Ahmedabad University

Illustrated Science

Monsoon 2024

Illustrated Science

Issue 3 | Monsoon 2024

Cover art Ananya Mohan
Executive, Communications

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Ahmedabad University
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From *the* Instructors

Dear Readers,

Welcome to the third issue of our magazine *Illustrated Science*. It chronicles the semester long efforts of the students from the COM211 Science Communication using Digital Media course at Ahmedabad University.

In an era where scientific advancements significantly impact our lives, the role of effective science communication is crucial. This issue covers articles in Environmental Toxicology, Forensic Biology, Disaster Preparedness, Public Health, Ecology, Cancer Biology, Bioacoustics and Quantum Computing.

Join us in celebrating the dedication of these emerging science communicators and illustrators from across different disciplines as they contribute to the ongoing dialogues in Science.

Bhumi Shah & Tana Trivedi

About *the* Course

COM211 Science Communication using Digital Media is a unique, interdisciplinary course offered at Ahmedabad University. The course trains students to bridge the gap between complex scientific concepts, and popular understanding of science through explanatory science illustrations created using digital tools and software. As a part of the course, students engage in the following activities during the semester:

01 | Collaborating with a Science Mentor to simplify and introduce cutting-edge research for the general audience to newer ideas, discoveries and scientific progress. Students work closely with faculty researchers, to understand their research and translate it into engaging popular science and illustrated articles.

02 | Writing a Feature and a News Story by observing, describing and explaining. Students learn how storytelling and other literary techniques can help communicate science news. They also understand the difference between science writing and science fiction.

03 | Storytelling Strategies for Graphics by grasping the fundamentals of science graphics, organisation and emphasis, visual Style, colour and typography. Students understand the role that visualizations of data and concepts of science play in enhancing public understanding, and increasing engagement with science.

04 | Sketching Digital Illustrations by learning tools like Sketchbook and Inkscape to develop illustrations.

05 | Crafting Illustrated Articles, data visualizations and info-graphics. Students learn to communicate complex ideas and relationships through a visual language of diagrams, charts, maps and imagery with annotated explanations.

Through a combination of creative assignments, readings, listening to podcasts, and field trips, this course exposes students to multiple approaches and perspectives on understanding and communicating science for lay audiences.

Course *I*nstructors

Tana Trivedi is a faculty at the Amrut Mody School of Management at Ahmedabad University. With over seventeen years of teaching experience in business history, literature, literary theory, and postcolonial diaspora studies, her research interest lies in examining the notions of nation and identity formation. At Ahmedabad University, she offers science fiction and science writing courses, both of which she enjoys reading and discussing. She completed her PhD from Christ University and did her Postdoctoral research at the University of Edinburgh.

Bhumi Shah is a Fellow at Digital Curve, Centre for Learning Futures at Ahmedabad University. Her work is interdisciplinary and ranges across learning design, digital heritage, interactive media and research communication. She teaches courses in Interactive Media and Creative Coding at Ahmedabad University. She develops projects with researchers to understand, interpret, and communicate ideas, concepts or processes through interactive media and explanatory illustrations. She holds a Master in Computer Applications, specialising in Mobile Computing, and a Master of Management Studies in Heritage Management.

Preface

"*I believe the intellectual life of the whole of Western society is increasingly being split into two polar groups: literary intellectuals at one pole and scientists at the other.*"

— C. P. Snow, *The Two Cultures and the Scientific Revolution* (1959).

The quote by the renowned English scientist, novelist and public intellectual -CP Snow, who, in one of his famous lectures of 1959, described a “gulf of mutual incomprehension” between the sciences and humanities, uncannily presents an existing problem that the modern academia still grapples with. In his paper, he argued that the education systems in place lay the groundwork for the categorisation of disciplines and fields of study, giving rise to ignorance and thus restricting the focus of our understanding. This is an emotion that is shared by most, even today. Early specialisation and narrowing of educational focus have led to a lack of cross-disciplinary understanding and appreciation of fields outside of one’s own.

This divide is further strengthened by definitions and complex jargon existing in respective fields that prevent proper understanding of otherwise simple concepts and phenomena. A course such as science communication intends to deconstruct the notion of streamlined compartmentalisation of subjects and disciplines. For example, it might appear incomprehensible to most biologists that a layperson would be incapable of defining the process of mitosis, given the simplicity yet fundamental nature of the topic. However simple a subject may be, students, pursuing the course Scientific Communication Using Digital Media know that a well-informed explanation of a topic uses precise vocabulary along with suitable illustrations that stem from a conceptual understanding of the same.
Anatomical illustration is one such subset of scientific communication that highlights scientific accuracy working together with a creative school of thought. Leonardo da Vinci stands as a pivotal figure in this field, who, by merging art and science through his studies, explained the synchronicity of the workings of internal and external structures of the human body using beautiful and explanatory illustrations. Leonardo's work laid foundational principles for modern scientific illustration, emphasizing clarity and accuracy in depicting complex topics in a simplified manner.

The subsequent articles are the fruition of months of intense communication between students and their respective mentors. Each meeting contributed to deciding the details of the articles with deliberations by both the students and their mentors. This is why each written piece displays a unique flow and subject of topic. Some leverage a character-driven explanation of highly scientific topics along with commenting on the social consequences, while others incorporate suitable illustrations and appropriate analogies. Comprehending the research done by their mentors in disciplines of their respective interest and simplifying the writing, yet honouring the complexities driving the studies in the first place, has been the outcome of this course.

This course actively incorporates an interdisciplinary approach to explaining phenomena within scientific papers of their choice. Employing more than just the students’ scientific knowledge and accuracy; It requires a sense of aesthetics to integrate data visualisation elements while upholding the general visuals of the article. More importantly, it requires the skill to understand what exact illustrations would stand to describe subjects that are not tangible, especially when no previous work can serve as inspiration. In that, this course encourages its students to tap into their already existing skills and interests, such as sketching, visualisation and reading. This creative exploration provides an opportunity for students to engage with their topics in a manner that resonates personally, enhancing both their learning and furthering their intellectual understanding. As they work on their projects, the use of familiar skills serves as a powerful incentive.

Having gained an insight into the process of writing for COM211, I wish you an enjoyable and informative reading! Should you want to congratulate us, or provide feedback, do write to us at: *tana.trivedi.ahduni.edu.in* and *bhumi.shah@ahduni.edu.in*.

Shiven Tripathi
Integrated Master of Science
Class of 2028
Ahmedabad University

Inside

Order out of Disorder

Studying Stochastic Effects in Collective Behaviour

Writer and Illustrator **Siya Bhandari** | *Science Mentor* **Jitesh Jhawar**

In nature, we come across remarkable patterns shown by animals, such as flocks of birds flying together as they head home, mosquitos swarming towards water bodies, and ants forming trails towards their food sources. These are some of the fascinating examples of animal collective behaviours around us; irrespective of the size and scale, collective behaviour is omnipresent.

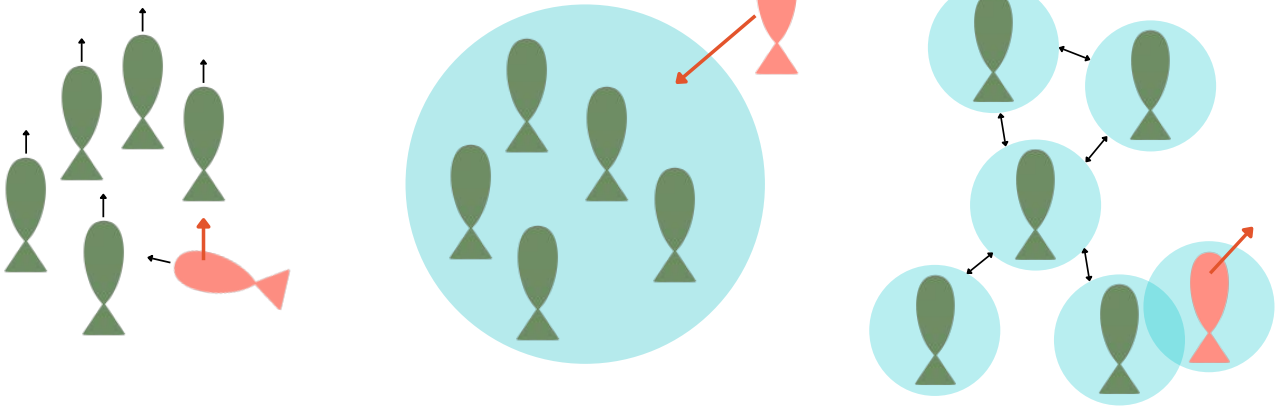
How such collective patterns emerge and why they have evolved in nature are fundamental questions studied by researchers across the globe. Thus, the collective behavioural phenomenon is studied from two perspectives: ***How are the groups formed and maintained?*** And ***Why they form.*** Research suggests that groups provide several benefits to individuals, such as protection from predators and finding mates. To reap such benefits, individuals must come together and remain part of the group. Here, we look at how individuals follow each other to do so.

Jitesh Jhawar, a professor of Behavioural Ecology at Ahmedabad University, studies group dynamics and self-organization in biological systems. In his paper titled "***Noise-induced Schooling of Fish***" in 2020, he and his team explored how individuals coordinate their motion while in a group.

Rosy Starling Murmuration
Rosy starling murmurations are a spectacular phenomenon where thousands of rosy starlings perform aerial acrobatics in a synchronized ballet. You can view them at the Ahmedabad University campus during winter.

How do organisms maintain coordination in a group?

Individuals exhibiting collective behaviours are likely to follow some rules for interacting with each other. Each individual within a group monitors their neighbours' movements, i.e., their positions and velocities, and rapidly responds to changes in them. These rules are commonly referred to as alignment, attraction, and repulsion. Let us take an example of a group of fish to illustrate the same.



Alignment
Individuals try to follow the direction of other individuals.

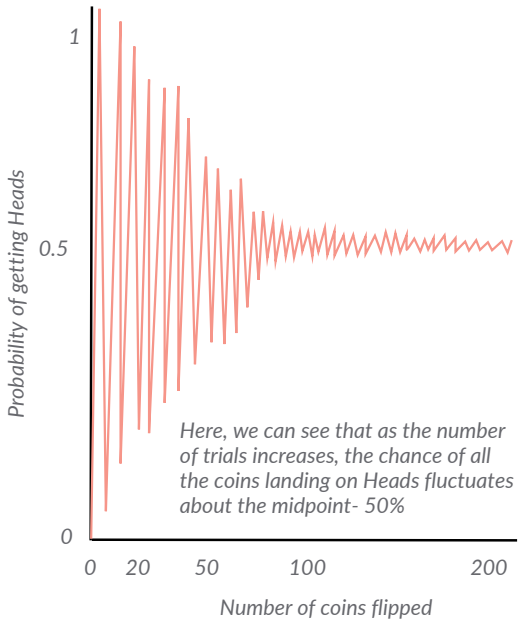
Attraction
Individuals try to move towards other individuals.

Repulsion
Individuals move away from other individuals if they are too close.

Noise and Stochasticity: How do they affect Collective Behaviour?

Imagine flipping an unbiased coin. Each flip is a random event, with a 50/50 chance of landing on heads or tails. If you flip the coin once, the outcome is highly unpredictable. However, as you flip the coin more and more times and count the total heads and tails, a pattern emerges: the number of heads and tails tends to equalize. This is due to the random fluctuations, or "noise," from individual flips averaging out over many trials. Note that for a small number of trials, the chances of all heads or all tails are high

Similarly, in a group, each individual's behaviour can be influenced by random factors. These random fluctuations in individual behaviour can lead to noise in group dynamics. Just like for the small number of tosses, it is possible to have the coins show either all heads or all tails; a small group can come to a consensus or alignment just by random chance. But in larger groups, random behaviour is less likely to lead to collective alignment for a long time -- similar to the coin toss, 50 % of the population will be in one direction (in a minimal two-direction case) and the rest in the other, which means no group alignment or consensus!

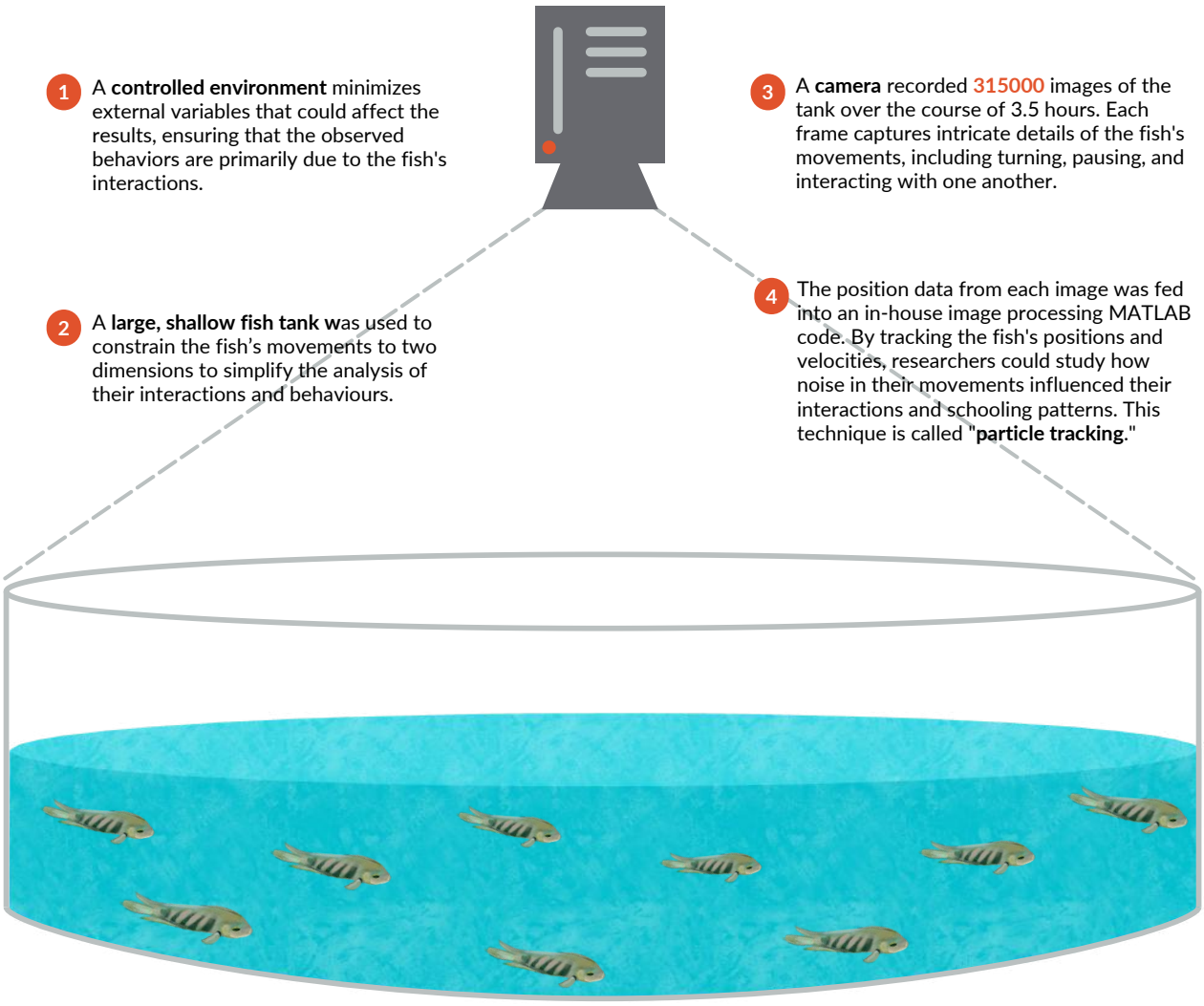


Hence, the randomness arising from individual behaviours translates to noise or stochasticity in group dynamics. Reflecting on the coin toss example again, the strength of stochasticity in the dynamics of small groups is higher as the group-level outcomes can fluctuate more around an average or expected value just by chance. Whereas a larger group has low stochastic fluctuations in its behaviour as the group outcome remains relatively stable and closer to an average value. This phenomenon has an influence on the dynamics of directional alignment in groups, resulting in "noise-induced effects" in which finite-sized groups exhibit stronger order in motion due to intrinsic stochasticity in group dynamics.

