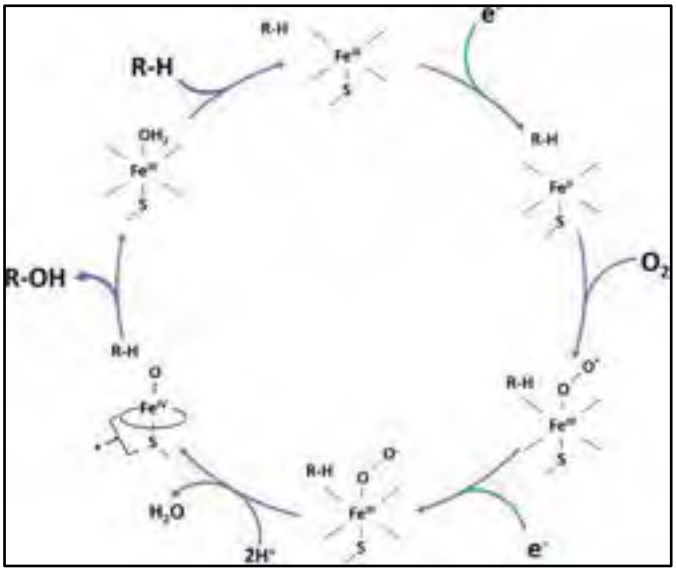

Figure 10: Cytochrome P450 Monooxygenase mechanism

5. DNA Damage

The mutagenicity and genotoxicity of Nitrosamines are well-established. Formaldehyde and methyldiazonium ion are the two reactive intermediates alkylates the DNA to form methyl DNA derivative which play a crucial role in carcinogenesis induced by NDMA.

The alkylating agents are mutagenic and toxic, which is commonly known as human carcinogens. Various positions in the DNA can be substituted via nucleophilic substitution depending on the given alkylating agent. Alkylating agents specifically target oxygen and nitrogen atoms of purines and pyrimidines. Alkylation is highly mutagenic and cytotoxic. N^7-alkylguanine and O^6-alkylguanine represent the more sensitive kind of DNA O-alkylation and *N*-alkylation damage. Alkylation induced specific mispairing. Alkylation of the O^6 position of Guanine as well as the O^4 spot of Thymine, tends to mispairing with the Thymine and Guanine respectively[17].

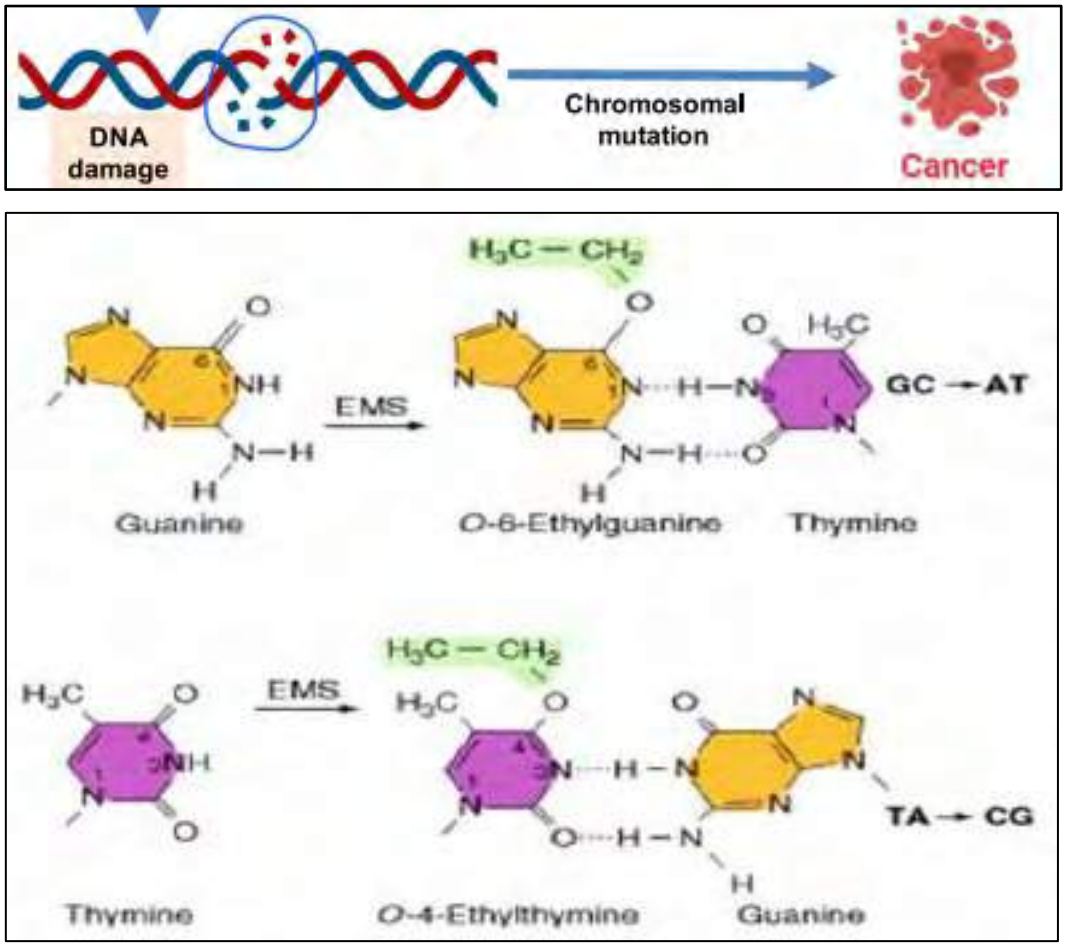

Figure 11: DNA Mutation and carcinogenesis

6. Risk Assessment Approach

The risk assessment is necessary for determination of potency of nitrosamine compounds. In risk assessment approach if the assessment lacks the potential of nitrosamines, then no action is required but if any risk related to nitrosamines is observed in drug substances or products then further confirmation tests were carried out using validated and sensitive analytical methods. Further root cause investigation is required if there is existence of nitrosamine impurities in samples tested. According to the root causes the change in process of manufacturing were made to prevent the contamination of samples with nitrosamine impurities[18].

7. Mitigation of Nitrosamines

As stated above, the optimization of design of manufacturing process for drug substances since development of route of synthesis (ROS) to reduce the generation of nitrosamine impurities. Avoiding reaction conditions (use of nitrosable substances in acidic environment) which leads to generation of nitrosamines whenever possible. Use of purge studies proves the process is controllable and can vanish the nitrosamines. Use of other bases than amines to prevent formation of nitrosamines. Caution is required while using amide solvents.

For decomposition of azide other extinguishing agents were employed in place of nitrites. Optimization of reaction sequence, processes and their conditions like; temperature, pH and time of reaction. The manufacturing sites of API should frequently audit and monitor their supply chains for risk assessment of intermediate and raw materials. Recovered solvents, catalysts and reagents were used to prevent cross-contamination during manufacturing procedure. API manufacturers require analysis of nitrite and nitrosamine levels in water[19].

8. Setting Limits for Nitrosamine Impurities

Nitrosamine impurities have potential and established toxicity with no therapeutic value. As nitrosamines comes under the structurally high-potency mutagenic carcinogen category therefore threshold of toxicological concern (TTC) was not applied, instead it is “cohort of concern”.

The acceptable intake (AI) was established using safety data available which is material specific. The intake level of any drug substance with negligible health risk is known as AI i.e. after 70 years of exposure approximately there is 1:100,000 cancer risk.

Toxicologists have employed various methodologies in determining acceptable intakes (AI). To determine the acceptable risk level, linear extrapolation of median tumorigenic dose (TD_{50}) of NDEA, NDMA and other nitrosamines data were established.

As nitrosamines exposure is relatable to Maximum Daily Dose (MDD) of drug substance therefore various aliquots of nitrosamine (ng/g) would be reliable for individual substituent assessed. The adequate concentration of nitrosamines in the substances changes with product and can be determined in terms of ppm, depending on MDD of drug using following equation

Concentration limit (ppm) = AI (ng/day) / MDD (mg/day) (1)

Nitrosamine	FDA limit (ng/day)	EMA limit (ng/day)
NDIPA	26.5	26.5
NDMA	96.0	96.0
NEIPA	26.5	26.5
NDEA	26.5	26.5
NMBA	96.0	96.0
NMPA	26.5	34.3
NDBA	26.5	26.5

Table 4: Nitrosamine AI Limits

A TTC of class-specific nitrosamine according to Food and Drug administration (FDA) and European Medicine Agency (EMA) is 26.5 ng/day and 18 ng/day respectively used as default when the impurity recognized with no complete substance specific data to determine substance specific limit. If API has single nitrosamine, then only the limits are applicable. The total amount of nitrosamines should not be greater than 26.5 or 18 ng/day based on MDD if more than one of the nitrosamine impurities are detected. The formulations with less MDD than 880mg/day the specified limit is not greater than 26.5 ng/day and with greater MDD than 880 mg/day, the former should be modified in a way that it is not greater than 26.5 ng/day. Nitrosamines should be controlled within API/drug product specification. Skip testing: consistently ≤ 30% of the limit. Omission from the specification: consistently ≤ 10% of the limit defined.