Studying Schooling Behaviour in the Lab

Schooling is a type of behaviour in which a group of multiple fish swim collectively in the same direction. This can help fish protect themselves from predators, forage better, and swim more efficiently. Not all fish schools, but this behaviour has been observed across various fishes, from tiny guppies to some large ocean sharks. Fish exhibit remarkable synchronization in their movements- owing to the three rules of collective motion: alignment, attraction, and repulsion. Using these rules, one can reproduce schooling behaviours through computational models. Therefore, such models can help us understand and, ultimately, predict individuals' behaviours.

Jitesh Jhawar, an Ecology Professor at Ahmedabad University, investigated the role of noise in collective behaviour. He used the schooling of the freshwater fish Green Chromide (*Etroplus suratensis*) as a model to explore how individual interactions within a group can lead to emergent collective dynamics. Green Chromide is a cichlid fish native to freshwater and brackish waters in India, and Sri Lanka are known for their vibrant green colouration, especially on their sides. This species was selected for this study because it is known for its schooling behaviour, making it an ideal candidate to observe collective motion in a controlled environment.

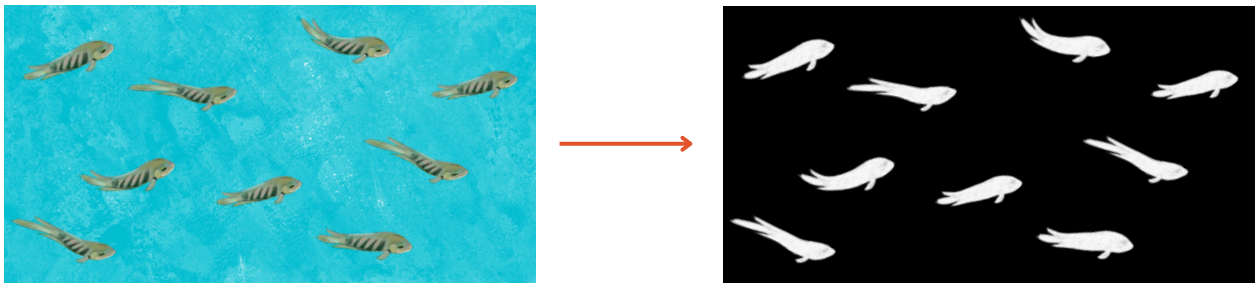


The experiment focused on small to medium-sized groups of fish (groups of 15, 30, and 60). This variation was important to observe how group size influences collective behaviour. As we know, intrinsic noise in collective dynamics can change with group size; understanding the differences in noise with varying group sizes can shed light on the mechanisms of schooling.

Mapping the Fish's Journey through Particle Tracking

1 Detection of fish in each frame

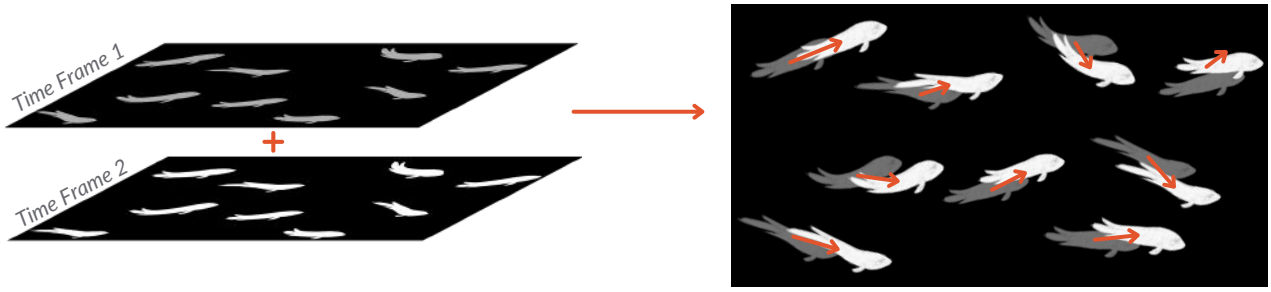
The first step in particle tracking is to detect objects, in this case- fish, in a given frame. The objects are first detected using methods such as background subtraction or thresholding. In this study, the researchers used the image subtraction technique for ease of detection and tracking of each fish.



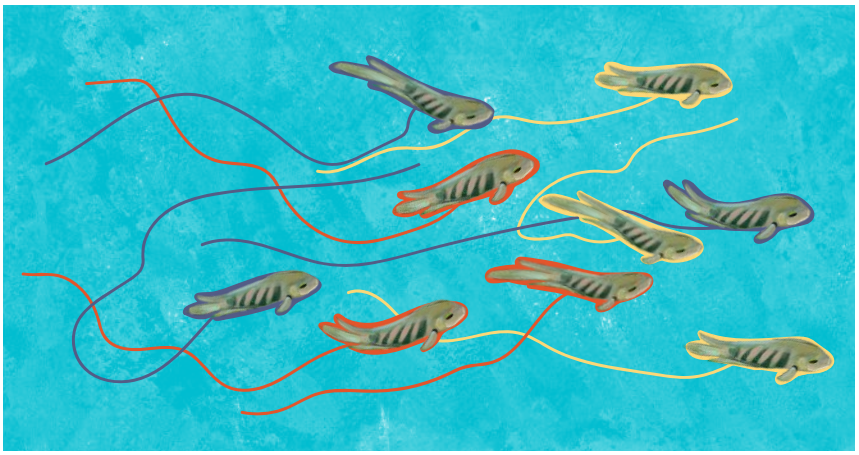
From each frame, the background is removed and each fish is converted into an easily identifiable and trackable object.

2 Tracking of fish across multiple frames

The next step is to stitch the objects between different frames. This is important to extract the velocities of individuals. In this case, one needs to stitch two objects for atleast two consecutive frames to obtain the velocities of each fish. The Kalman filter or Hungarian algorithm is typically used to do so.



Kalman filtering predicts the most likely position of a fish in the next frame, while the Hungarian algorithm assigns these predicted positions to detected fish in the new frame, ensuring accurate tracking. This combined approach improves tracking accuracy, especially in challenging conditions like rapid movement or situations where fish are partially hidden from view.

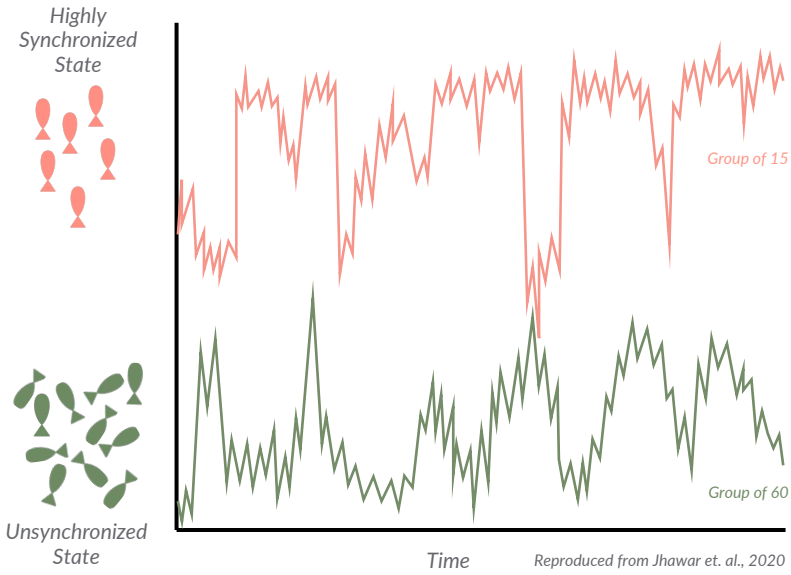


Particle tracking provides visual insights into school formation, individual movement patterns, and social interactions such as alignment and attraction. This data can validate mathematical models of collective behavior, illustrating how simple individual interactions result in complex group behaviors.

Illustrative results from particle tracking of Green Chromides after 3.5 hours.
Adapted from Jhawar et. al., 2020

Smaller Groups, More Noise and More Alignment

When fish are in smaller groups, they tend to school more tightly together. This means they align their movements and swim in the same direction more often. For example, a group of 15 fish showed a high level of alignment compared to larger groups like those with 60 fish, where their movements were more scattered and less synchronized. Interestingly, as shown in the depiction below, the smaller group shows high fluctuations as it largely stays in a synchronized state while sometimes switching to an unsynchronized state. The larger group, on the other hand, remains in an unsynchronized state with very small fluctuations around it.



Reproduced from Jhawar et. al., 2020

The smaller group remains more in the highly synchronized state as individuals follow each other. Occasionally the group spontaneously switches to the unsynchronized state. Compared to the larger group, the smaller group has more strength in fluctuations between states as depicted here. Hence, noise induces these transitions.

In the larger group, the individuals must also try and copy each other when unsynchronized, but the low strength of fluctuations inhibit the transitions between states.

Therefore, schooling in fish is found to be a combination of individuals copying each other's directions and a small group size effect.

Noise-Driven Order in Smaller Schools

The empirical observations showed that as the group size decreases, the group becomes more and more coordinated. The researchers quantified the strength of the fluctuations in the dynamics. Using the high-resolution time series data of group alignment obtained from the experiments, the strength of noise in the time series was quantified. This revealed that, indeed, the small groups had greater stochasticity while the larger groups had lesser. Finally, using a stochastic differential equation framework, the researchers first identified the expected behaviour of the group. Regardless of size, the group's expected behaviour is to remain in a disordered state, and it is the noise which provides order. The combined observations of small groups exhibiting high order and the order being stochastic were further captured by a simple pairwise copying model using computer simulations.

How do individual fish influence each other in a group?

The pairwise model is a way to describe how individual fish in a school influence each other. In this model, each fish can either copy the direction of a nearby fish or change its direction randomly. This mimics how fish actually behave in real life. The researchers developed this model and found that it successfully reflects important behaviours observed in real fish schools; it predicts that small groups have a high degree of alignment, and the order in the system, derived using the simulations, is also noise-induced. The authors also tested another model where they incorporated interactions between three individuals and ruled out this possibility for their system as this model produced completely different dynamics, which they did not observe in their system.

In a pairwise copying model, either one of the fish will copy the other and change its direction to become more aligned.

Noise Matters: A New Perspective on Collective Behavior

The study emphasizes the fact that noise from probabilistic interactions among a finite number of individuals is very important to consider. The researchers have highlighted how we can better understand the dynamics of real systems by using models while studying collective behaviour. Traditional approaches to studying how groups move, where individuals' actions are modelled deterministically, and noise is only added *post hoc*, are not enough. Insights from this study can help in studying other animal groups as well, where similar copying behaviours might occur. We need to consider how randomness and individual choices affect the whole group's behaviour. This understanding can help us learn more about social interactions in nature, like how animals find food or avoid predators.

Overall, Jhawar's study not only advances our knowledge of the schooling behaviour of Green Chromide but also emphasizes the importance of considering noise in studying collective behaviours across different species and environments. In conclusion, this research opens new avenues for investigating how individual actions contribute to complex and intricate group dynamics. Studying collective behaviours is crucial to understanding emergence in complex systems- ultimately enriching our knowledge of social interactions not only in animals but also across other kingdoms in biology.

References

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Boettiger, C. (2018). From noise to knowledge: How randomness generates novel phenomena and reveals information. Ecology Letters, 21(9), 1255–1267. https://doi.org/10.1111/ele.13085

Siya Bhandari is a student of Integrated Master of Science at Ahmedabad University. With a background in Life Sciences, she has always had a passion for art and graphics. Whether creating straightforward illustrations of cells or crafting detailed flowcharts to grasp complex biological processes, visualization has played a vital role in her learning approach. Fascinated by bird congregations, she decided to delve deeper into the study of collective behaviour. Through this exploration, she gained insights into schooling behaviours and the experimental methods used to study collectives.

Jitesh Jhawar is an Assistant Professor at the School of Arts and Sciences at Ahmedabad University. His research focuses on understanding group dynamics and underlying mechanisms that also fall under self-organisation in biological systems. His research is driven by fundamental proximal questions on animal behaviour while they are in groups. His research is also highly interdisciplinary, as he uses computer vision, motion detection, and machine-learning-based techniques for data collection from videos of animal groups. He completed his PhD at the Indian Institute of Science, Bengaluru (2019) and moved to the Max Planck Institute of Animal Behaviour and the University of Konstanz, Germany for postdoctoral work.

Hell or High Water - Why Preparedness is Key

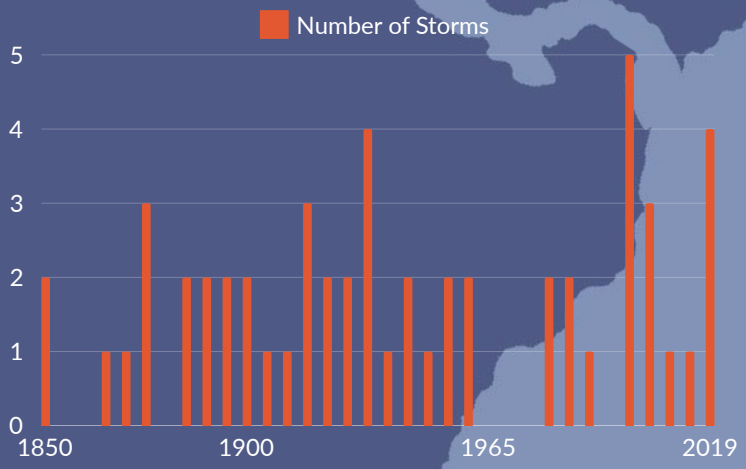
Writer and Illustrator **Anoushka Bhatha** | *Science Mentor* **Kaumudi Joshipura**

Often, we read in the papers about how yet another cyclone struck Odisha and day by day this headline shifts from the cover story to the third, the fifth and finally, a corner of a page. We curse the fact that the damage we have done to this planet has led to such results, and we shake our heads grimly. Some send help to ease the pain caused to the affected areas, but slowly, we move on to the next new thing. It is human nature to never consider the consequences until the damage is already done and then try to mitigate the reactions in hindsight. Being prepared for natural disasters can make all the difference in how we let such disasters impact us.

To continue this story, let me take you about fourteen thousand kilometres away to a tiny Caribbean Island – Puerto Rico. In September 2017, Puerto Rico made history with one of the most cataclysmic natural disasters to ever have affected that area - Hurricane Maria. Since the 19th century, Puerto Rico has been victim to around 50 major hurricanes to date, leaving the island in very poor condition with every added disaster. As of 2020, 20% of the island is considered to have a high risk of landslides due to hurricanes.

Why Is Puerto Rico at Such a High Risk of Hurricanes?

The recipe for a perfect hurricane is some warm water, humid air, a low wind shear or wind gradient, and pre-existing thunderstorms. It is not easy to predict a hurricane because various climatic factors can contribute to its formation.
For Puerto Rico, factors like the Coriolis Effect - the cyclonic motion caused by the Earth's rotation, the high humidity levels of the tropical region, the Tropical Waves - disturbances from the African Coast towards the Atlantic, and the Bermuda High, a high-pressure wind system over the Atlantic, all make Puerto Rico susceptible to hurricanes during the hurricane season - from June 1st to November 30th.



The number of tropical storms in Puerto Rico per 5 years from 1850 to 2019

The El Nino and La Nina effects play a crucial role in Puerto Rico's hurricane season. El Nino winds are responsible for increased wind shear. When there is a higher wind shear, there is a lower possibility of hurricane formation because these winds do not get the required turning force to form the storm. This means reduced intensity of hurricanes during the El Nino years. Recently, El Nino events and warm Atlantic waters have coincided, due to which hurricanes have developed even though there is substantial wind shear.