Limit Calculation for drug product when more than one nitrosamine is identified (EMA)

- Option-1: For all the identified nitrosamines, the total daily intake is not greater than AI of the potent nitrosamine identified.
- Option-2: For all the identified nitrosamines the total risk level does not exceed 1 in 100,000 [20, 21, 22].

Nitrosamines	**Option 1**	**Option 2-Fixed in 20:80 ratio**	**Option 2 - not Fixed**
NDMA	Not needed	0.064 ppm (0.32 ppm X 20 %)	NMT 0.32 ppm
NDEA	Not needed	0.070 ppm (0.088 ppm X 80 %)	NMT 0.088 ppm
Total	NMT 0.088 ppm	Not needed	NMT 100 %

Table 5: Specification possibilities for different control options

9. Establishment of Acceptable Intake (AI)

Two schemes are expected for the identification of newer nitrosamines:

- Nitrosamines recognized with substance specific sufficient animal carcinogenicity data were used to determine TD_{50} and further to determine substance specific limit as described in ICH M7(R1) guideline.
- Nitrosamines recognized with no substance specific animal carcinogenicity data, ICH M7(R1) guideline specifically carcinogenic potency categorization approach (CPCA) were used.

Group AI for complex *N*-Nitrosamines

Primarily the determination of single AIs for greater number of impurities employing a read across approach was carried out and allocated the configurationally complex nitrosamines into 13 groups presumed on the structural resemblance of different nitrosamine substituents. On the basis of previous studies about structure activity relationships for mutagenic/carcinogenic potencies the categories were classified. Certain impurities were inspected for individual category and structural category AIs was pronounced as the highest potency cancerous *N*-nitrosamine in individual categories[23].

10. Structural Features Affecting Carcinogenicity

The critical rate-limiting step in identification, metabolic activation and quantitation of nitrosamines is α-carbon hydroxylation, the effect of different configurational attributes on the present step can furnish beneficial discriminations into their carcinogenic capabilities[17, 24].

Potency diminishing substituents	**Potency enhancing substituents**
Tertiary butyl group	Small alkyl group
Isopropyl group	Benzylic group
Carboxylic acid at any position in the molecule	β-carbonyl group
Aromatic group	Allylic or Propargylic group
Strong β-electron withdrawing group	
β-hydroxyl group	

Table 6: Substituents having considerable impact on carcinogenic potency

11. Carcinogenic Potency Categorization Approach (CPCA) for NDSRIs

The NDSRIs is a category of nitrosamines that are investigated in numerous drug substances and products. The generation of NDSRIs in formulations happens due to nitrosation of API which contains tertiary or secondary amines leads to formation of remnant nitrite within pharmaceutical aids employed to articulate the formulation. Because nitrosamine impurities are investigated in many formulations, disturbances in supply and passage have enhanced, occasionally emerging in drug scarcities.

Deserving AI limit for NDSRIs is frequently too critical compared to deriving limits for smaller molecules, because each API has unique NDSRIs therefore, limited or no safety data are available. NDSRI's have similar structural features like API or API fragment. The CPCA approach is a scientific apocalyptic method to suggest AI limit for different NDSRIs.

The activating or deactivating features are responsible for enhancing or reducing the carcinogenic potency respectively, was specified in this approach. The present perspective also includes SAR studies for nitrosamine substances which describe that the α-hydroxylation reaction for metabolic activation is indebted to its mutagenic potency. Configurational characteristics state that contiguously enhance or reduce the favorable activation or enhance the clearance from another biological processes will have direct impact on its potency. The NDSRIs with two *N*-nitroso groups, the corresponding AI limit is determined on the basis of high predicted carcinogenic potency group for whole molecule. The present approach is

conservative, which explains the better availability of scientific features and is further expected to be more developed as newer insights are available.

- The CPCA is applicable to NDSRIs having carbon atoms on both sides of *N*-Nitroso group, where heteroatom is not directly double bonded with the carbon. (i.e., *N*-nitrosoureas, *N*-nitrosamides, *N*-nitrosoguanidines, and another associated structure are eliminated).
- Moreover, this is not applicable to NDSRIs having *N*-nitroso group in an aromatic ring. (e.g., nitrosated indoles)[25, 26, 27, 28].

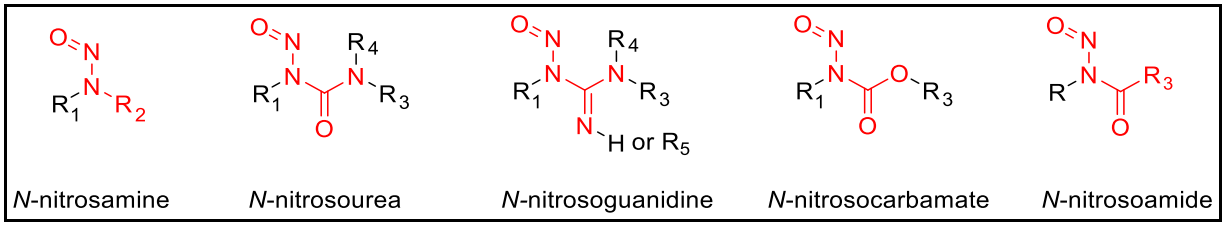

Figure 12: Double bonded heteroatom on an aliphatic chain

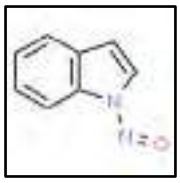

Figure 13: Bonded heteroatom in the aromatic ring

Potency Category	Recommended AI (ng/day)	Comments
1	26.5 or 18	AI limit specified on the basis of most potent nitrosamine (NDEA)
2	100	AI limit specified on the basis of two most potent nitrosamines NDMA and 4-(methylnitrosamino)- 1-(3-pyridyl)-1-(butanone) (NNK)
3	400	Four times lesser carcinogenic strength contemplated to category 2 due to deactivating structural characteristics
4	1500	Lower potency due to disfavored alpha-hydroxylation because of steric and electronic influences.
5	1500	Lower potency due to disfavored alpha-hydroxylation because of steric hindrance or deficiency of α-hydrogens or generate unstable compounds which is unreactive to DNA.

Table 7: Potency categories and their specified AI Limits

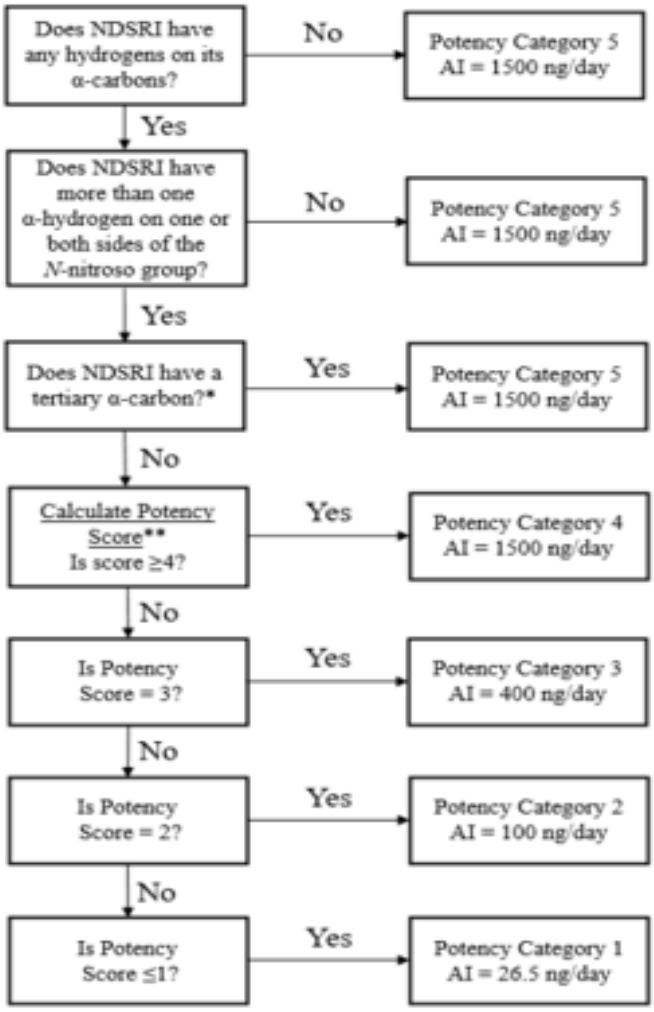

Figure 14: Potency category prediction flowchart

Conclusion

Genotoxic impurities like nitrosamines have carcinogenic potential shows the warning sign for the living things on earth. Moreover, the crucial task for researchers and industrialists is to identify and quantify these impurities from various drug substances precisely. By using genuine catalysts, reagents and solvents for the production of drug substances the formation of nitrosamines can be avoided. The *in-vivo* generation of nitrosamines in humans is a crucial feature to contemplate the threat, this probably happens in GI tract where nitrite and nitrate were ingested from food and acidic pH plays a vital role in formation of nitrosamines.

The Amine groups have higher *in-vivo* volume of distribution (V_d) prone to greater pharmacokinetic characteristics like; extended half-life, leads to good dose frequencies and impressive medicinal compliance. Medicinal products are impossible to make nitrosamine-free

because of the presence of nitrite traces in raw materials and excipients which further generate nitrosamines, the API is also susceptible to nitrosation process.

To make drug and drug products sustainable there is need to bypass the threat of API scarcities or absolute lack of medicinal choices due to impurities like *N*-nitrosamines, which requires cooperation of Regulatory Authorities with Pharmaceutical industries is of greater importance.

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Glossary

***N*-Nitrosoamines-** A class of organic compounds that are likely carcinogens to human.

Genotoxic- Substances can be chemicals or agents that can directly or indirectly harm an organism's DNA.

Mutagenic- Having ability to cause permanent changes in sequence of an organism’s DNA.

API- It's the active ingredient in a drug that's responsible for its beneficial effects.

Nitrosation reaction- Nitrosation is a chemical reaction where a nitroso group (-NO) is introduced in organic compound, typically an amine.

Cytochrome P450- CYP450 is a family of enzymes that play crucial role in the metabolism of various substances, including drug, toxins, and harmones.

ICH M7 (R1)- This guideline emphasizes considerations of both safety and quality risk management in establishing levels of mutagenic impurities that are expected to pose negligible carcinogenic risk.

Tumorigenic dose 50 (TD_{50})- TD_{50} is the dose of carcinogenic substance required to produce tumors in 50% of the test subjects.

CPCA- CPCA is a model that predicts the carcinogenic potency of a nitrosamine compound. It's used to determine recommended acceptable intake (AI) limits for nitrosamine impurities in pharmaceuticals.

NDSRIs- NDSRIs are a class of nitrosamine impurities in drugs that are structurally similar to the API.

Hepatoxic agent- The chemical which may damage the liver.

Nitrosating agents- Substances that can cause nitrosation, a chemical reaction that produces N-nitroso compounds.

Pharmaceutical aids- Substances which are of little or no therapeutic value, but are necessary in the manufacturing, compounding, storage, etc., of pharmaceutical preparations or drug dosage forms. They include solvents, diluting agents, and suspending agents, and emulsifying agents.

Bioactivation- The process by which enzymes or other biologically active molecules are able to perform their function.

Threshold of Toxicological Concern TTC- TTC is a concept used in toxicology to establish a threshold below which a chemical substance is unlikely to pose a risk to human health.

Cohort of concern- a group of compounds that are highly potent carcinogens and mutagens.

Acceptable intake (AI)- The amount of a substance that can be consumed daily without posing a significant health risk.

***In-vivo*-** That refers to experiments performed on living organisms or cells.

Assessment of Factors responsible for Game Zone Fire Accident in Rajkot: A Case Study

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Abstract

Numerous accidents claim the lives of many people each year. One significant category includes accidents occurring in places of entertainment. To study such accidents, we listed many such cases in Gujarat in the past 5 years like Harni Lake incident in Vadodara 2024, Morbi Bridge Collapse 2022, Ahmedabad Ride Collapse 2019 and TRP Game zone fire 2024. This work has been carried out as the assignment for University Foundation Course – 'Critical Thinking and Research'. The authors were given this particular topic on "TRP Game Zone accident" as research project as it is the most recent incident and research on this incident may help the society and policymakers take proactive action to avoid such accidents in future.

The process of formulation of Research question triggered several questions related to our scientific process of construction and maintenance, legislation related to safety protocols and Fire No Objection Certificate (NOC), morals in business and Indian Jurisdiction. It also triggered a question whether the incident was fatal or a manmade disaster. The main objective of our research was to brainstorm on the possible reasons behind this incidence and learn what can be done to avoid such situations as citizens.

The research was conducted with the help of primary as well as secondary data. The primary data was collected by floating questionnaires to 62 respondents and conducting interviews. The secondary data comprised of research papers, Gujarat

Comprehensive General Development Control Regulations (GDCR) report, and an article authored by interns at IIT Gandhinagar. All this data played a crucial role in deriving valuable insights and meaningful conclusions for the above stated research problem. These conclusions are based on science, legislation, judiciary and protocols. The present research paper dives deep into all the above aspects and suggests protocols and inferences from the incident.

The inferences can be categorized in fire specific safety protocols, scientific solutions, legislative judiciary based solutions. These conclusions can be effectively utilized to implement preventive measures, thereby reducing the likelihood of similar incidents occurring in the future.

Keywords

Science in construction, legislative loopholes, fire NOC, fire safety, delayed Judiciary, Business feud, Capital punishments, parental awareness, children's safety

Introduction

On 25 May 2024, a fire accident occurred at the TRP game zone in Rajkot, Gujarat, India causing death of 27 people.[3] Media sources and government reports gave abundant information on the probable causes, mistakes and aftermath. With detailed analysis of the information, this accident is an eye opener to many such incidents.

TRP fire accident is not the only example accidents such as Harni Lake incident in Vadodara 2024, Morbi Bridge Collapse 2022, and Ahmedabad Ride Collapse 2019 and not just in Gujarat but all over the country there have been countless mishaps. Such incidences raise questions on the improper implementation of the process of construction and maintenance, legislation related to safety protocols and lack of Fire NOC, compromised morals in business and our jurisdiction. All these factors further trigger a question whether the incident was fatal or a manmade disaster.

It was found that at the game zone place, which was under partial construction, contained 3500 liters of fuel[4]. This was due to uncalculated and unplanned construction policy.

So, what are scientific hazards, scientific precautions and safe methods to use and maintain at

a construction site? How can we make such places safe not just for common people but also for workers and management working there? Automation in construction area- in the world of technology, only artistic fields are not digitalized but there are two more fields' agriculture and construction are highly labored. Can we digitalize and automate these fields? Correct work environment and managed workspace with technology and automation can reduce such hazards. Also, there was no need to store large quantities of fuel. How can we reduce this wastage and follow the sustainable zero wastage policy?

Legally, quoting from the article[3] "According to Her FIR, the accused individuals constructed a structure measuring 50 meters in width and 60 meters in length, with height of approximately two or three stories, using metal sheet fabrication to establish gaming zone." Many times, there are loopholes in the law and system. Is there any way we can increase transparency to make sure these loopholes aren't exploited? How to be sure if it is legislation issue or lack of moral values? How can we increase moral grounds collectively as a society so that less people use law for their own benefit? Who is responsible? Is one individual is culprit or the entire system? When the construction work was going on, couldn't the facility remain closed to ensure the safety of the customers? If it was possible, then why didn't the same happen? When the facility didn't have fire NOC then why was it allowed to operate? Can this be called just an "accident" when it could have been stopped or prevented in the first place? Can this be called a 'manmade disaster' caused due to selfishness of few individuals? Victims were given lakhs of rupees from the National Relief Fund; can money be equated to life? Can we make sure more lives are not lost by maintaining a safe workplace at such construction places? What are the preventions to control such hazards? And if such accidents take place, then what kind of protection should be maintained? Should there be a regulating department to maintain such entertainment parks safety because this is not the first such accident at an entertainment park. Which steps should be taken by government officials to prevent such incidents in future?

Morally, A social loop: this incident did shake up the people of Gujarat. The incident was criticized, the government did shut down similar places temporarily and compensated the families for their loss but at the end all those protests and criticisms matter. Things didn't change. People and government forget such incidences. How can us as a society end this loop? Hence the question is to avoid such similar manmade disasters by science to improve construction workplace, by legislation and formulation of stringent laws against hazard control,

by capital punishments, by better and speedy jurisdiction and by moral development of the society. How do we bring a change in policies and protocols to save lives of people from such accidents.

We focus on the lessons learnt and deeper aspects of these accidents on scientific, judicial, legislative and moral grounds. The collected information thus helps derive the inferences listed in the research paper. This work has been carried out as the assignment for University Foundation Course – 'Critical Thinking and Research'. The authors were given this particular topic on "TRP Game Zone accident" as research project as it is the most recent incident and research on this incident may help the society and policymakers take proactive action to avoid such accidents in future.

Methodology

The research process included multiple methods of data collection. The Primary data that included questionnaire and interviews. 53 individuals from common people category were chosen for Questionnaire-1 and 9 persons from business community were chosen for Questionnaire-2. Here the subjective answers were analysed manually, and graphs were plotted on the bases of the common word in the answers.

The interviews included from: a) Survivor and eyewitness b) Lawyer (JAG entry AIR 1) and c) Civil engineer and 25+ yrs of field experience. The transcripts of these interviews were meticulously summarized by the authors, who presented the findings in a clear and concise manner. The Secondary data included GDCR, NBC, Research papers, and Article by interns at IIT Gandhinagar. The secondary data not only reinforced our initial inferences but also provided additional valuable insights, further enhancing the depth of our conclusions.

Results and Discussion

Primary Data

Questionnaire-1 (This was meant for common people)

What is your age group?