The La Nina conditions decrease the wind shear over the Atlantic, which is why these conditions increase the vulnerability.

The Effect of Climate Change

Global Climate Models have predicted that Climate Change plays a key role in the increased intensity of hurricanes. These studies show that the number of storms may not be significantly impacted by climate change, but there is a definite relation between the increasing hurricane intensity and Climate Change. When the global temperatures rise and the Atlantic Ocean becomes warmer, a tropical storm can turn into a hurricane more easily. The warmer the water, the more pressure imbalance there is in the hurricane system and the more intensity the storm has.

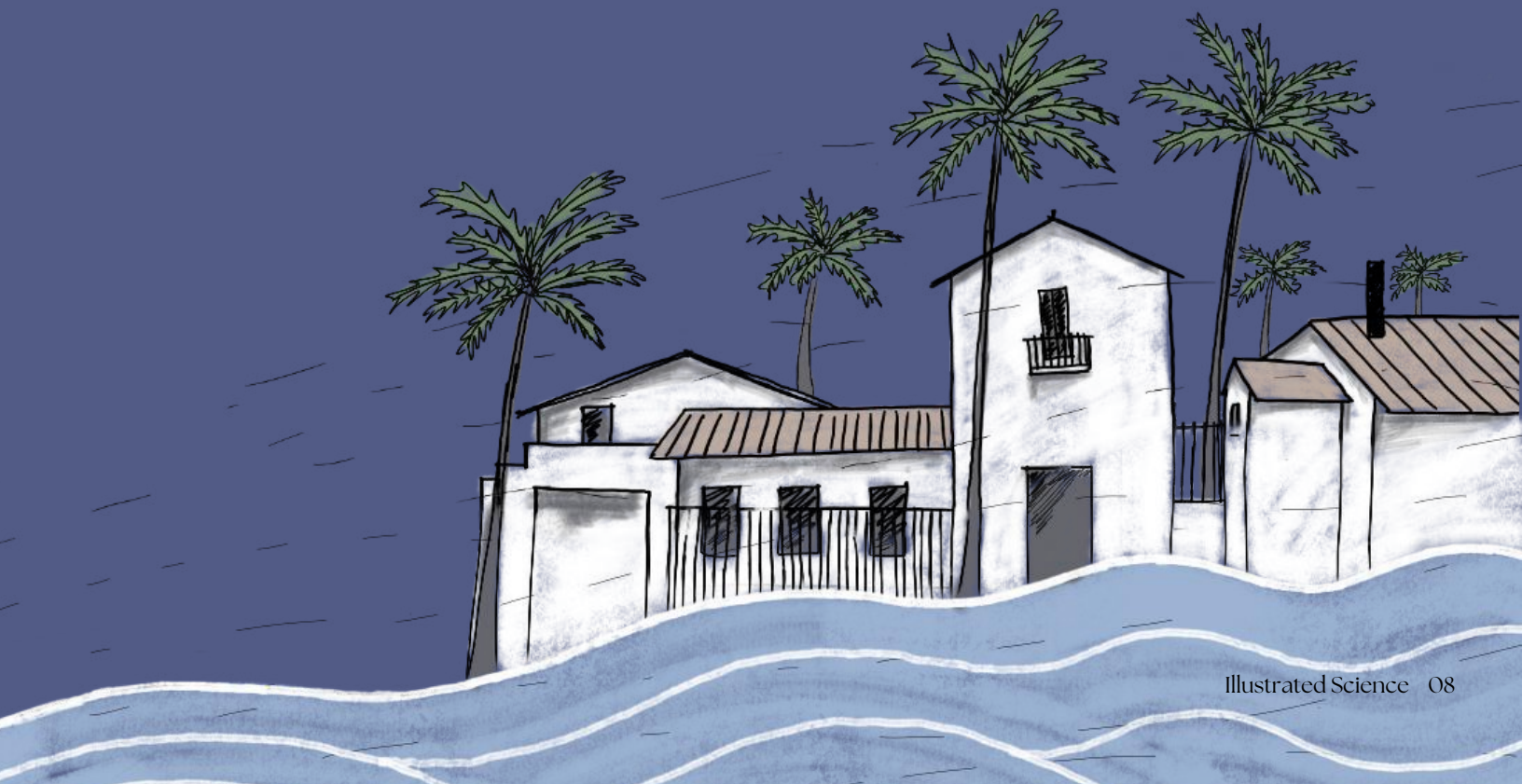
Another effect of Climate Change, the rise in the sea level, is also a major contributor to the damage inflicted by hurricanes. With a higher sea level, the flooding caused by these tropical storms is worse, and there is more intense rainfall when these hurricanes come ashore. The increased humidity also causes this fierce rainfall due to the rising temperatures. The increased moisture becomes another factor that adds to the severity. These factors all add up to Puerto Rico's plight, and with every added year, hurricane impacts become more severe.

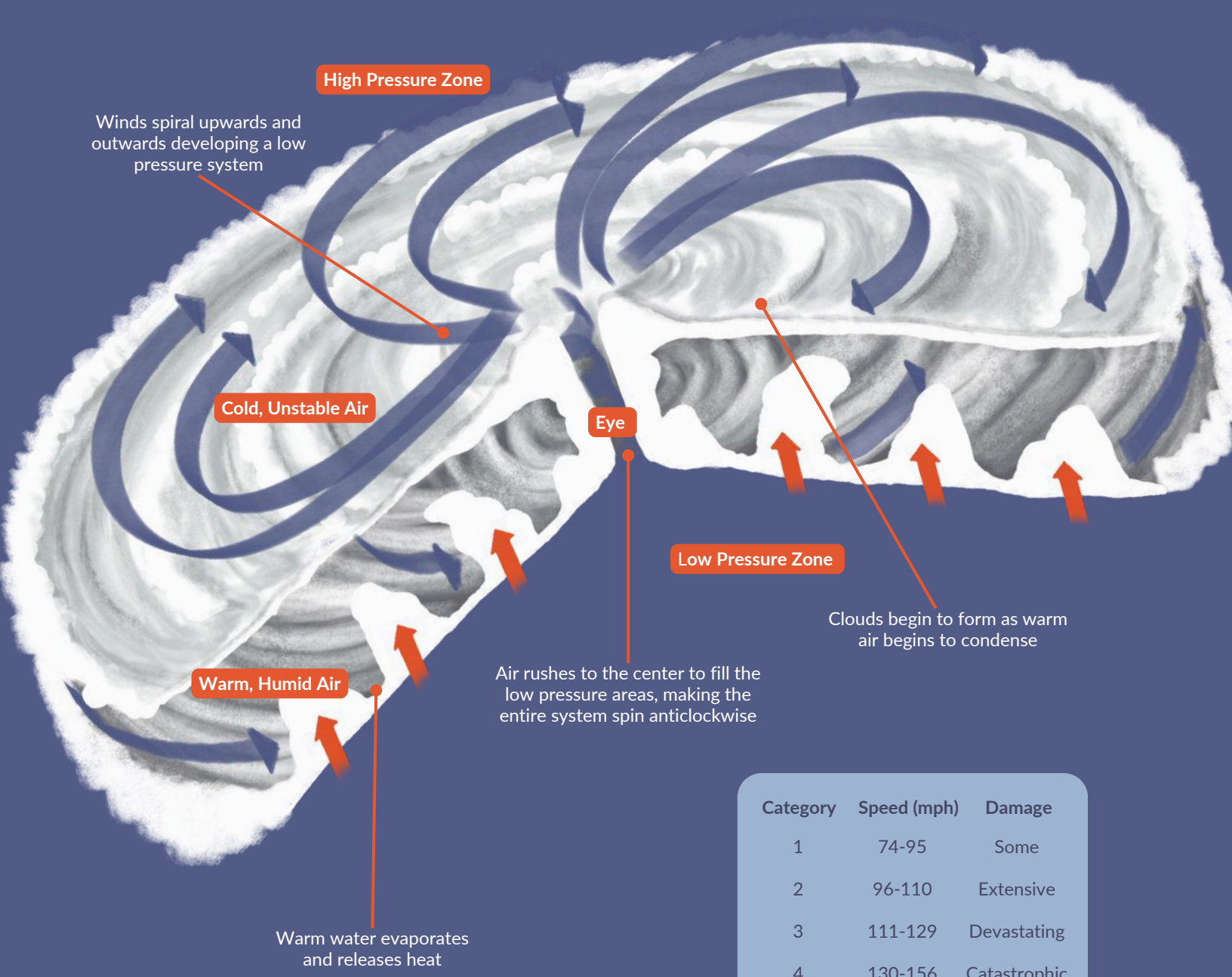
How Preparedness Comes into Play

Exposure to natural disasters has been known to often lead to adverse health outcomes. Hurricanes do not just cause mental health issues to those affected but also lead to the worsening of chronic diseases and the development of new non-communicable diseases.

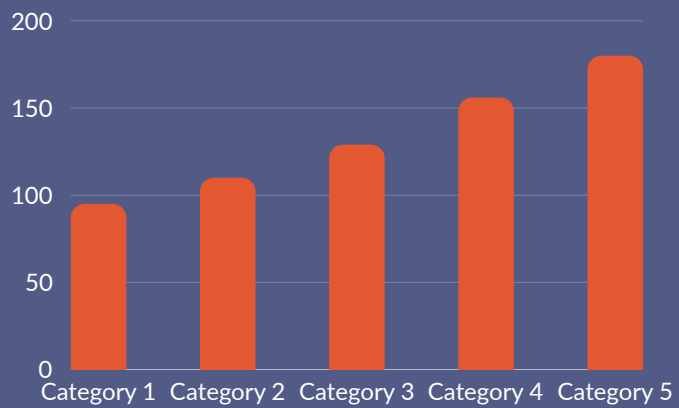
Where and when a hurricane will strike and how bad it will be is generally estimated reasonably by meteorologists a couple of days before the hurricane hits land. This gives enough time to warn the inhabitants, ensure that evacuation begins, and ensure that the area is braced to handle the damage.

Scan this QR Code to learn more about **Preparedness for Hurricanes** from The Bagchi School of Public Health at Ahmedabad University





Category	Speed (mph)	Damage
1	74-95	Some
2	96-110	Extensive
3	111-129	Devastating
4	130-156	Catastrophic
5	157+	Catastrophic



Saffir Simpson Wind Scale - Damage Due to Wind Speed

In September 2017, Puerto Rico faced Hurricane Irma, with Category 5 Winds, according to the Saffir Simpson Wind Scale, and just a fortnight later, Hurricane Maria, with Category 4 winds. There was severe flooding, power outage, water shortage, extensive damage to infrastructure as well as a death toll of almost 3000. Only few lives were lost immediately due to the direct impact, but many lives were lost due to the multiple indirect impacts including the limited water access and the long-term power loss as an aftermath of the floods.

2975 *Official death toll due to Hurricane Maria*

73% *lost water services for an average of 8.5 weeks after the calamity*

96% *reported being without power for over a month after the calamity*

41% *reported being highly prepared for Hurricane Maria*

For places such as Puerto Rico, it is crucial to be prepared for such disasters beforehand. It is interesting to note that there is a gap between the perceived level of preparedness and the actual preparedness for disasters. In a study by the Behavioural Risk Factor Surveillance System in 2006, it was seen that in the United States, 78% of the participants felt that they were prepared for a disaster, but only 45% were adequately prepared. What we can understand from this is that there is a certain level of unclarity on what it means to be prepared for a disaster.

In a study on disaster preparedness and its relation to hurricane impacts by Kaumudi Joshipura, an epidemiologist and a Professor of Public Health, and her fellow researchers, some interesting associations between preparedness and hurricane-related health impacts came to light. It was clearly observed that higher self-reported hurricane preparedness was directly associated with lower self-reported hurricane health impacts. This association included health impacts such as injury, infectious disease, development or worsening of non-communicable diseases, and mental health impacts. This association was independent of age, location, education or income.

66.2% *chance of experiencing adverse health with low - moderate preparedness*

67.4% *chance of experiencing adverse health effects with drinking water disruption*

72.6% *chance of developing a non communicable disease with low - moderate preparedness*

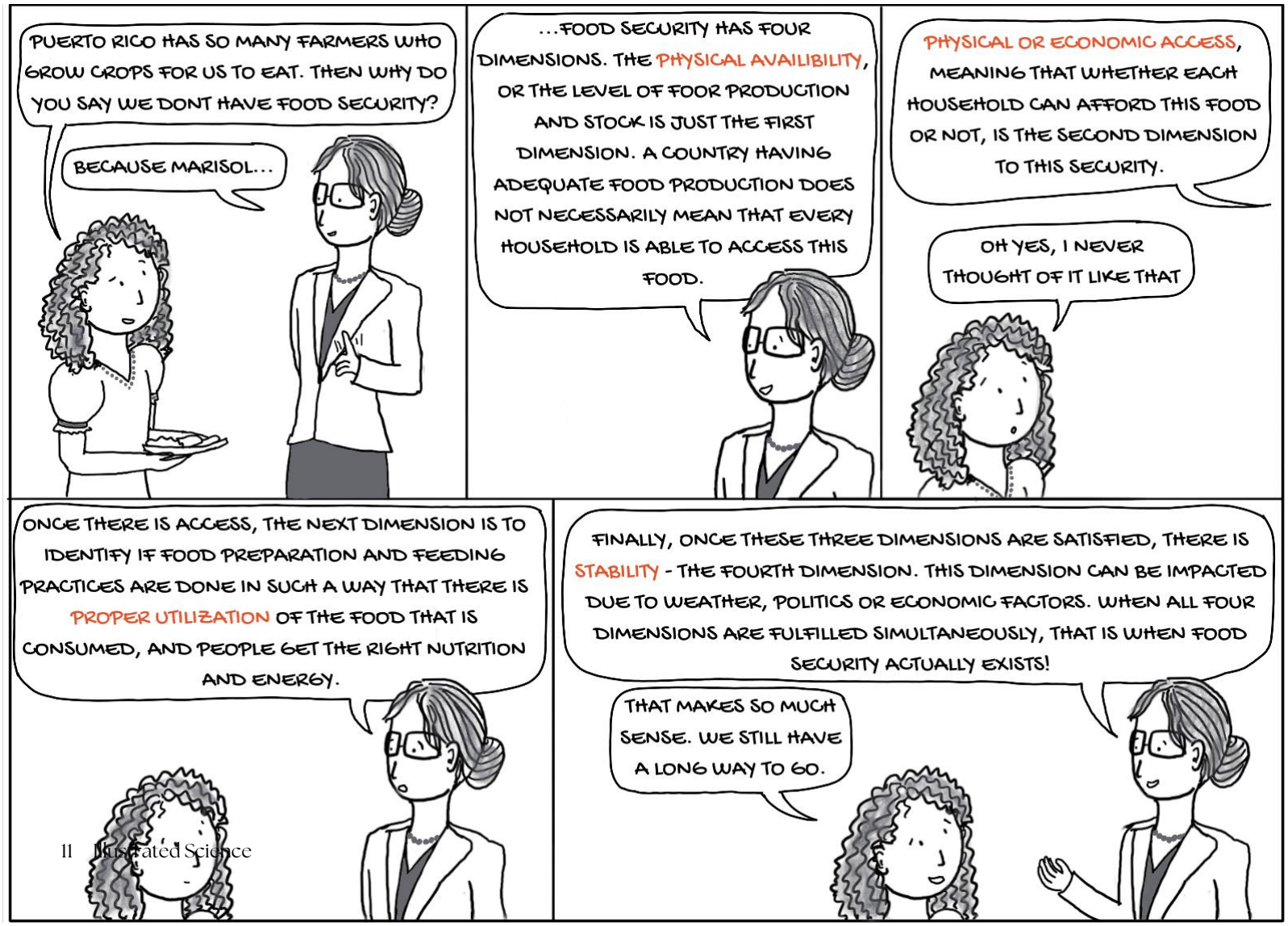
73.9% *chance of experiencing adverse health effects with dietary change due to financial impact*

Preparedness and Food Security

The clear conclusion is that preparedness is more than just a mental state - some participants felt that they were prepared but were not armed with adequate resources to actually support this claim; it is a holistic approach to disaster management where necessary efforts are planned in the spheres of resources, operations, logistics, health and security to mitigate the effects of a disaster whenever it may prevail.