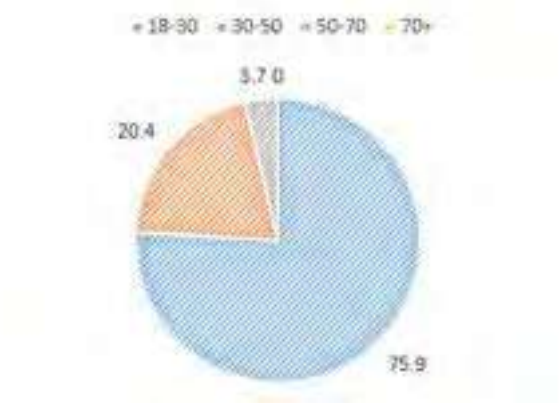

Figure 1: Age group distribution of survey participants.

Most of the stakeholders are below 30 and are the future of our country whereas 20.4 % of stakeholders are current working force.

Was the accident manmade or a coincidence of fatal accident?

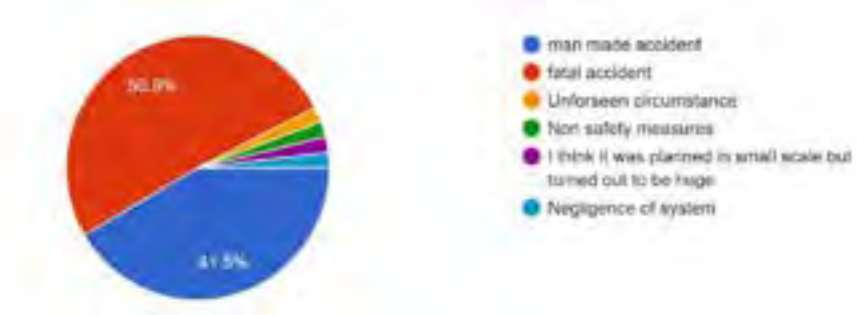

Figure 2: Participants' views on whether the accident was manmade or a fatal accident.

50.9% stakeholders believe that this accident was a manmade accident as suggested in article (by Nandini Singh, Business Standard. If deemed a manmade accident, then the scope of the study expands opening up new avenues for analysis.

Who do you think was responsible for this accident?

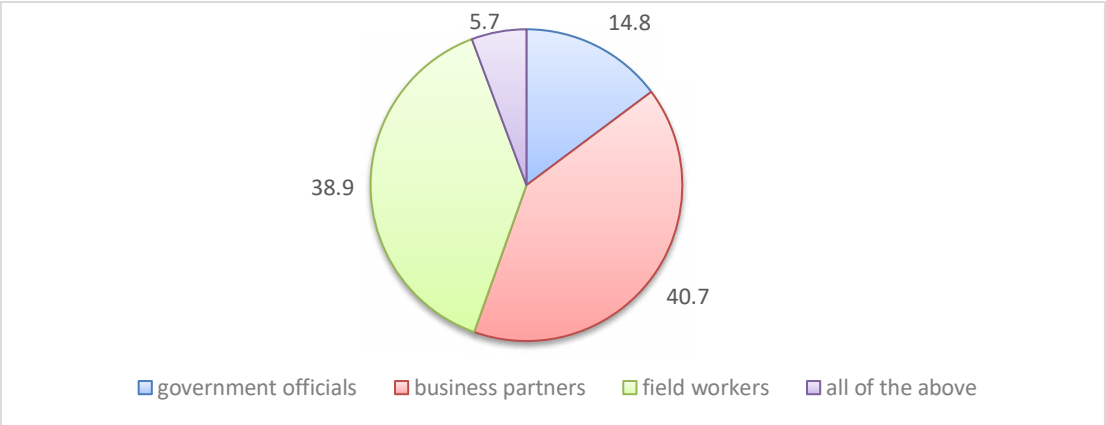

Figure 3: Participants' perception on accountability of the accident

Majority stakeholders think either business partners or field workers were at fault. Althought there was a fairly good number of individuals think that there might be governments fault as well. Hence this can be taken in as a scope of our study.

Do you think this incident could have been avoided?

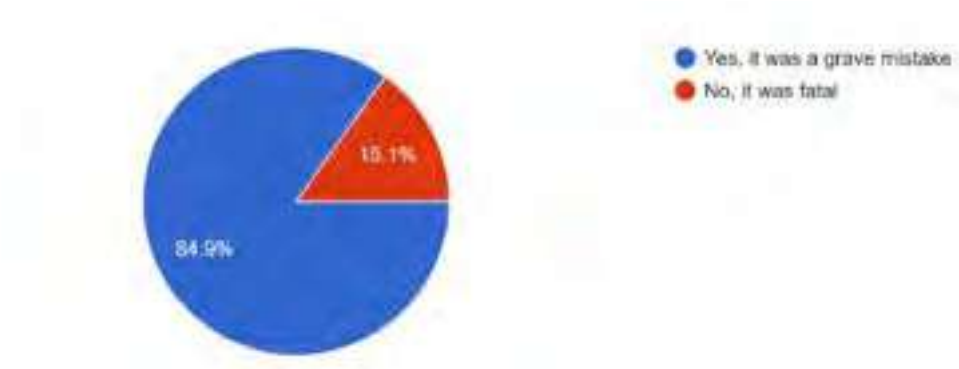

Figure 4: Participants' opinion on the preventability of the incident

In the opinion of the majority stakeholders, this incident was a mistake rather than being fatal. Hence the incident can be examined scientifically to identify the underlying mistakes and implement required measures, so similar incidents are not repeated in the future.

Do you think the media has given sufficient information about the incident?

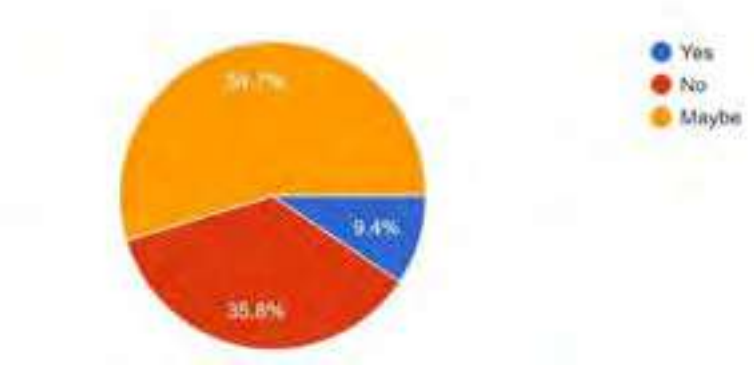

Figure 5: Public's opinion on role of the media and sufficiency of information provided by it regarding the accident

Do you think a proper inspection should be done by the authorities?

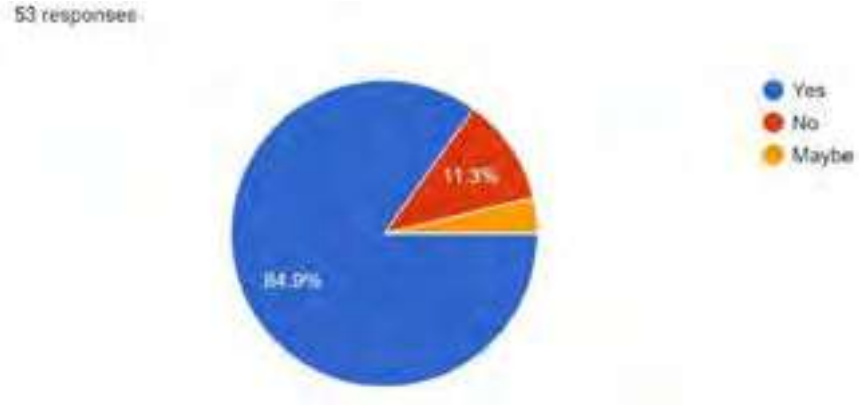

Figure 6: Survey participants' opinion on the requirement of inspection to be carried out by the authorities

84.9% agree with a proper inspection of the incident.

By what means do you think these accidents could have been avoided? (one or more)

Figure 7: Participants' views on the ways to avoid accidents

The majority of the participants think that by following rules and regulation regarding fire safety the incident could have been avoided, while many think the correct scientific approach, capital punishment and moral development of workers could have also helped avoid the incident.

Should customers be allowed in places where there is ongoing construction?

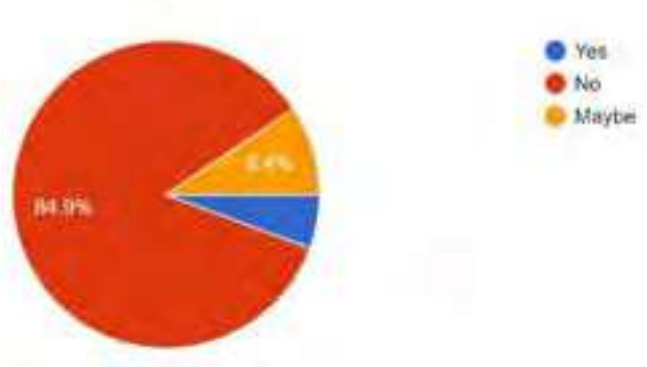

Figure 8: Participants' opinion on the permission to the customers in the premises with ongoing construction

Majority of the participants hold this opinion that people should not be allowed while there is ongoing construction work.