When the gaps in awareness and resources are filled, several outcomes appear. Patients with pre-existing conditions need access to a stock of medications. People need to be informed about food security and storage.
Food Security is, to date, one of the most significant challenges faced by people globally. Climate change adds to this already existing insecurity and makes access to nutritious food more difficult and expensive with every new day. Food Security has four dimensions:

Access | **Utilisation** | **Stability** | **Availability**



Shelf-stable nutritious food can last months if stored properly, and storing such foods is a must for disaster-prone areas. Such measures also require financial stability, which can be supported by the government and other philanthropic organizations. When such steps are taken to improve access to nutritious food and clean water even after a disaster, the harmful impacts on health are mitigated. Better preparedness directly leads to lowered morbidity and mortality in the aftermath of such disasters.

Why is this important for us?

The key learning from this story is that instead of having to rebuild the house of cards every time the wind blows it apart, it is better to reinforce the walls and give it a sturdy frame. Global efforts and a multidisciplinary approach are required to deal with disasters beforehand because the most prone places are incapable of managing them holistically due to economic strain. Adequate resources need to be allocated, and information needs to be disseminated at individual, national, and global levels.

At an individual level, there is limited action one can take. Knowledge and information become an individual's ally, but there is little one can do with it if they do not have the resources to apply this knowledge practically. Together, we can approach this problem through the lens of Public Health. As a community, we can join forces to uplift our lesser-privileged compatriots with information and resources to ease their distress. With the lessons learned from Puerto Rico, the implementation can be practised at a global level and in other places as well.

Coming back to Odisha, if funds and efforts are allocated to spreading awareness about disaster preparedness and supporting preparedness efforts, the aftermath of hurricanes will not be as grim. With multidisciplinary research and global efforts, people, institutions, and the government will be able to bounce back onto their feet faster, come hell or high water.

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The Electric Sixth Sense

The Fish with a built-in battery

Writer and Illustrator **Agamya Mehendiratta** | *Science Mentor* **Rama Ratnam**

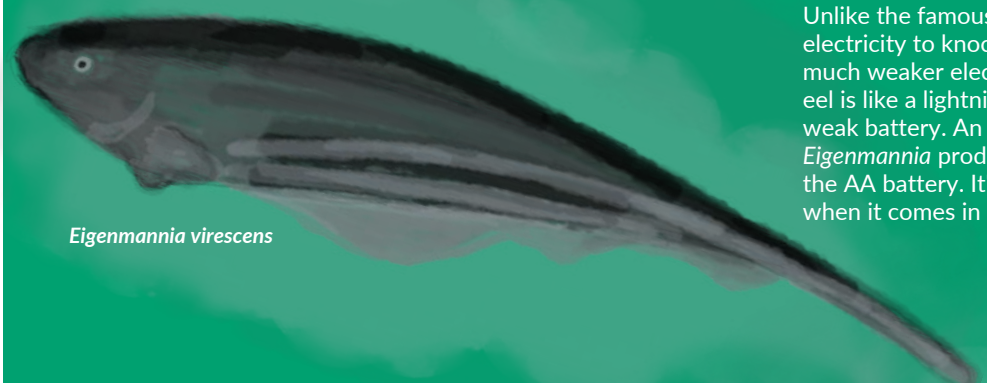
Imagine you're floating down the Amazon River. The water is gloomy, full of life you can't see. But beneath the surface, an invisible dance is taking place – a dance of electricity. No, we're not talking about electric eels. We're here to explore a group of fish that are true masters of electrical finesse: the weakly electric fish, and in particular, a species called *Eigenmannia virescens*. These fish aren't just using electricity – they are living in a world defined by it. They navigate, communicate, find food, and avoid predators, all using their electrical superpowers. And the most incredible part? They've solved a problem that human engineers are still grappling with today. Let's dive in and discover the shocking truth about these underwater electric dancers.

Why Eigenmannia Matters: The Bigger Picture

As we face growing environmental challenges, understanding creatures like Eigenmannia becomes increasingly essential. These fish are not just fascinating curiosities; they're a crucial part of the Amazon's ecosystem and a potential source of innovation for human technology. Moreover, the health of electric fish populations can serve as an indicator of the overall health of their aquatic ecosystems. Changes in water chemistry or the introduction of pollutants can affect the fish's ability to generate and detect electric fields, making them sensitive biomarkers for environmental change.

Meet *Eigenmannia virescens*: The Fish with a built-in battery

First things first, let's get to know our star performer. *Eigenmannia virescens*, also commonly known as the glass knifefish, doesn't look much at first glance. It's a slender, nearly transparent fish about the size of a Lady's finger. But don't let its unassuming appearance fool you – this fish is packaged with some serious electrical abilities, too.

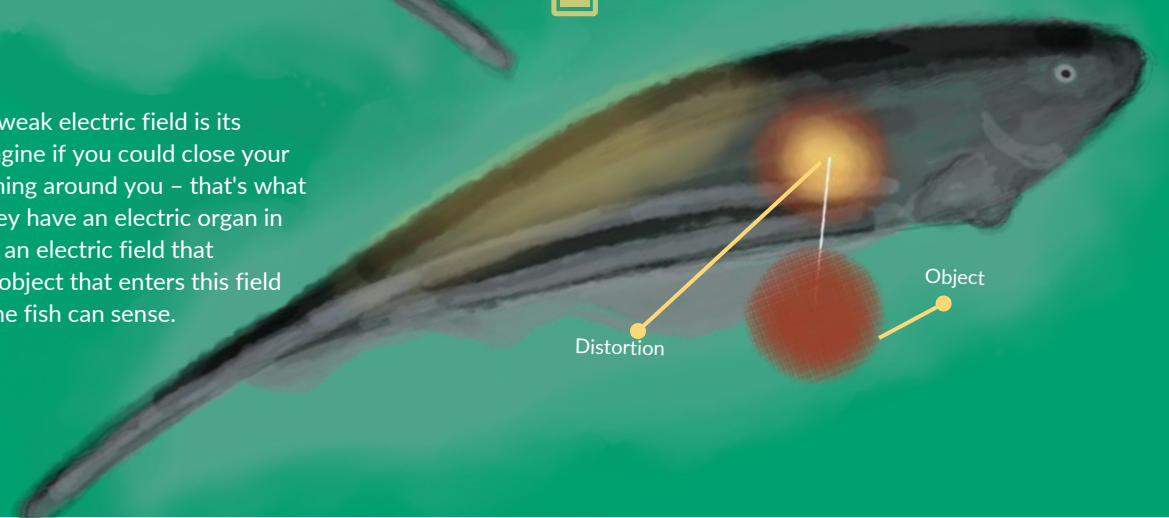


Eigenmannia virescens

Unlike the famous electric eel, which can generate enough electricity to knock out a horse, *Eigenmannia* produces a much weaker electric field. How weak? Well, if the electric eel is like a lightning bolt, *Eigenmannia* is more like a very weak battery. An AA battery produces 1.5 volts, but *Eigenmannia* produces about one-thousandth the voltage of the AA battery. It's so weak that humans can't feel it at all when it comes in contact with us.

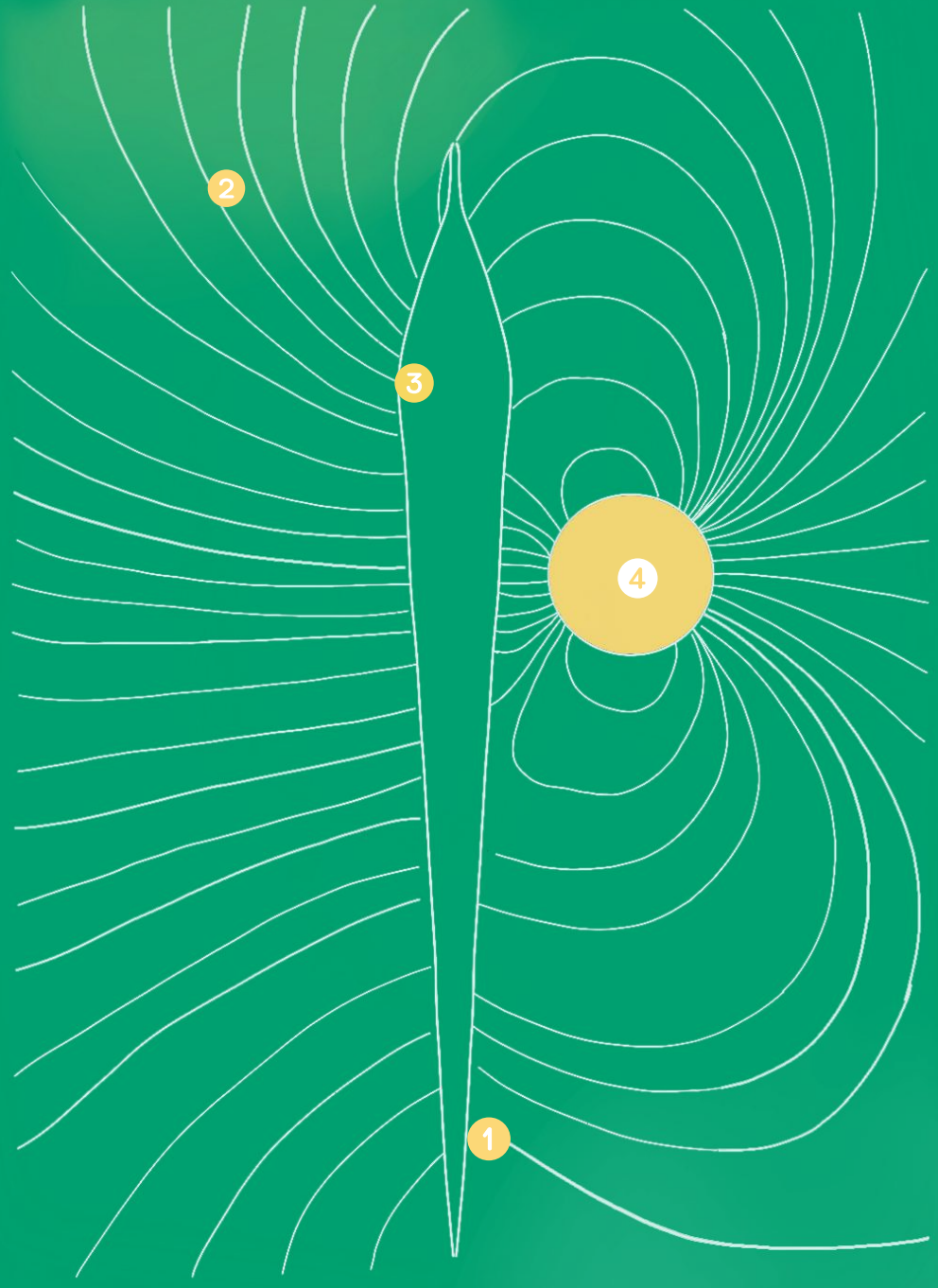
= 1000 Eigenmannia virescens

But for *Eigenmannia*, this weak electric field is its window to the world. Imagine if you could close your eyes and still 'see' everything around you – that's what it is like for these fish. They have an electric organ in their body that generates an electric field that surrounds them, and any object that enters this field causes a distortion that the fish can sense.

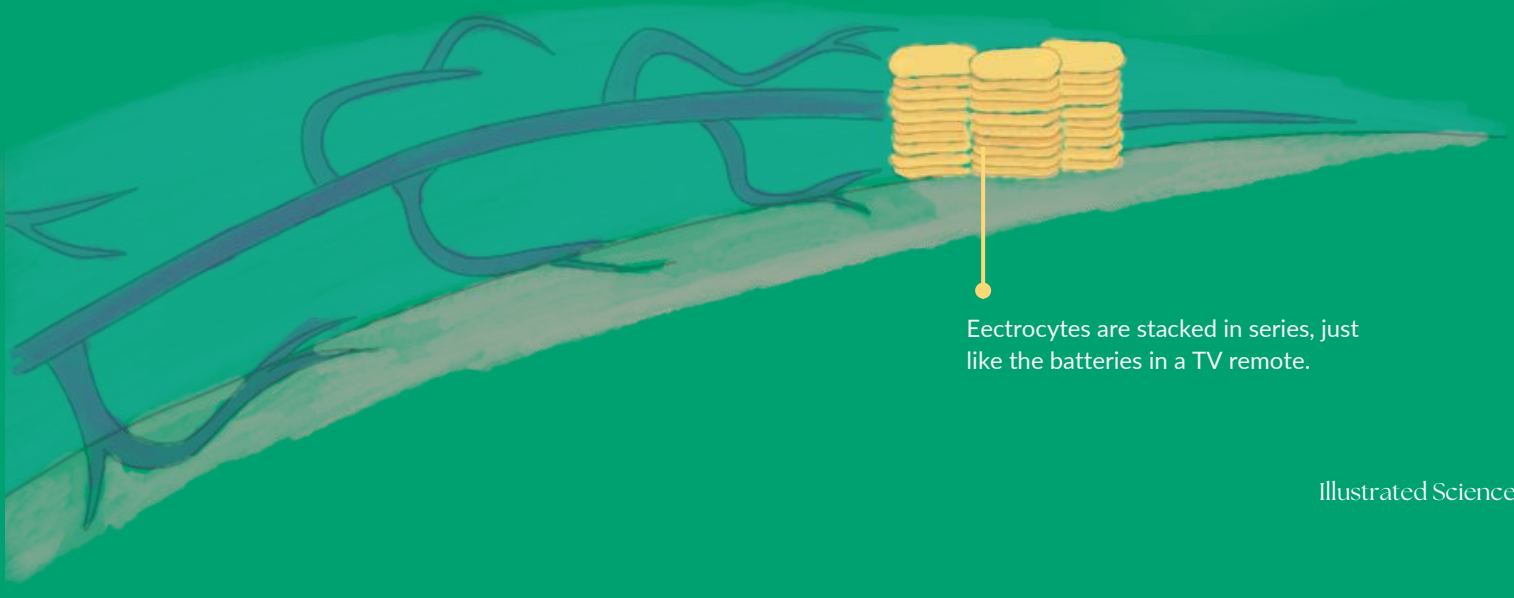


The Living Battery: How *Eigenmannia* Generates Electricity

Inside *Eigenmannia's* body is an electric organ that is essentially a living battery. This electric organ is made up of thousands of specialised cells called electrocytes. When activated, each electrocyte adds its tiny voltage to the total, creating the fish's electric organ discharge (EOD) and the electric field. But here's the really cool part: *Eigenmannia* can control these electrocytes with incredible precision, allowing it to fine-tune its electric field as needed. The fish's skin is also covered in special sensors called electroreceptors. It's this combination of electric field generation and sensation that gives *Eigenmannia* its electrical 'sixth sense'.



1. **Electric organ** runs through the entire length of the fish's body
2. **Electric field** by EODs
3. **Electroreceptors** allow the fish to detect even tiny changes in the electric field around it.
4. Non-Conducting Object



Eectrocytes are stacked in series, just like the batteries in a TV remote.

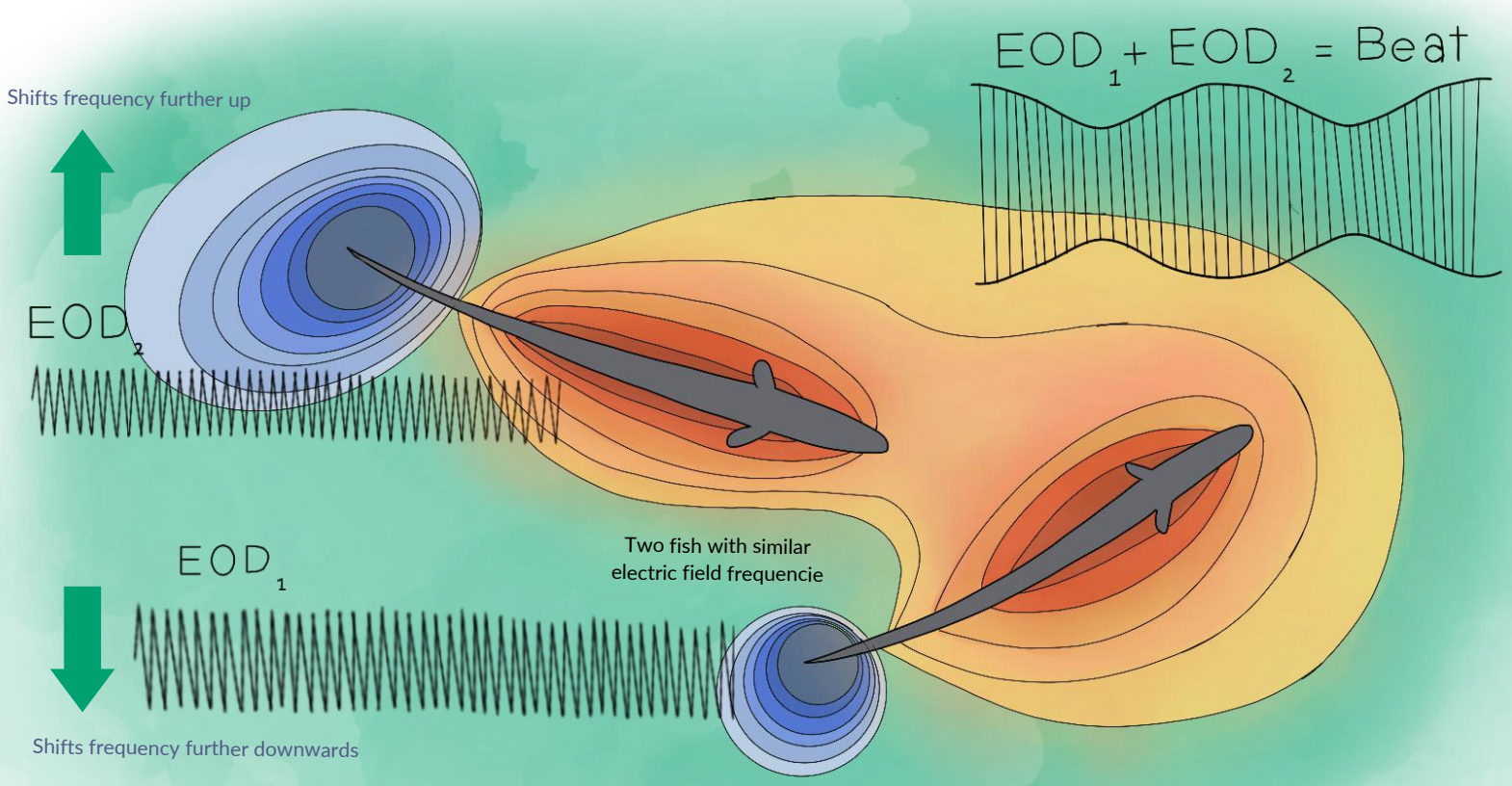
The Noisy Neighborhood: When Electric Signals Collide

Now, you might be thinking, That's all very impressive, but what's the big deal? Why are scientists so excited about these fish? *Eigenmannia* lives in large groups; this creates a problem that scientists call 'jamming'. Imagine you're at a crowded party. Everyone's talking at the same time and jamming each other, making it difficult to hear the person next to you. What if, instead of talking, everyone at the party is broadcasting their own radio signal to communicate? This is precisely how electric fishes communicate within their groups. Each fish is continuously producing its own electric field, and these fields can interfere with each other. When two fish with similar electric organ discharge frequencies come close to each other, their signals 'jam', making it hard for the fish to sense their surrounding environment accurately. It's like trying to listen to your favourite radio station, but there's another station broadcasting on a very similar frequency. The two signals mix together, and you can't hear either one clearly. For *Eigenmannia*, this isn't just annoying – it's potentially life-threatening. If a fish can't correctly sense its environment due to electrical interference, it might miss approaching predators or fail to locate food.

So, how do these fish solve this problem? That's where the real magic happens.

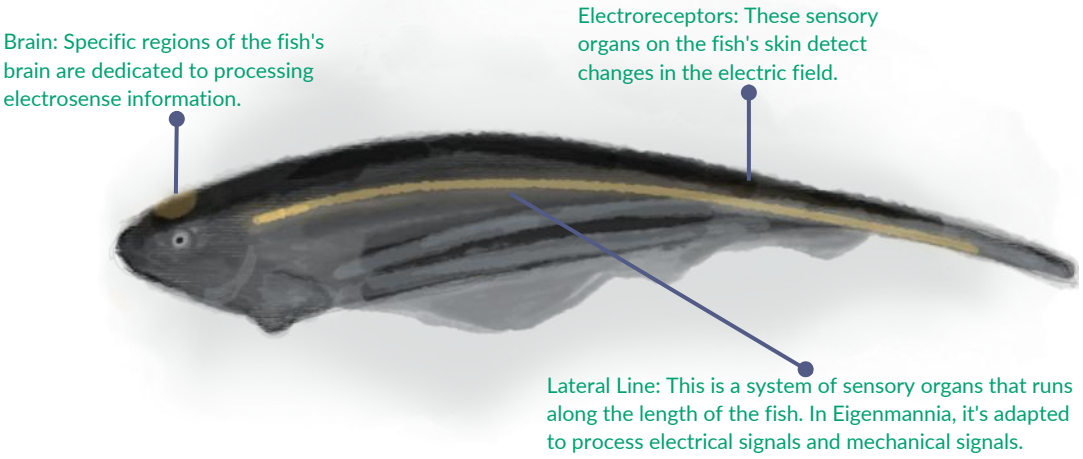
The Jamming Avoidance Response: Nature's Frequency Modulation

Eigenmannia has evolved an extraordinary solution to the jamming problem: the Jamming Avoidance Response, or JAR for short. When two fish with similar electric field frequencies come close to each other, they can detect the interference. In response, the fish with the higher discharge frequency will shift its frequency further up whereas the fish with a lower frequency will shift it further downwards, thereby increasing the separation in their frequency. This ability to 'tune' their electrical frequency in real-time is an impressive feat of biological engineering. At the heart of the Jamming Avoidance Response is a concept called beat frequencies. When two frequencies are close but not identical, they produce a third frequency called the beat frequency. This cycle of going in and out of sync creates a regular pattern – that's the beat frequency.

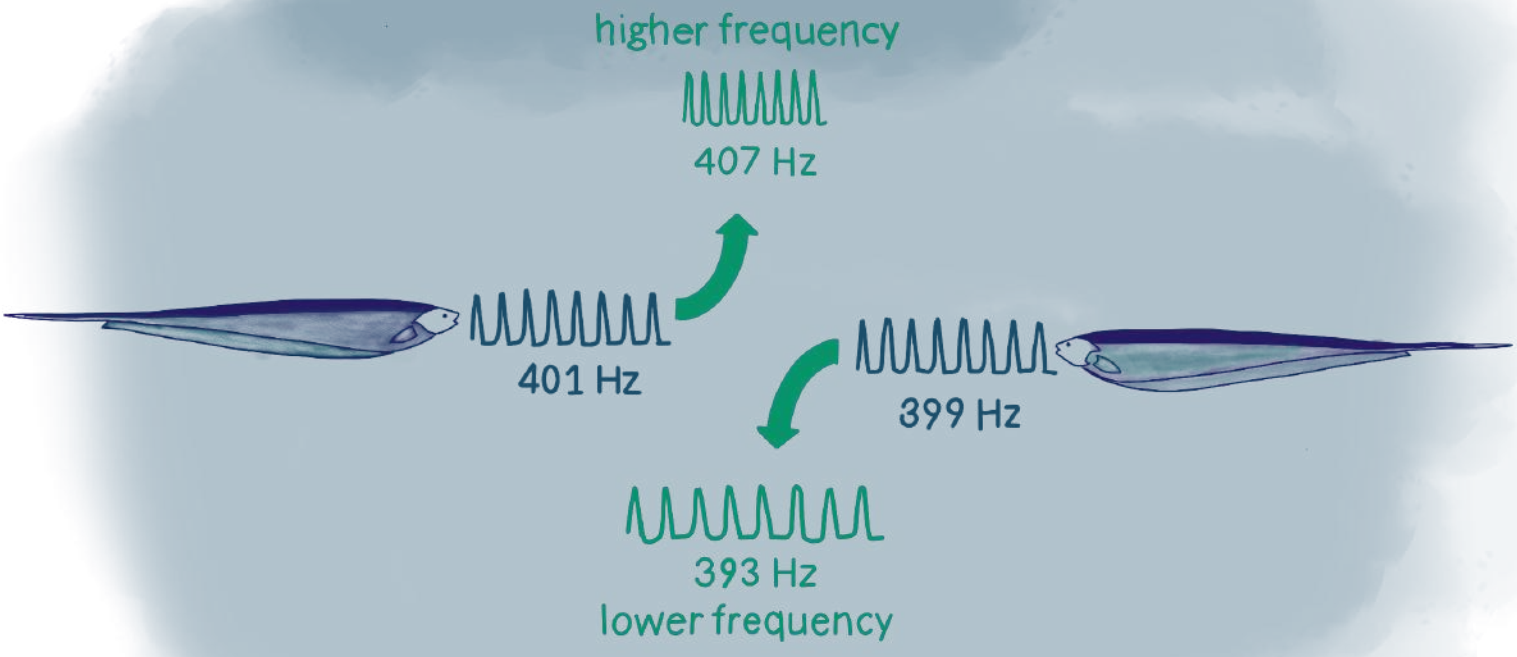


How *Eigenmannia* Uses Beat Frequencies

If the fish detects that its frequency is lower, it lowers its frequency even more. If it detects that its frequency is higher, it raises it even more. This pushes the two frequencies further apart, reducing the interference. But how does the fish actually detect and process these beat frequencies? That's where the fish's anatomy comes into play.



When jamming occurs, the electroreceptors detect the beat frequency. This information is sent via the lateral line to the brain, which then determines whether the fish's frequency is higher or lower than the interfering signal. Once the brain has processed this information, it sends signals back to the electric organ, telling it to adjust its frequency. This entire process happens in a fraction of a second, allowing the fish to constantly fine-tune its electric field in response to its environment. Mathematically, we express the beat frequency (let's call it fb) like this: fb = |f1 - f2|
Where f1 and f2 are the frequencies of the two fish's electric fields, and | | means "the absolute value of". So if one fish is producing a field at 400 Hz (cycles per second) and another at 405 Hz, the beat frequency would be: fb = |400 - 405| = 5 Hz



While the Jamming Avoidance Response is impressive on its own, the electric sense of *Eigenmannia* serves many other purposes in its daily life.

1. Navigation: The electric field helps the fish create a three-dimensional 'map' of its surroundings, allowing it to navigate through complex underwater environments even in complete darkness.

2. Prey detection: Small distortions in the electric field can reveal the presence of prey. It's like having a built-in metal detector, the fish can sense small invertebrates hiding in the sediment that would be invisible to its eyes.

3. Communication: Changes in electric field patterns can convey information to other fish. They can change the frequency or amplitude of their electric discharges to communicate things like species identity, sex, and even courtship intentions. It's the silent language of electricity.

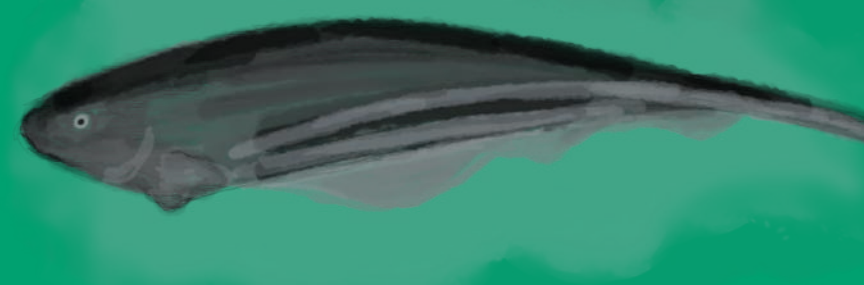
4. Camouflage: Some predators, like electric eels, can sense electric fields. *Eigenmannia* can temporarily stop its electric organ discharge to become 'electrically invisible' when it senses danger.

From Fins to Antennas: How Fish Inspire Modern Technology

The principles behind the Jamming Avoidance Response have intriguing parallels in human technology. The concept of amplitude modulation, used in radio communications, bears a striking resemblance to *Eigenmannia's* natural ability to locate nearby objects in their field. The applications go beyond just communications. Engineers are looking at how the electric sensing abilities of these fish could inspire new types of underwater sensors for submarines or autonomous underwater vehicles.

As we conclude our deep dive into the world of *Eigenmannia virescens*, we're left with a profound appreciation for the ingenuity of nature. These small, unassuming fish have evolved a sophisticated system for generating, sensing, and modulating electrical signals – a system that rivals and, in some ways, surpasses our own electronic technology. From their living batteries to their real-time frequency modulation, from their electrical camouflage to their silent electrical language, Eigenmannia and its weakly electric kin showcase the incredible diversity and adaptability of life on Earth. The next time you use your smartphone or Wi-Fi, spare a thought for *Eigenmannia*, quietly performing its own electrical wizardry in the depths of the Amazon. In a world increasingly dominated by human-made electric and electromagnetic fields, perhaps we have something to learn from a fish that mastered the art of electrical communication millions of years before we invented the radio.

As we continue to explore and understand the natural world, who knows what other electrical marvels we might discover? The underwater electric dance of *Eigenmannia* reminds us that sometimes, the most shocking innovations come from the most unexpected places.



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Rama Ratnam is a Professor at the School of Arts and Sciences at Ahmedabad University. He is a neuroscientist with a broad interest in brain and behaviour, particularly in neurobiological mechanisms of sensory processing that give rise to perception. His research interests include Neuroscience, Brain And Behavior, Sensory Processing, and Neural Engineering. He obtained his doctoral degree from the University of Illinois at Urbana-Champaign. His engineering roots from IIT Delhi have deeply influenced his research in biology to combine biology and engineering to explore how natural selection mirrors optimal design.

Spitting Image of Health

Could Saliva Help in the Early Detection of Cancer?

Writer and Illustrator **Het Desai** | *Science Mentor* **Vivek Tanavde**

Every second, our bodies produce new cells, and every second, there's a chance one of those cells could turn rogue, setting off a chain reaction that might go unnoticed by us until it's too late. Head and neck cancers are masters of this stealth, often **eluding detection until they have already spread,** turning what could have been a small skirmish into a full-blown war. Cancer is a word that brings fear to many, and for good reason—it remains one of the leading causes of death worldwide, claiming millions of lives each year. But there's a simple truth that every doctor knows: the earlier cancer is detected, the better our chances of defeating it.

Some cancers play a particularly dangerous game of hide and seek. One of the most elusive cancers that begins in the **cells lining the mouth** and throat is known as Oral Squamous Cell Carcinoma (OSCC). Unlike other cancers that form noticeable lumps, **OSCC often grows in flat, thin layers**—like a stain slowly spreading across a surface. This flat, subtle growth makes it almost **impossible** for traditional methods—designed to detect solid, abnormal masses—**to catch it early**. The quest to outpace these hidden threats has driven researchers to explore unexpected avenues—approaches that could turn the clock in our favour, catching cancer in the act long before it can strike.