Incident such as Rajkot Fire incident, Harni Lake incident, Ahmedabad Amusement Park accident and Morbi Bridge Accident cause harm to children. Do you think such places are safe for students and children?

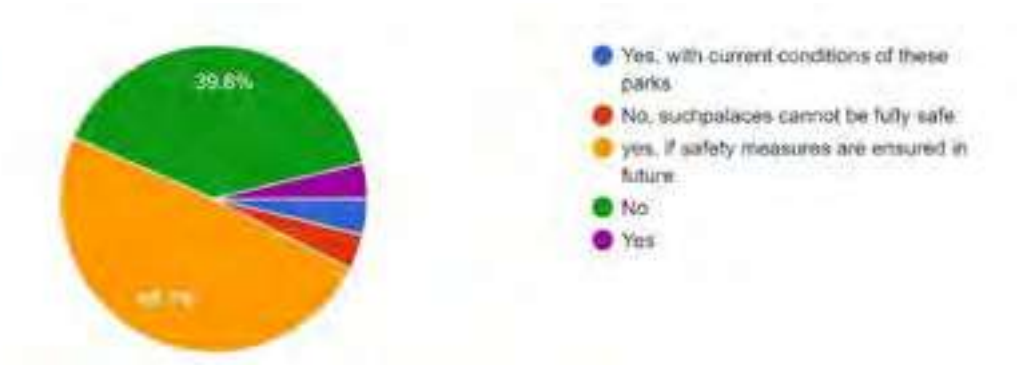

Figure 9: Participants perception on the safety of the amusement parks for children

The statistics suggest that half of the participants think that amusement places are safe to go to provided safety measures are ensured, while many think it is not safe.

Do you think our judiciary system is slow?

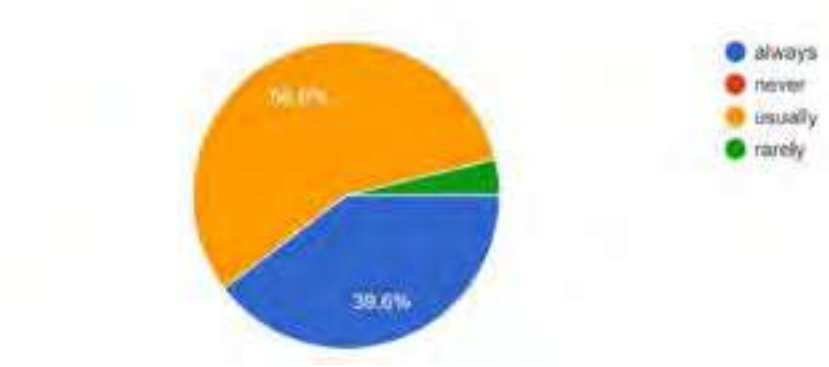

Figure 10: Participants' perception about the speed at which the judicial system works

Since in opinion of 56.6% stakeholder's Indian judiciary system is usually slow and 39.6% think it's always slow. We can further analyze this into our inferences. This key point is also subsequently discussed in the interview section.

Currently the government has closed all the game zones and such entertainment parks to ensure and apply safety protocols. Do you think this should be done in all states?

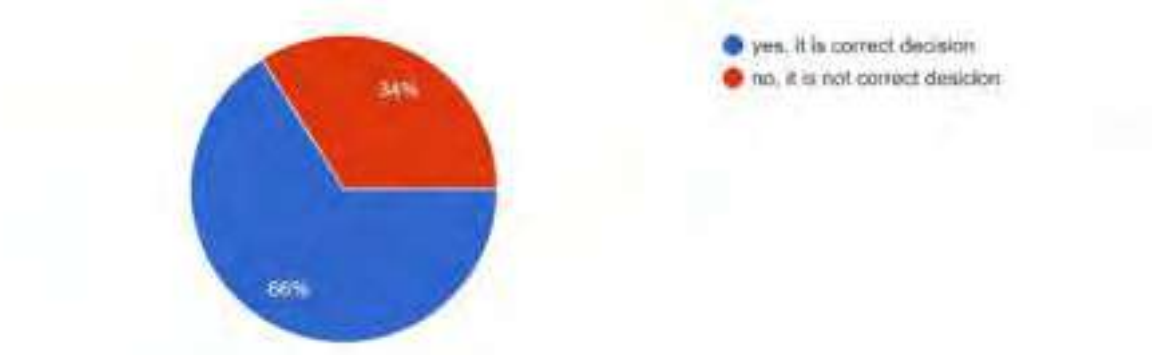

Figure 11: Participants' opinion on the temporarily shut game zones and amusement parks amid the Rajkot incident

66% of individuals believe this decision is correct and should be implemented in other states as well. We can also draw our inferences from the new policies and rules Gujarat government has made "According to new rules, the game zones have to display the capacity of their zones and the validity of their licenses on a big board visible to the visitors. All the game zones will have to depute fire, safety, and electrical-related staff at the site, apart from training all the staff working in the zones, as they need to evacuate visitors in case of an emergency."[8]

According to media sources 3500 liters of fuel was at site along with other inflammatory materials. Do you think it was required, or should it not have been there?

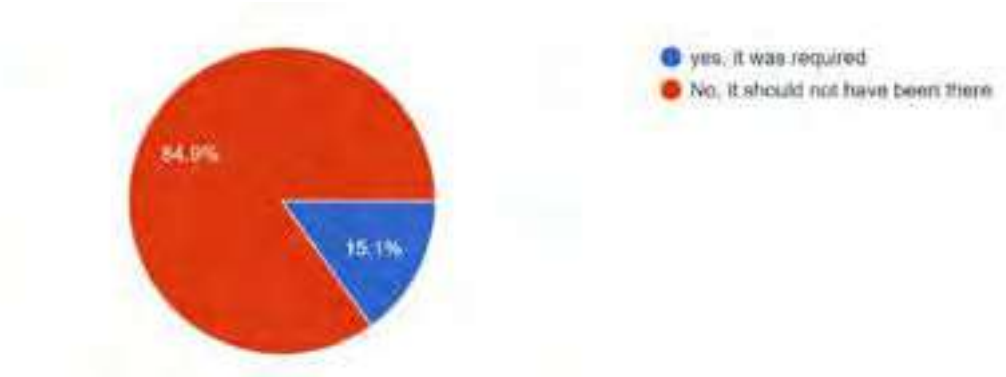

Figure 12: Participants' opinion on the storage of inflammatory material at the site

Majority of the partcipants think that the fuel should not have been there.

Central and State governments compensated the families of victims. Your opinions on it:

We received 22 responses written by the stakeholders and on further analysis of them we can plot the following graph

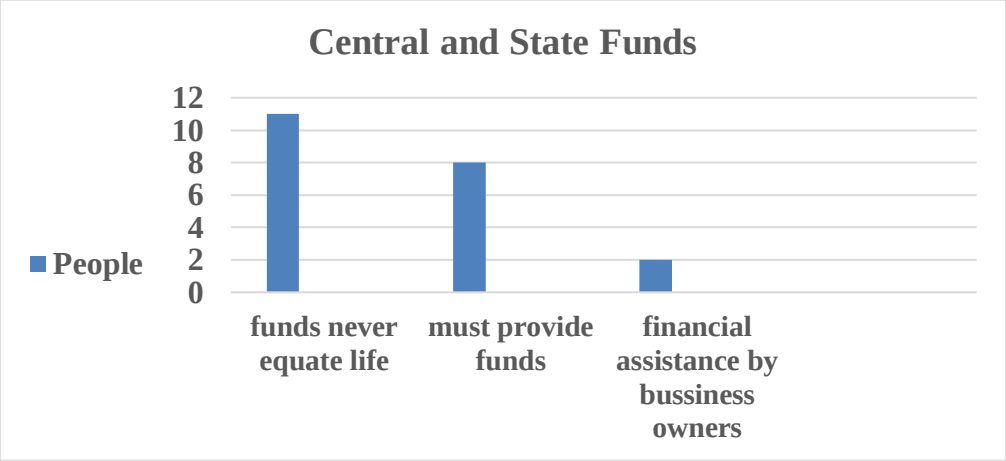

Figure 13: Public opinion on the compensation provided by Government to the victim's family

The responses suggest that most people believe life doesn't equate to money.

Give suggestions on how such an accident could have been avoided.

We received 22 responses written by the stakeholders and on further analysis of them we can plot the following graph

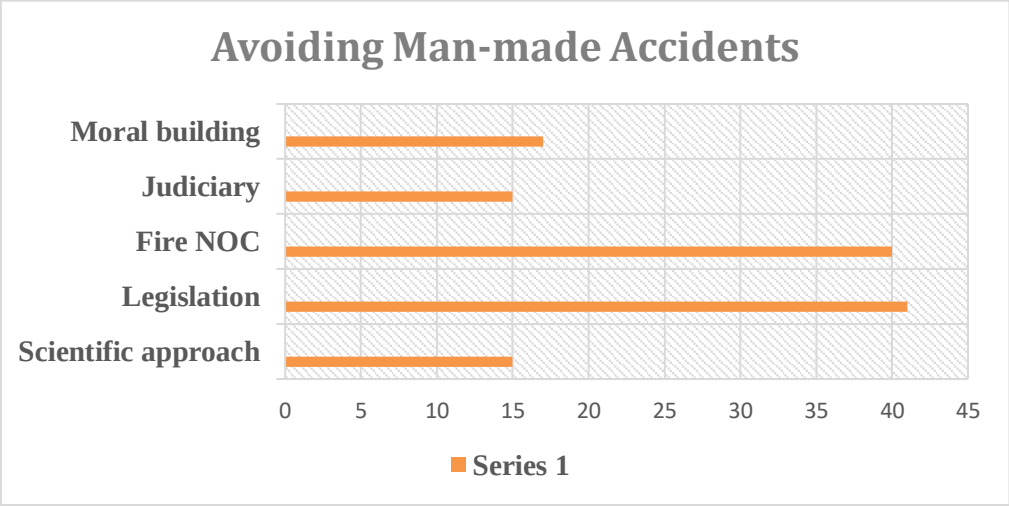

Figure 14: Participants' opinions on how such accidents can be prevented

This question is of significant importance, as it yields and provides us with the above statistics that form the basis for deriving our inferences drawn from the answers given by the stakeholders. Also, many safety measures suggested have been used to derive our inferences. These inferences are subsequently detailed in the inferences section.

Questionnaire 2 **(This was meant for business community)**

Assume you are the owner of a construction business. you are about to construct another floor for a shopping mall which has 3 floors and the top floor is game zone and movie theater. but the problem is Fire NOC. A government document required whose inspection takes place in three stages Assume you are the owner of a construction business. you are about to construct another floor for a shopping mall which has 3 floors and the top floor is game zone and movie theater. but the problem is Fire NOC. How would you make this tedious process faster? (you can type your ideas)

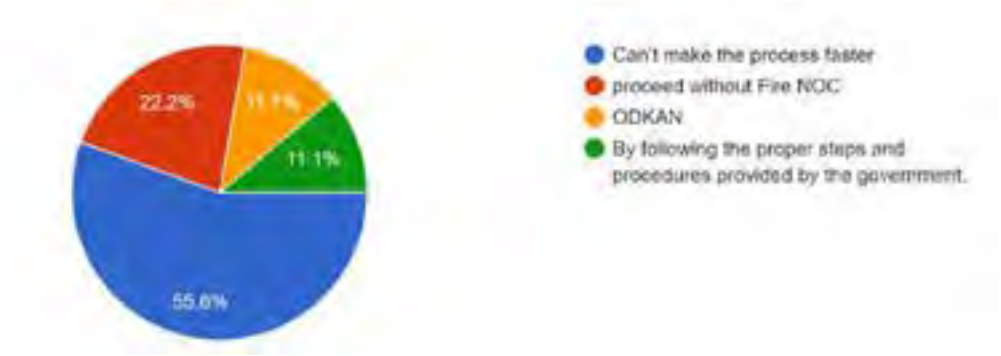

Figure 15: Perception of participants from business backgrounds about Safety documentation process

This question was meant to examine what business individuals would do morally when in a situation similar to our study. It suggests that the business community would try to avoid going through the legal process required for fire NOC. It also suggests that the legal procedure is not user friendly.

Interview

The structured interview with 3 Experts was conducted.

a. Survivor and Eyewitness
b. Lawyer and AIR 1 JAG ENTRY (INDIAN ARMY)
c. Civil Engineer and 25+ years of field experience

a. Survivor and Eyewitness

Questions

1. How your experience was in the TRP game zone and in detail explain the sequence of events that took place.
2. Did the place look safe initially when you entered the place?
3. Were you injured? What impact did the accident have on you physically or mentally?
4. Did you receive government funds or not?
5. Safety protocols you would suggest to such entertainment parks.
6. Your opinions on this accident and how do u think this could have been avoided?

Summary of the interview

The interviewee describes a harrowing experience at TRP Game Zone, where a fire broke out while they were bowling on a busy Saturday. Initially, they dismissed a strange noise, but soon after, smoke and darkness engulfed the area, leading to panic. Despite attempts to call for help, no one from downstairs responded, prompting the group to break through a steel wall and escape. While the interviewee suffered minor burns, their friend's younger brother sustained serious injuries and was hospitalized. The government provided financial aid for the injured and the families of those who died, though the exact amounts were unclear. The interviewee emphasized the importance of fire safety measures, such as obtaining a Fire NOC, ensuring emergency exits, and keeping hazardous materials like petrol and diesel separate from flammable work areas.

These safety measures and incidents described by the interviewee further help us deriving the inferences for our research

b. Lawyer and AIR 1 JAG ENTRY (INDIAN ARMY)

Questions

1. A lot of common people say that jurisdiction in India is slow. But many times, we have heard from people practicing the law that such a lengthy procedure is necessary. "No innocent should be punished". Please put some light on this and let us know about a

few legal terms or sentences taught during your education period. Also give your opinion on it.

Answer

One of the main reasons for the delays in the justice system is the lengthy procedures that must be followed.

The concept of due process ensures that every individual has the right to a fair trial, which is a fundamental right in India. This means that proper evidence must be collected, witnesses examined, and legal protocols adhered to, all of which contribute to the extended duration of cases.

The Indian Constitution is structured around a system of checks and balances involving three branches: the judiciary, the legislature and the executive. The judiciary plays a crucial role in ensuring that laws are not in violation of fundamental rights. For instance, if a law is perceived to infringe on the right to freedom of speech, any citizen can challenge it in the Supreme Court. The Court will thoroughly analyze the law, considering various factors, which can be a time-consuming process.

A core principle of the justice system is to prevent the punishment of the innocent, even if that means some guilty individuals may evade justice. This commitment to fairness is paramount, reflecting the philosophy that it's better for ten guilty individuals to go free than for one innocent person to be wrongfully convicted

2. Referring to the Rajkot fire incident that caused death of 27 people. Quoting from the article, "According to FIR, the accused individuals constructed a structure measuring 50 meters in width and 60 meters in length, with height of approximately two or three stories, using metal sheet fabrication to establish gaming zone."

   There will always be loopholes in law and system. There will also be people who use this grey area. Is there any way we can increase transparency and frame rules in way such that we can minimize the grey area, is this a problem with legislation or a problem of lacking moral ground? How can we increase moral grounds collectively as a society so that less people use the law for their own benefit?

Answer

There are two perspectives here, both of which should be balanced.

First, laws should be defined clearly to minimize confusion and prevent varied interpretations. Increasing awareness about laws and legal processes is essential. Also, instilling values of morality and integrity from a young age is crucial. For which, education system should incorporate ethics and civic responsibility into their curricula to nurture a sense of accountability and respect for the law. Second, on the other hand, grey areas allow for flexibility in interpreting laws, enabling courts to adapt legal principles to unique circumstances. In the landmark judgment in Justice K.S. Puttaswamy (Retd.) vs. Union of India (2017), the SC interpreted the right to privacy as a fundamental right under Article 21 of the Constitution.

3. As a lawyer, what are your opinions on capital punishment for criminals? Many people side with capital punishment but there is a huge group of people who say that capital punishment might not give chance to the culprits to live a better life after the punishment. What are your opinions? Would capital punishment decrease crime rates, or would it cause lack of trust in the judiciary system?

Answer

Capital punishment can serve as a deterrent for severe crimes like mass murder and rape, providing a sense of justice for victims and their families. Though, it is crucial to have a strict legal process to ensure that no innocent person is wrongfully sentenced to death. The Indian legal system, particularly through Hon'ble Supreme Court ensures this by applying it in "rarest of rare" cases. This principle aims to ensure that only the most egregious offenders warrant such severe punishment, aligning with natural justice principles. Furthermore, for capital punishment to be an effective deterrent, it must be implemented swiftly. Delays in legal proceedings can undermine their intended purpose, as potential offenders may not perceive an immediate consequence for their actions.

4. The government often gives funds to the families of victims. In the recent fire accident. That's what the government did. Yes, helping the family of victims is a must and this is the least the government can do. Although our survey proved that many people have opposite opinions. A survivor from the same incident quoted " these funds might help the injured and their family but not the dead." Your opinions on this.

   Answer

   While compensation cannot erase the emotional pain of losing a loved one, they can alleviate some immediate financial burdens. This support helps families manage day-to-day needs during a devastating time. The loss of a sole breadwinner is devastating, that no amount of money can replace. Therefore, it's crucial that financial aid is paired with accountability for the incident. This includes investigating the causes of the tragedy and addressing any negligence or regulatory failures. Ensuring strict safety regulations and learning from past mistakes can help prevent similar incidents in the future. A holistic approach needs to be taken that addresses both immediate and long-term needs to make a significant difference

5. As a lawyer, what is something you might want to change about our judiciary and legislative system?

   Answer

   Laws should be drafted in a clear and unambiguous manner to prevent misinterpretation. This could help in reducing litigation arising from vague legal language. Forming balanced committees, including legal experts, practitioners, and representatives from diverse backgrounds, can ensure that laws are comprehensively reviewed and reflect a broad range of perspectives before being finalized. Simplifying the documentation required for legal proceedings can make the system more accessible and efficient. Implementing measures to reduce the number of adjournments and streamline court schedules can help ensure that cases are resolved more quickly. This might include stricter regulations on the grounds for requesting delays and better case management systems.