When doctors suspect cancer, they often need to remove a small piece of tissue from the affected area to examine it closely under a microscope—this is called a **tissue biopsy.** While this method can confirm if cancer is present, it has limitations. It's **invasive, often painful**, and only provides a brief glimpse of the tumour's condition at that specific moment—like taking a single photograph in time. This means it can't show how the tumour is behaving, growing, or responding to treatment over time.

For decades, doctors have relied on the tools traditionally used to catch cancers designed to find abnormal lumps or masses, much like the formation of a fully developed tumour. However, such machines, namely CT scans and MRI, fail to detect OSCC. **How do you detect something that doesn't create a bump at all?** Imagine trying to spot a thin coat of paint on a wall when you are only looking for bulges—this is the challenge doctors face when trying to detect OSCC. Because OSCC spreads in a flat pattern, it often remains invisible to these imaging techniques. By the time it is detectable, the cancer has often progressed significantly, making treatment more difficult and often less effective.

A Surprising Solution: Saliva's Role in Diagnosis

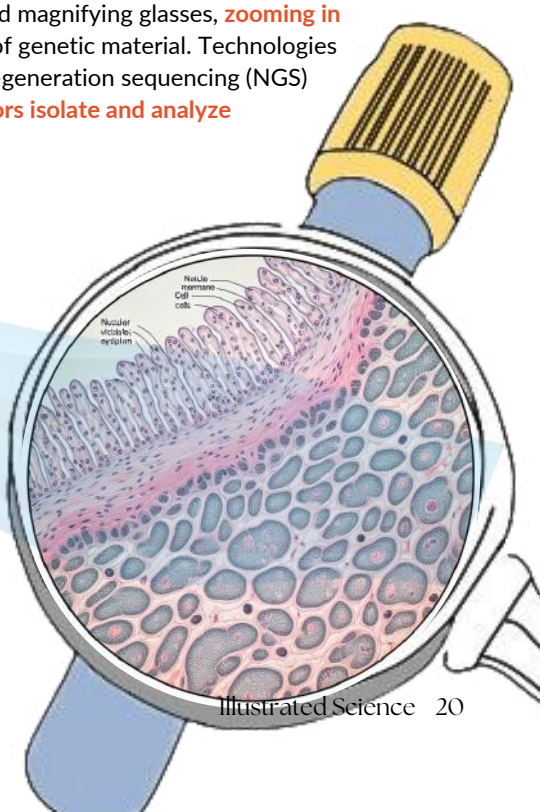
Imagine if detecting cancer was as **simple as spitting into a cup at home and mailing it to your doctor**—no hospital visits, no painful procedures. This seemingly ordinary fluid, saliva, could hold the key to early cancer detection. Far from being just a mundane part of daily life, **saliva carries molecular clues** about what's happening inside the body. These clues—called **biomarkers**—are tiny fragments of genetic material, proteins, and cells that signal diseases like cancer long before a tumor becomes visible.

The beauty of saliva testing lies in its **simplicity and accessibility.** No painful biopsies or uncomfortable scans—just a quick swab of saliva that can be sent to a lab for analysis. In places where traditional screening tools aren't always available, and the disease is prevalent, like in Southeast Asia, saliva collection offers a life-saving opportunity to detect cancer early when it is still manageable, and treatment is most effective.

But here is the breakthrough: Researchers have discovered that saliva can reveal early signs of cancers like OSCC. This is more than a theory—the data is backed by clinical evidence, something that sets this study apart from others. The ability to detect cancer through a simple, non-invasive saliva test could change everything about how we screen for diseases like OSCC.

The Technology Behind Saliva-Based Detection

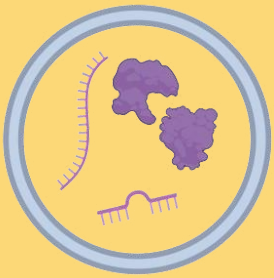
While the potential of saliva is exciting, identifying the molecular signals it contains is like searching for tiny clues hidden in a vast ocean of data. To uncover these microscopic details, doctors use tools that work like high-powered magnifying glasses, **zooming in** on even the smallest fragments of genetic material. Technologies like digital droplet PCR and next-generation sequencing (NGS) make this possible, **helping doctors isolate and analyze** biomarkers floating in the saliva.



These technologies allow doctors to detect cancer much earlier than traditional methods, long before a tumor would show up on a scan or become large enough for a biopsy. Saliva offers a real-time glimpse into what's happening in the body, helping doctors catch cancer in the act—early, when it's **still manageable**.

Understanding Biomarkers

When spotting footprints on a trail—each mark tells you where someone's been and what they might be doing. Biomarkers in saliva act like **"molecular clues"**, leaving traces of what's happening inside the body. When health changes, like cancer, these biomarkers shift, creating specific "tracks" that doctors can follow. By analyzing these molecular clues, they can **detect cancer early, monitor its progress, and even predict its next steps**, offering a clear view of what's going on within.

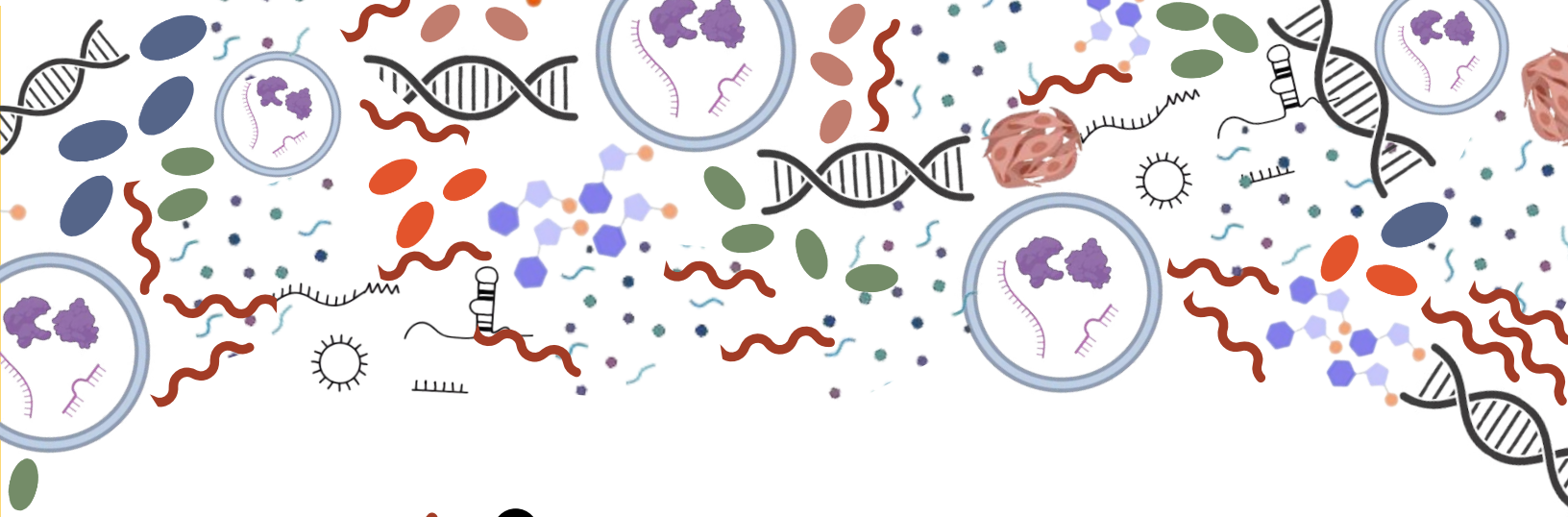


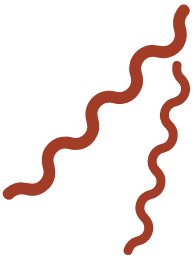
1 Extracellular Vesicles

Think of **molecular mail carriers**—tiny packages that carry important messages between people. In the case of cancer cells, these messages are delivered in the form of Extracellular Vesicles (EVs), which are tiny bubbles that carry critical molecules like RNA. These vesicles reveal key information about **how the tumour is behaving**, whether it's growing aggressively or becoming resistant to treatment. By intercepting this "molecular mail," doctors can understand the tumor's actions and adjust treatment plans accordingly.

2 Circulating Tumor Cells

When cancer spreads, it sends out rogue cells—like seeds blown by the wind—searching for a place to take root. These circulating tumour cells (CTCs) break away from the main tumour and **travel through the bloodstream**. They carry vital information about how far the cancer has spread and its **risk of metastasis** (cancer spreading to other parts of the body). By identifying these wandering cells early, doctors can intervene before the cancer settles elsewhere.



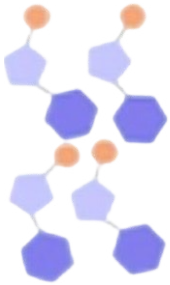


3 Circulating Tumor Nucleic Acids (ctNA)

Imagine a trail of breadcrumbs left behind by a wandering creature—these breadcrumbs allow you to track where the creature has been. Similarly, cancer cells shed tiny fragments of their genetic material as they grow and die. These fragments, called Circulating Tumor Nucleic Acids (CTNAs), are scattered throughout the body's fluids, including saliva. By following this trail of genetic "breadcrumbs," doctors can **detect the presence of cancer long before it becomes visible in scans** or large enough for a biopsy.

4 Metabolites

When something is baking, you can often smell it before you see it. Metabolites work in a similar way—they're **tiny byproducts of the body's processes** that act like "scents," revealing what's happening inside. When cancer is present, these metabolic byproducts shift, leaving a **unique chemical fingerprint** in bodily fluids like saliva. Analyzing these subtle shifts can provide early clues about cancer's presence and behaviour.

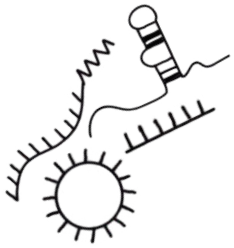


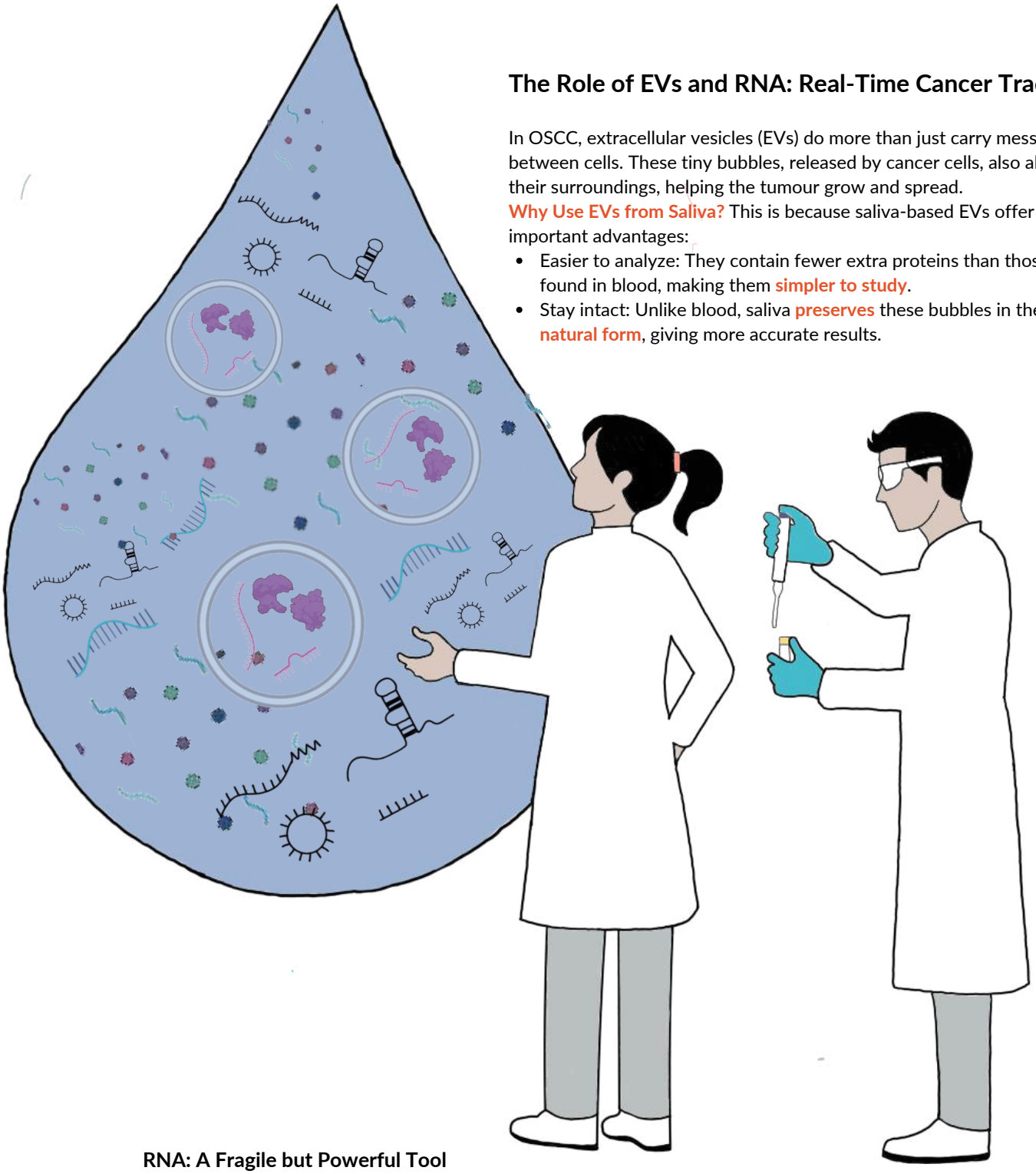
5 Circulating Tumor DNA (ctDNA)

Pieces of a puzzle scattered across a table each hold a clue to a larger picture. By gathering and assembling them, a full story emerges. Similarly, cancer cells release tiny fragments of their DNA into the bloodstream, called circulating tumour DNA (ctDNA). These fragments c**arry unique mutations that reveal the tumour's genetic makeup**. By analyzing ctDNA, doctors can detect cancer early, monitor its progression, and identify effective treatments.

6 Circulating Tumor RNA (ctRNA)

Much like overhearing snippets of conversation through a window—each bit of dialogue gives a glimpse into the story happening inside. Circulating tumour RNA (ctRNA) works similarly, with fragments of RNA from cancer cells drifting through the bloodstream. These RNA pieces carry real-time information about the **tumour's activity,** like **growth or treatment resistance**. By "listening" to these snippets, doctors gain insights into the cancer's current state, allowing for more timely and targeted treatment.





The Role of EVs and RNA: Real-Time Cancer Tracking

In OSCC, extracellular vesicles (EVs) do more than just carry messages between cells. These tiny bubbles, released by cancer cells, also alter their surroundings, helping the tumour grow and spread.
Why Use EVs from Saliva? This is because saliva-based EVs offer some important advantages:

- Easier to analyze: They contain fewer extra proteins than those found in blood, making them **simpler to study**.
- Stay intact: Unlike blood, saliva **preserves** these bubbles in their **natural form**, giving more accurate results.

RNA: A Fragile but Powerful Tool

RNA inside EVs offers **real-time insights** into how the tumour is behaving, changing, or resisting treatment. However, RNA breaks down quickly, which is why most studies avoid focusing on it. This study stands out by successfully capturing and analysing RNA within EVs, where it stays safe and stable.

By studying both EVs and the RNA they carry, doctors get a **full view of the cancer's life cycle**—from how it's behaving now to how it might act in the future. With regular saliva samples, doctors can track these changes over time, allowing for **earlier detection** and better treatment decisions. This further proves that saliva-based testing is a simple, non-invasive, and reliable way to monitor cancer and improve care.