6. Corruption is a major issue that is faced by almost all countries. Give light on the laws that prevent corruption. State your opinions on corruption and how it could be prevented.

Answer

Prevention of Corruption Act (1988), Lokpal and Lokayuktas Act (2013), Foreign Contribution (Regulation) Act (FCRA), Prevention of Money Laundering Act (PMLA). Multifaceted Approach to Combat Corruption is needed. First is Promoting a culture of integrity and ethics in both public and private sectors is essential. Education and awareness campaigns can instill these values. Second is Strengthening institutions tasked with enforcing anti-corruption laws is critical. Lastly, utilizing technology, such as e-governance platforms, can minimize face-to-face interactions and streamline processes, reducing opportunities for corrupt practices.

c. **Civil Engineer and 25+ years of field experience**

Summary of the interview

The interviewee explains fire-safety construction practices, emphasizing that there are safer alternatives to metal sheets for dividing floors, as metal can leak and is not always fireproof. They emphasize the need of providing personnel with adequate fire safety training, correctly storing combustible products, and periodically maintaining electrical equipment. The respondent further claims that Fire NOC is required for all building projects and must be obtained from a government-approved organization. To eliminate potential dangers, they recommend scheduling work and client zones apart. When asked about worker safety, the interviewee indicated that their crew is trained in fire safety practices and has never had a close encounter with a dangerous situation. They feel that adhering to fire safety laws and protocols would have helped to prevent the Rajkot fire, and that guaranteeing safety is a moral responsibility shared by engineers and business owners alike.

Secondary Data

1. GDCR[1]

GDCR (Gujarat Development control regulations) is general development control regulations under clause (m) of sub section (2) of section 12 of the Gujarat Act.

The fire at the TRP Game Zone in Rajkot, Gujarat on May 25, 2024, was a man-made disaster that killed 27 people and injured three:

Cause

Sparks from welding work on the first floor of the game zone fell on flammable materials stored on the premises.

The game zone was built on temporary structures to avoid getting the required permissions and approvals, including a fire no objection certificate.

Court's observations

The Gujarat High Court noted that the fire took advantage of loopholes in the Gujarat Comprehensive General Development Control Regulations (GDCR).

Important references from GDCR

- *Section B between Page 17 to page 57 highlights permissions required for development and building use and clearly states procedures to be followed during construction. It highlights the procedure for obtaining, revising and revalidating a development permission.*
- *Section B page 26 clearly states the responsibilities of owner and/or developer and persons on record.*
- *Section C page 59 to 81 explains general planning regulations.*
- *Section C page 122 briefs about Special buildings category under which a game zone is considered.*
- *Section D: page 154 states fire preventions and safety measures*

  Page 177 explains the regulations followed by special buildings

  Page 200 highlights the importance of quality control and inspection
- *Section F contains a total of 29 schedules which must be followed during and post construction.*
- *Section F form no 2D, Form 2E, form 15 and Form 16 can also be referred to in this case.*

Arrests

Twelve people have been arrested in connection with the fire, including six government employees and four owners and a manager of the game zone.

2. Articles from Newspapers/Magazines

2024 Rajkot gaming zone fire[2]

a. As per the information available publicaly[2], the Rajkot gaming zone fire in May 2024 involved many flammable materials, including:

   Diesel: 1,500–2,000 liters for generators

   Petrol: 1,000–1,500 liters for go-karts

   Oils: For various rides

   Fibers and fiberglass sheets: Highly flammable materials

b. The fire spread rapidly to the flammable materials, causing one of the biggest man-made tragedies in recent memory. The Gujarat High Court called the fire a "prima facie 'man-made disaster"[3].

c. A technical review article published by IIT Gandhinagar[4] meticulously examines the technical intricacies of the event, providing a comprehensive analysis of the underlying causes, outlining preventative strategies, and detailing precautionary measures to mitigate the likelihood of similar occurrences in the future. The article suggested general preventive measures regarding structure and materials used to build it, location and spacing, permissible population, evacuation routes, sing boards, adequate fire safety and firefighting equipment, trained staff. These preventions are also mentioned in NBC (National Building Code)[5].

The NBC norms that can be referred to for the same are 6.4.2.1, 6.4.2.1.d, 4.9, 5, 3.1.5, D-8, 6.4, 6.4.1.1, 4.8, 3.4.5.4, 5.1, 4.4.2.2.b & Table 5, 4.4.1.d, 4.11

RAJKOT FIRE TRAGEDY: A TECHNICAL OVERVIEW[4]

"The tragic fire at the TRP Game Zone in Rajkot, Gujarat, on May 25, 2024, which resulted in 28 casualties, underscores the critical need for stringent fire safety protocols and regulations, particularly in temporary structures. The incident was triggered by sparks from welding work igniting flammable foam sheets stored nearby, leading to a rapid and devastating blaze. The response from the fire department was delayed and hampered by inadequate safety measures, contributing significantly to the high casualty rate.

Key observations reveal multiple lapses, including improper storage of flammable materials, lack of fire alarms, insufficient fire-fighting equipment, inadequate evacuation routes, and unauthorized structural modifications. Additionally, the presence of obstructive elements and insufficiently trained staff further complicated the rescue operations.

In the aftermath, legal actions were taken against six individuals, including the game zone owner, and the government suspended several officials for negligence. The Gujarat High Court termed the incident a "man-made disaster" and a Special Investigation Team (SIT) was formed to probe the fire. Moreover, financial assistance was announced for the victims' families.

Foam sheets, typically made from flammable polyurethane or polyethylene, contain many C-H bonds. When heated, these bonds break, releasing volatile compounds that react with oxygen, quickly producing heat, flames, and combustion gases. The C-H bond, with a bond energy of about 413 kJ/mol, stores significant potential energy. When broken, it releases high energy, sustaining the fire.

Combustion of these materials releases toxic gases such as carbon monoxide, carbon dioxide, formaldehyde, and hydrogen cyanide, causing dizziness, headache, nausea, confusion, and loss of consciousness. High concentrations can be fatal within minutes, while prolonged exposure to lower concentrations can lead to chronic respiratory issues, cardiovascular problems, and neurological damage. These toxic gas releases likely contributed significantly to fatalities.

This incident highlights the dire consequences of neglecting fire safety standards and emphasizes the urgent need for comprehensive fire safety audits, stricter enforcement of regulations, and enhanced training for staff to prevent such tragedies in the future."

3. Research Papers

The global construction industry is witnessing an emerging trend towards "zero-waste" practices at the site level, yet our understanding of this concept remains limited. As per the literature, Zero-waste construction also seemed to be an important practice to be followed for several reasons, including:

Environmental benefits

Zero-waste construction reduces the amount of waste sent to landfills, which helps to preserve natural ecosystems and reduce greenhouse gas emissions. It also reduces the need for raw materials, which helps to conserve resources and mitigate environmental degradation.

Economic benefits

Zero-waste construction can save money through more efficient use of materials, reduced waste disposal costs, and lower operational costs. It can also lead to increased property value and lower maintenance costs over time.

Social benefits

Zero-waste construction can create healthier living environments by reducing exposure to harmful substances. It can also boost community awareness and involvement in sustainability.

Hence, we studied two research papers based on zero wastage policy, and we presented their findings below.

a. Analytical Framework of 'Zero Waste Construction Site": Two case studies of Shenzhen, China

This research paper by Lu et al.[6], endeavors to illuminate the waste management concept of "zero-waste construction site" by meticulously defining its core meaning, establishing clear system boundaries, specifying the appropriate assessment period, and outlining operational strategies. These elements are subsequently integrated into a comprehensive analytical framework.

The research paper promising approach to understanding and achieving zero waste in construction which includes multifaceted approach that gives a robust foundation to research. The paper acknowledges the system's complexities and focuses on practicality that contributes to a broader goal. This goal is to contribute to societal shift to zero wastage.

b. Study of Zero Waste Management in Indian Construction Industry

This article by Yoganandam et al.[7], has presented a detailed study about zero waste management in Indian construction industry. They have categorized the construction waste primarily in two types: (i) structure waste, which includes materials such as broken concrete, steel bars, and unused wood; and (ii) finishing waste, which encompasses a wider range of materials like leftover cement, broken tiles, excess paint, and packaging from appliances. India, with its rapidly expanding urban population and numerous high-rise buildings, faces a significant challenge in managing the substantial volume of construction and demolition waste. This waste occupies considerable space in landfills, posing significant environmental concern.

Conclusion

It is very important for the entertainment parks in fact all constructions in public domain to follow the guidelines and the rules set by the government through GDCR and NBC.
For fire safety, the following norms can be referred to:

NBC (National Building Code)[5].