Tree of Hope
DNA, RNA, and magnifying glasses symbolize ongoing research and the promise of early cancer detection.

A Paradigm Shift in Cancer Detection

While the potential of saliva-based testing is undeniable, it's essential to proceed with **cautious optimism**. The study's findings are promising, but more research is needed to determine whether this method will be scalable for widespread use. As Vivek Tanavde, a Professor of Cancer Biology at Ahmedabad University and one of the lead authors, wisely pointed out, "Science tells us to doubt everything, including yourself. However, that does not mean that we do not believe in it." This humble yet confident approach ensures that the method will be rigorously tested before becoming a clinical standard.

This research represents more than just a novel diagnostic tool—it marks a **paradigm shift** in cancer care. Instead of waiting for tumours to grow large enough to be seen, we now have the potential to catch cancer much earlier through a simple and accessible saliva test. Saliva-based diagnostics could change the future of cancer care, making early detection faster, easier, and more affordable.

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Het Desai is a student of Integrated Master of Science at Ahmedabad University. Deeply interested in cancer research, she chose to write this article through her fascination with how even the simplest, most overlooked things—like saliva—can revolutionize the way we detect and fight this disease. She believes science is a language of discovery, capable of transforming knowledge into meaningful change. With a passion for bridging the gap between scientists and the public, she strives to make scientific research accessible and impactful for everyone.

Vivek Tanavde is an Associate Professor and Associate Dean of the Undergraduate College at Ahmedabad University. His research focuses on saliva-based diagnostics for cancer, addressing challenges in isolating high-quality RNA from saliva by studying salivary exosomal miRNAs and cell-free DNA and advancing liquid biopsy technology. At University's Oral Cancer Cluster, his team has identified biomarkers for oral cancer progression and chemoresistance while exploring miRNA-mRNA networks in tumours. His research also extends to serum exosomal miRNAs for early glioblastoma detection, contributing to innovative approaches in cancer diagnosis.

Social Buzz-furcation

Integrating Ecology and Social Sciences

Writer and Illustrator **Sanat Naval** | *Science Mentor* **Shomen Mukherjee**

Following a surge in dengue cases in her town, Sarjapura, Vijaya had recently become more observant of mosquitoes. She knew that mosquitoes lived near water. She could also distinguish between different varieties of mosquitoes, knowing that the white-spotted one causes Dengue and the other black one causes Malaria. But mosquito-borne diseases are way more complicated than simply being bitten by a mosquito. Most kids her age would be curious as to ***how*** mosquito-borne diseases are spread, but Vijaya had a more important question - ***Where*** were mosquito-borne diseases spread?

This Question led Vijaya to different types of land classes - which range from rural patches of land, with just trees and animals, to a packed town centre, wholly covered with concrete. This encompassed a complete urban gradient, covering a rather green village and a housing colony.

One thing Vijaya noticed through her journey was that despite the differences in the land classes, mosquitoes were equally **abundant** across Sarjapura. However, as she traversed the rural landscape, she noticed a lot more flora and fauna. Vijaya lived in the centre of the town in a rather cramped house with her family. She had to go to the courtyard to complete all her chores- from washing utensils and clothes to hanging them to dry. It was a daily battle against the mosquitoes which bred near a faulty water pipe right across Vijaya's verandah. Yet, as simple of a difference as a larger variety in animals, birds, and plants leads to a change in the ecological dynamics of mosquitoes.

As much as we may associate mosquitoes with sucking our blood, they are primarily vegetarian, preferring flower nectar, thus playing an essential role as pollinators. As females need vertebrate blood, they may prey on other animals like reptiles and other mammals. However, in urban areas, most species prefer human blood, as they are the most common vertebrates, owing to the loss of wildlife across the urbanisation gradient. The species diversity of mosquitoes also differs from habitat to habitat, with mosquitoes being more diverse in rural areas.

Sarjapura is located around 20 Km Southeast of Bengaluru. Sarjapura was primarily an agricultural village, but recent growth in the IT industries around Bengaluru has led to the urbanisation of Sarjapura. Many colonies and housing schemes are being set up near the city with IT professionals and other migrants relocating here. Although these colonies are not too far away from the village centre, where Vijaya lives, It seems like a totally different world. Despite only being apart by a few kilometres, these neighbourhoods were separated via many socioeconomic factors. People belonging to a lower socioeconomic background would have outdoor plumbing and would have to frequent the outdoors for chores and work, which would leave them exposed to vulnerable to mosquitoes.

People living in gated colonies, though, accessed the outdoors for more pleasurable and leisurely activities. It also had the convenience of controlling the outdoors via methods like fogging, which drastically decreased the vulnerability to disease and led to a more positive experience with respect to the outdoors.

Even though the differences in how mosquito dynamics changed with the shifting urban gradient and heterogeneity, Vijaya still wondered how one could understand the variation within mosquito species across the different land classes. She also wondered how one could study exactly how abundant mosquitoes were through Sarjapura. Although curious and high-spirited, Vijaya did not have the experience or knowledge to carry out field ecology experiments. She needed somebody who could help her out with these experiments.

As she headed back home, Vijaya spotted a man laying out contraptions, which she did not recognise at first, but what caught her eyes were the mosquitoes gathering around one of the devices.

Vijaya asked the man shyly what he was doing. Vijaya realised she had hit a stroke of luck when the man told her that he's an ecologist who was working on mosquitoes.

Vijaya asked if she could follow him as she wanted to know more about mosquitoes to which the ecologist happily obliged.

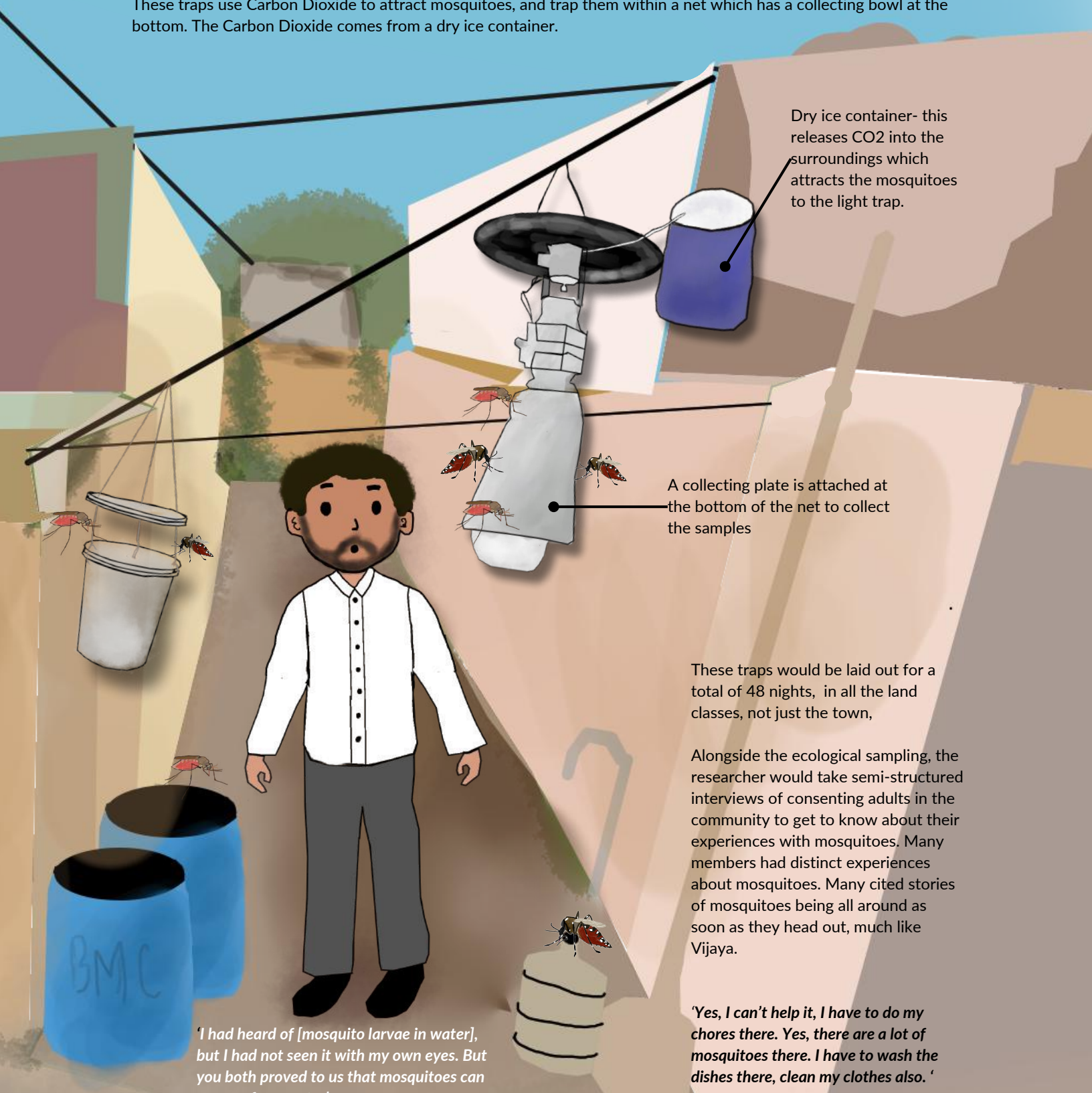
The Experimental Setup

The objective of the study was to understand the diversity of species and their abundance across different land classes. Being an interdisciplinary study, researchers wanted to understand the daily mosquito experiences of the local communities and how this varied among the different socioeconomic classes. The ecologist explained how he would go about conducting this study to Vijaya, who herself was a local living in the town.

Rather than "parachuting in" and researching without interacting with the community, we must hold meaningful conversations and build a rapport. The locals near the site will help researchers determine areas with high mosquito activity to set up equipment for assessing mosquitoes using (a) Oviposition traps and (b) CDC Light traps.

a) Oviposition traps are used to provide mosquitoes with a place to lay eggs, and once these eggs hatch, to count the mosquito larvae. These traps were simply made using food containers with water. These are hung from the roof or a wall, some six feet high.

CDC traps refer to Centre for Disease Control traps. These contraptions are useful in capturing adult mosquitoes. These traps use Carbon Dioxide to attract mosquitoes, and trap them within a net which has a collecting bowl at the bottom. The Carbon Dioxide comes from a dry ice container.



Dry ice container- this releases CO2 into the surroundings which attracts the mosquitoes to the light trap.

A collecting plate is attached at the bottom of the net to collect the samples

These traps would be laid out for a total of 48 nights, in all the land classes, not just the town,

Alongside the ecological sampling, the researcher would take semi-structured interviews of consenting adults in the community to get to know about their experiences with mosquitoes. Many members had distinct experiences about mosquitoes. Many cited stories of mosquitoes being all around as soon as they head out, much like Vijaya.

'Yes, I can't help it, I have to do my chores there. Yes, there are a lot of mosquitoes there. I have to wash the dishes there, clean my clothes also. '

- An interviewee

'I had heard of [mosquito larvae in water], but I had not seen it with my own eyes. But you both proved to us that mosquitoes can emerge from water'

- A community member

From Field to Lab: Understanding Mosquito Sampling and Identification

Vijaya understood the methodology of the research and how it was conducted. But she was curious about what happened after the samples were collected from the sites.

The ecologist told her that the adult mosquitoes captured via the light traps would be taken to a laboratory nearby, where they would be frozen to -40°C, after which they would be observed, and their species would be identified.

The pupae and larvae of the mosquitoes (juvenile stages of the mosquito), which were sampled using oviposition traps, were grown to adulthood, then frozen and studied.

The testing ultimately revealed that the diversity of the mosquito population changes with a change in the surroundings through the town's urban gradient, as noticed by Vijaya. It also revealed that the mosquito abundance was relatively the same throughout the land classes; however, when interviews with people living in different spaces were taken, everybody had a different experience with mosquitoes.

"There's an open drain right behind the temple, I wait there for my bus to come, when I'm standing there itself i can't take it because I have to cover my face."

"If there is one case of dengue or anything is happening...immediately fogging will happen."

"The only reason we are all right now able to sit here in peace and quiet and have a conversation is because [of fogging]."

"Well that's right in front of our house so we don't really have a choice."

"You can definitely see [mosquitoes] are there and you want to avoid that area [the running track] I avoid, and the sewage I can't avoid because it's my parking, but it definitely feels uncomfortable, and you don't want to spend a lot of time there."

Although Vijaya's enquiry started with a strictly scientific question about mosquitoes and where one could find them, there are many things that are solely science. In this case, ecology could not answer. These questions require an interdisciplinary approach, which would help understand the situation more comprehensively. Now homebound, Vijaya thinks about how two very different questions she posed would somehow overlap and would both be key in understanding one problem. This probably holds true with many other similar problems we notice around us, but we haven't looked at them through the lens of interdisciplinarity.

Interdisciplinary Insights on Mosquito Ecology

Vijaya's story is based on a research project conducted by Shomen Mukherjee, an Ecology Professor at Ahmedabad University, and his team in Sarjapura. One objective of their research was to estimate the mosquito abundance and species diversity across different land classes, which is the same as mentioned in the article. The researchers adopted a rather interdisciplinary approach to ecological data collection by taking into account socioeconomic factors. The findings of the research also included interviewing inhabitants from different neighbourhoods and understanding their experiences with mosquitoes. People belonging to different socioeconomic classes had varying experiences, with people living in the more densely packed towns being more vulnerable to mosquito-borne diseases. They faced problems in daily chores, where mosquitoes would essentially be everywhere as soon as they headed outside. People who lived in the colonies- which are essentially newly built communities housing mostly migrants who work as IT Professionals- were less vulnerable and had access to resources that would help them counter mosquito-borne diseases.

From an ecological standpoint, another objective that the paper discusses is understanding the role of mosquitoes in an ecosystem- and how their dynamics shift with a shifting urban gradient. Rural and forested areas possess more species of mosquitoes, which have more diverse feeding habits, including consuming nectar and acting as key pollinators or feeding on other animals. However, as a result of industrialisation and relatively fewer animals, with more humans inhabiting towns, their prey shifts to human beings, which leads to mosquito-borne diseases being spread.

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Sanat Naval is a student of Integrated Master of Science at Ahmedabad University. He has always been interested in biology and its various domains, including ecology. As someone who already writes, his aim for this course was to gain more insight on how to explain Science and effectively communicate it to a more general audience while understanding the concepts more clearly himself.

Shomen Mukherjee is an Associate Professor at the School of Arts and Sciences at Ahmedabad University. His research has primarily focused on understanding predator-prey interactions, which he has studied in various ecosystems worldwide. He has collaborated with government agencies, such as the Forest Department (in India) and the Durban municipality (in South Africa), to address more applied questions. Currently, his lab research focuses on understanding the role of biodiversity in regulating vector-borne diseases, which he studies both in the wild (Kutch district) and in the city (Ahmedabad). He teaches a field-based course – Introduction to Field Ecology- which not only introduces students to the field of Ecology but also helps them understand rural India and its challenges.