The NBC norms that can be referred to as the same are

6.4.2.1, 6.4.2.1.d, 4 .9, 5, 3.1.5, D-8, 6.4, 6.4.1.1, 4.8, 3.4.5.4, 5.1, 4.4.2.2.b & Table 5, 4.4.1.d, 4.11

GDCR[1]

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- *Section F contains a total of 29 schedules which must be followed during and post construction.*
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Further the inferences made are categorized as:

i. Safety concerns
ii. Safety measures for fire accidents
iii. General safety measure for hazards
iv. Rules for the
v. Legislation
vi. Judiciary

Safety Concerns

- One Way in, One Way Out: A big problem is that there's only one entrance and exit. This could be dangerous if there's an emergency.
- Blocked Exits: People might not be able to get out quickly because the exits are blocked.
- No Fire Alarm: There's no system to warn people if there's a fire.
- Built Without Permission: The structure wasn't built with the proper approvals, which means it might not be safe.
- Flammable Materials: The structure is made of materials that can easily catch fire, which is a major concern.
- Flammable Storage: Storing a lot of flammable liquid like diesel is very dangerous.
- Electrical Hazards: The way the electricity is wired is unsafe and could cause a fire.
- Broken Equipment: Some of the fire extinguishers don't work, which could be a problem in an emergency.
- Hard to Find Exits: People might not be able to find the exits quickly.
- Staff Not Trained: The people working there don't know what to do in case of a fire.

Safety measures for fire accidents (Questionnaire, interview of survivor, IITGN)

Fire Safety

- Clear the Area: Keep the area around the structure clear of anything that could catch fire.
- No Open Flames: Generally, open flames like bonfires should be avoided.
- Kitchen Safety: If there's a kitchen area, it should be separate and protected.
- Electrical safety: Regular Inspections should be conducted and licensed electricians conduct frequent inspections of all electrical systems to prevent faults that could spark fires. There should be Backup Power Systems for example install fire-resistant backup power systems for critical operations, such as emergency lighting and communications.
- Flammable Materials: There should be proper storage to store flammable materials, such as fuel for rides or fireworks, in fireproof storage areas away from public spaces. Safe Cooking Areas should be designed by designating specific well-ventilated cooking areas for food stands with appropriate fire safety equipment nearby.
- Visitor Awareness should be maintained by displaying fire safety rules at entrances, ride lines, and in guest areas. Remind guests not to carry flammable materials or engage in unsafe behavior (e.g., smoking in non-designated areas).

Firefighting Equipment

- Water Supply: There needs to be enough water available in case of a fire.
- Fire alarms should be compulsory for all kinds of public buildings
- Fire Buckets: Make sure there are enough fire buckets on hand.
- Sprinklers can be added during the initial construction itself
- Professional Help: It's a good idea to have a plan for how the fire department will respond in case of an emergency.
- Someone in Charge: There should be someone responsible for fire safety and knowing what to do in an emergency

What Needs to Be Done

- More Exits: Add more exits to make it easier for people to get out.
- Clear the Way: Make sure there are clear paths to the exits.
- Install Fire Alarm: Put in a system that will alert everyone if there's a fire.

- Follow the Rules: Get the necessary approvals for the structure.
- Use Safe Materials: Use materials that are less likely to catch fire.
- Store Flammables Safely: Store flammable liquids in a safe and secure location.
- Fix Electrical Wiring: Make sure the electrical wiring is safe.
- Check Fire Extinguishers: Make sure all the fire extinguishers are working properly.
- Clear Signs: Put up clear signs that show people where the exits are.
- Train Staff: Train the staff on what to do in case of a fire.

Safety measures for fire accidents (Questionnaire, interview of survivor, IITGN)

General preventive measures that should have been followed:

Structure

The structure should be made from fire-resistant materials to ensure safety, avoiding easily flammable decorations like paper or synthetics. Since it is temporary, it must be removed when no longer needed. A sturdy build with a strong base, such as wooden posts, is essential for stability. Height restrictions must be followed for both ceilings and signs. Flooring should be made of treated wood or mats to prevent accidents. Additionally, the structure should be strong enough to withstand strong winds, ensuring durability in various weather conditions.

Location and Spacing

The structure should have ample clear space around it to ensure safety and accessibility. It must also be positioned at a safe distance from potential hazards like fences or railway lines to prevent accidents and obstructions.

Permissible population

Allow only no. of people such that they can sit and stand comfortably, no. of people that the structure is designed for.

Evacuating routes

It should be made sure that there are sufficient exits with clear signs so that it is easy to locate them, and the exits should be wide enough for people to evacuate and it should be easy for fire trucks to reach the structure in case of an emergency. There should be emergency power supply in case of blackout.

By Legislation (Questionnaire, NBC, GDCR)

Before starting operations and allowing public entry, obtaining legal permits or NOCs from the Municipal Corporation and the state fire department is mandatory. Any welding or work involving potential ignition must be closely monitored by the owner or contractor and should not be conducted when the site is occupied by the public. Storing flammable liquids beyond the permissible limit set by the National Building Code is prohibited. Regular site inspections must ensure proper storage of flammable materials and prevent fire hazards. Additionally, all workers should be trained in using first aid firefighting equipment and must be aware of potential workplace hazards.

- In reference to having better and well-structured laws:

i. laws should be defined clearly to minimize confusion and prevent varied interpretations. Increasing awareness about laws and legal processes is essential.
ii. Instilling values of morality and integrity from a young age is crucial. For which, the education system should incorporate ethics and civic responsibility into their curricula to nurture a sense of accountability and respect for the law.
iii. Grey areas allow for flexibility in interpreting laws, enabling courts to adapt legal principles to unique circumstances. In the landmark judgment in Justice K.S. Puttaswamy (Retd.) vs. Union of India (2017), the SC interpreted the right to privacy as a fundamental right under Article 21 of the Constitution.

- In reference to having capital punishments in law:

i. Capital punishment can serve as a deterrent for severe crimes like mass murder and rape, providing a sense of justice for victims and their families. Though, it is crucial to have a strict legal process to ensure that no innocent person is wrongfully sentenced to death.
ii. The Indian legal system, particularly through Hon’ble Supreme Court ensures this by applying it in "rarest of rare" cases. This principle aims to ensure that only the most egregious offenders warrant such severe punishment, aligning with natural justice principles.

iii. For capital punishment to be an effective deterrent, it must be implemented swiftly. Delays in legal proceedings can undermine their intended purpose, as potential offenders may not perceive an immediate consequence for their actions.

By Judiciary (interview of lawyer)

In the aftermath, legal actions were taken against six individuals, including the game zone owner, and the government suspended several officials for negligence. The Gujarat High Court termed the incident a "man-
made disaster" and a Special Investigation Team (SIT) was formed to probe the fire. Moreover, financial assistance was announced for the victims' families.

In the survey 96.2 % of people voted that our judiciary is slow and 28.3% of people think capital and speedy jurisdiction is the only solution.

Although, through the interview we know:

1. One of the main reasons for the delays in the justice system is the lengthy procedures that must be followed.

   The concept of due process ensures that every individual has the right to a fair trial, which is a fundamental right in India. This means that proper evidence must be collected, witnesses examined, and legal protocols adhered to, all of which contribute to the extended duration of cases.

   The Indian Constitution is structured around a system of checks and balances involving three branches: the judiciary, the legislature and the executive. The judiciary plays a crucial role in ensuring that laws are not in violation of fundamental rights. For instance, if a law is perceived to infringe on the right to freedom of speech, any citizen can challenge it in the Supreme Court. The Court will thoroughly analyze the law, considering various factors, which can be a time-consuming process.

   A core principle of the justice system is to prevent the punishment of the innocent, even if that means some guilty individuals may evade justice. This commitment to fairness is paramount, reflecting the philosophy that it's better for ten guilty individuals to go free than for one innocent person to be wrongfully convicted
2. Capital punishment can serve as a deterrent for severe crimes like mass murder and rape, providing a sense of justice for victims and their families. Though, it is crucial

to have a strict legal process to ensure that no innocent person is wrongfully sentenced to death. The Indian legal system, particularly through Hon'ble Supreme Court ensures this by applying it in "rarest of rare" cases. This principle aims to ensure that only the most egregious offenders warrant such severe punishment, aligning with natural justice principles. Furthermore, for capital punishment to be an effective deterrent, it must be implemented swiftly. Delays in legal proceedings can undermine their intended purpose, as potential offenders may not perceive an immediate consequence for their actions.

To enhance fire safety awareness in places like TRP Zone and Rajkot, public awareness campaigns using social media, posters, and workshops should be conducted. Regular fire drills and training for shop owners, employees, and security staff on using firefighting equipment are essential. Strict enforcement of fire safety guidelines, including inspections, proper equipment installation, and marked emergency exits, should be ensured. Engaging the community through local fire safety committees and educating students can further promote awareness. Lastly, government initiatives like helplines, stricter regulations, and incentives for businesses adopting fire safety measures can help improve overall preparedness

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