Illuminating Forensics

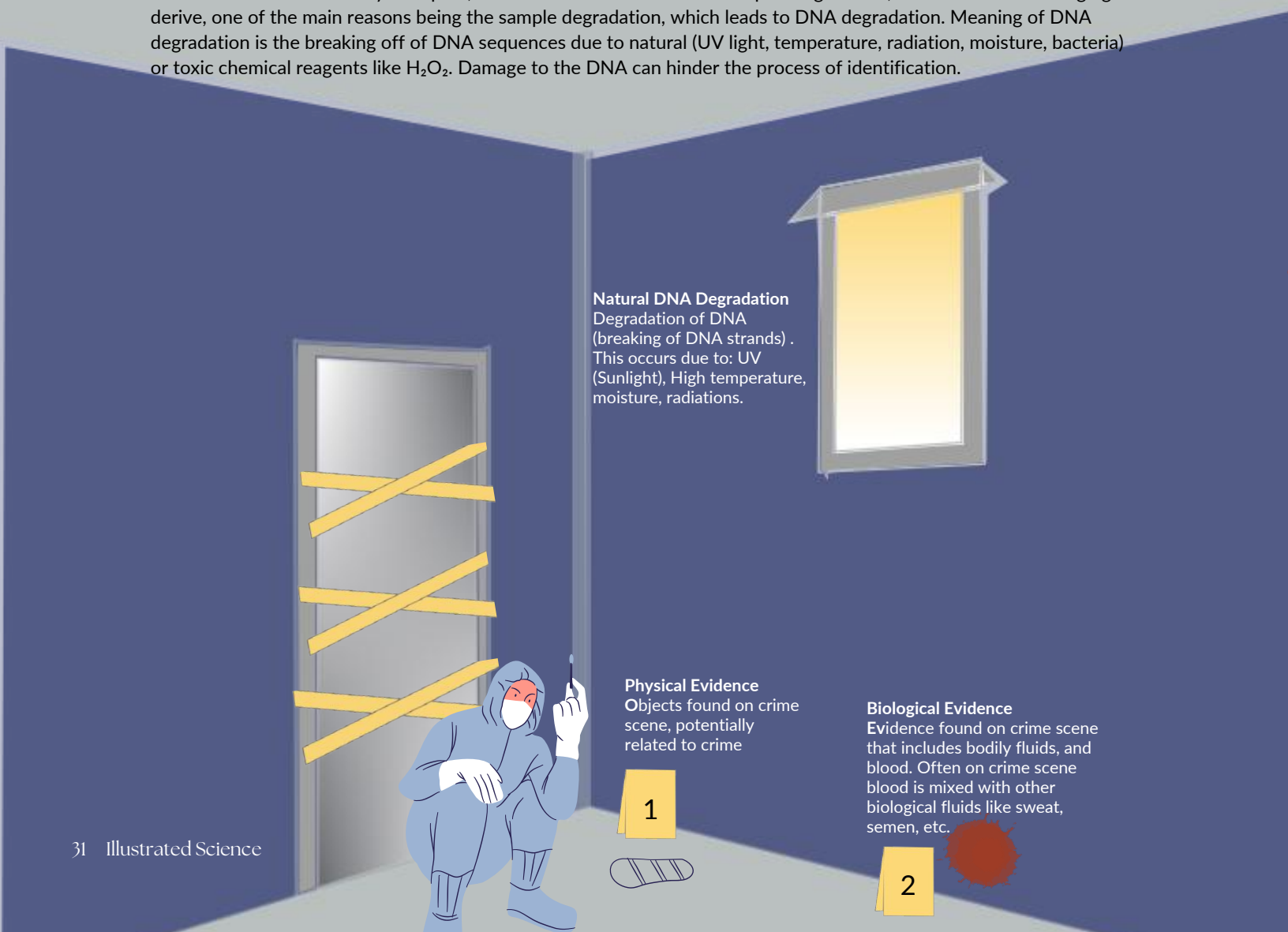
Fluorescent Dye Transforming Blood Detection

Writer and Illustrator **Keya Jantrania** | *Science Mentor* **Ritesh Shukla**

Who does not enjoy solving mysteries? The excitement of solving a crime, the twists and turns in the plot, and the final revelation keep us hooked until the end. It could be a gripping crime series or a novel; the suspense keeps us on the edge. The field of forensic science is a rapidly evolving field. The critical task is detecting blood because even when present in a small amount, it contains DNA, which helps identify the person. Evidence at the crime scene plays a crucial role in solving the crime. The evidence found generally falls into two categories: biological evidence, which includes blood, semen, and other bodily fluids, and physical evidence, such as fingerprints, weapons, documents, and letters. However, distinguishing between the biological fluids - especially blood- is the main challenge.

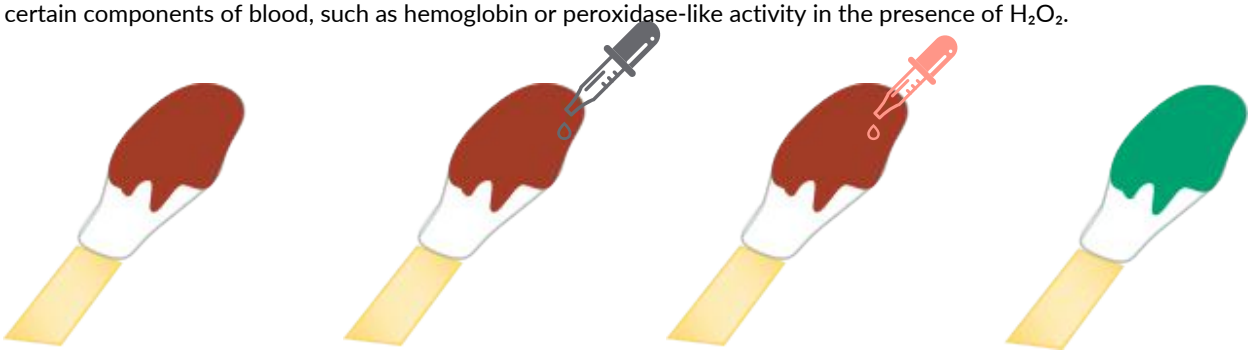
Blood as a Clue on Crime Scene

Blood comprises red blood cells, white blood cells, and platelets. Red blood cells contain haemoglobin, which has an iron component (Fe^{2+}). The white blood cells have DNA in them; unique DNA sequences help in a person's individualization. To identify a suspect, there should be a 100% match in profiling studies, which is often challenging to derive, one of the main reasons being the sample degradation, which leads to DNA degradation. Meaning of DNA degradation is the breaking off of DNA sequences due to natural (UV light, temperature, radiation, moisture, bacteria) or toxic chemical reagents like H_2O_2. Damage to the DNA can hinder the process of identification.



Blood Screening Tests

Different screening methods are being used to identify the blood found at the crime scene. The chemicals such as Tetramethylbenzidine (TMB), Luminol, Leucomalachite Green (LMG), and Phenolphthale are commonly used in blood detection and forensic analysis because they undergo a colorimetric change when they react with blood or with certain components of blood, such as hemoglobin or peroxidase-like activity in the presence of H_2O_2.

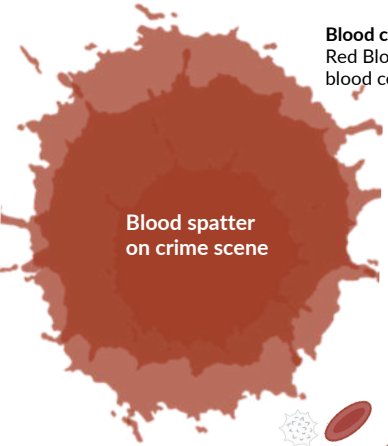


Leuchomalachite Green (LMG)
Chemically oxidized in presence of H_2O_2 , and changes color of blood from red to green

DNA degradation
Usage of chemicals like H_2O_2 leads to degradation of DNA.

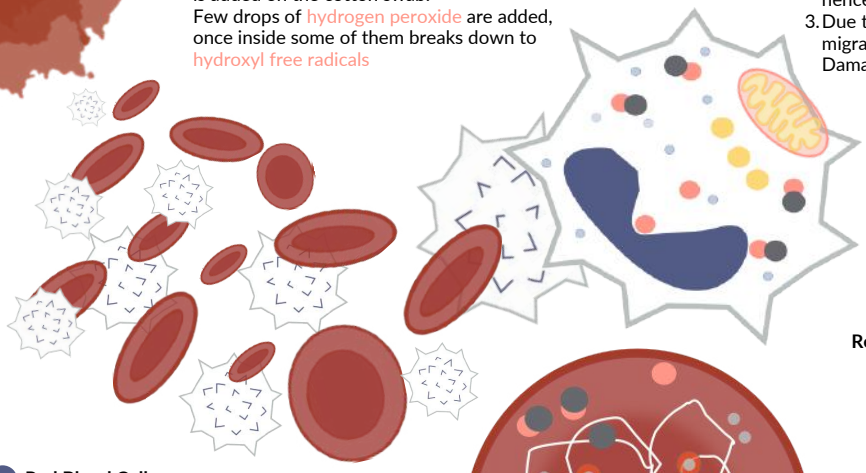
The chemistry behind the color change

The tests are based on the specific reaction of the heme group of Blood containing iron with chemicals in the presence of H_2O_2 via Fenton's reaction. In the blood screening test, applied dye/chemicals are oxidized in the presence of H_2O_2 and produced a colorimetric change as the outcome of the reaction. Hydroxyl Free radicals produced as the result of Fenton's reaction are chemically unstable but highly reactive in nature.



Blood cells
Red Blood Cells, white blood cells and platelets

1 Addition of dyes
Few drops of Leuchomalachite green dye is added on the cotton swab.
Few drops of hydrogen peroxide are added, once inside some of them breaks down to hydroxyl free radicals



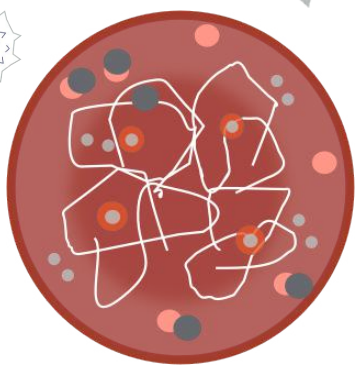
2 White Blood Cells consists of:

- Lobed Nucleus - has DNA
- Mitochondria - produces natural free radicals
- Hydroxyl free radicals by product of H_2O_2
- LMG Dye

Reaction

1. Hydroxyl Free radicals either formed naturally and due to dissociation of some H_2O_2.
2. Some H_2O_2 will also oxidize the LMG dye, and hence will also aid in color change
3. Due to excess free radicals, some of them will migrate towards the nucleus and will cause DNA Damage

3 Red Blood Cell
It consists of globulin chains (white), a Heme component (orange), an iron molecule (grey), H_2O_2 generated radicles, LMG dye, and Natural free radicals from Fenton's reaction.



Reaction

1. H_2O_2 in the presence of blood catalyzes the Fenton reaction; it also oxidizes the dye to change colour
2. Fenton's is the conversion change of iron from ferrous to ferric. Consequently, this leads to the generation of hydroxyl free radicals
3. H_2O_2 also provides hydroxyl free radicals.

Oxidation of LMG by some of H_2O_2 molecules present.

Method Roadblocks

Chemicals being used as blood screening tests are either harmful in nature (such as TMB dye is a derivative of Benzidine, which is known as a possible carcinogen to humans) or H_2O_2 that produces hydroxyl free radicals, which may interact with DNA and cause DNA degradation. Chemical tests being used for blood detection may also give false positive results to the samples that contain ferrous ions in them, like plants and fruit juices, due to Fenton's reaction. To overcome this limitation, there is an urgent need to develop new methods for blood detection.

Misleading Individualisation
DNA breaks leads to formation of partial profiling and hence we can not find the right individual whose DNA is belong

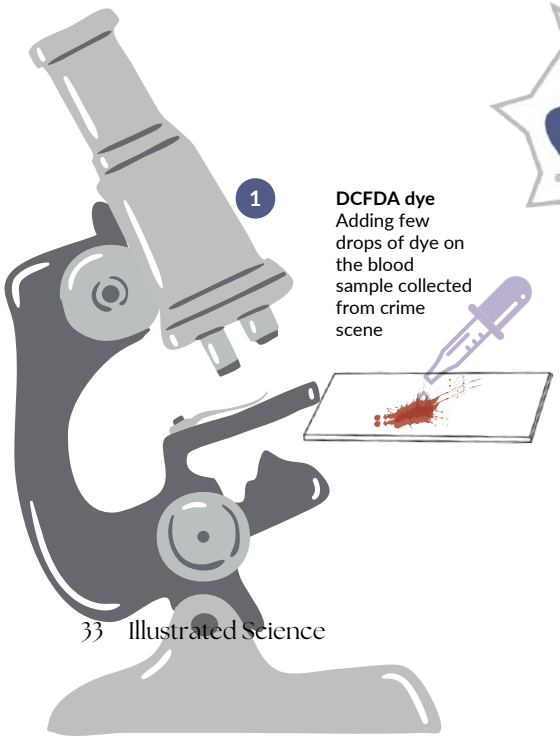
Harmful to the Investigators
Certain dyes are potentially carcinogenic or toxic in nature, like TMB, and when exposed could potentially cause harm to the investigating officer.

DNA Degradation
Degradation either natural or due to chemicals like H_2O_2 will lead to misleading individualization and usage of more sample

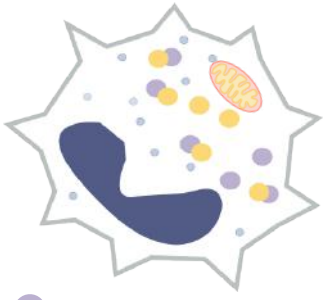
False Positive Results
Because there is presence of iron in other substances, the current methods can give a false positive when reacts with tomato juice, shoe polish, pomegranate juice,etc.

DCFDA dye: The Game-Changer

Ritesh Shukla, a professor of Cyber Forensics at Ahmedabad University, and his team have developed a new method to detect blood-based on the same principle of Fenton's reaction; however, it does not use H_2O_2. The new detection method used was dichlorodihydrofluorescein diacetate (DCFDA) dye, which is non-carcinogenic and highly specific to react with Hydroxyl free radical (OH*). DCFDA is a dye that can, upon entering the cellular system in the presence of OH* and intracellular esterase enzyme, break down into DCFH and DA. This DCFH further oxidized Fe^{2+} of heme into Fe^{3+} and converted into DCFH free radical (DCFH*). This DCFH* then, in the presence of O_2 molecule (O_2), converts into DCF, which can also oxidize Fe^{2+} of heme into Fe^{3+} via the Fenton reaction and form DCF free radical (DCF*), which is a fluorescent form. In addition, O_2 molecules may also converted into O_2 free radicals (O_2*), which, in the presence of superoxide dismutase, form H_2O_2naturally into the cellular system. This naturally formed H_2O_2 can further interact with the heme group of blood and produce hydroxyl ion (OH-) and free radical(OH*), which are further used by the DCFH molecule and converted into DCF and then DCF free radical (DCF*). This DCF* emits fluorescence at a specific wavelength (530nm) that can be observed through a fluorescence microscope. This method doesn't require additional H_2O_2 as a catalyst; it uses the H_2O_2 and free radicals produced in the body naturally, thereby the concentration of free radicals doesn't go above the threshold, and there is no damage to DNA.

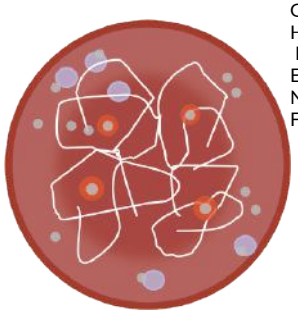


1 **DCFDA dye**
Adding few drops of dye on the blood sample collected from crime scene



2 **White Blood Cell**
Contains:
nucleus which consists of DNA,
mitochondria (produces natural free radicals)
Esterase enzyme

Reaction:
1. DCFDA enters to the cell and is converted into DCFH and DA by esterases.
2. DCFH donate electron and form DCFH free radical. This free radical in the presence of O_2 convert into DCF which further form DCF free radical.
3. Superoxide dismutase converts O_2* into H_2O_2, which produces OH^- and OH*.
4. DCF* emits fluorescence at 530 nm.



3 **Red Blood Cell**
Consists of:
Globulin chains
Heme component
Iron molecule
Esterase enzyme
Natural free radicals - Fenton's reaction

Reaction
1. DCFDA enters to the cell and is converted into DCFH by esterases.
2. DCFH oxidizes Fe^{2+} in heme to Fe^{3+}, forming DCFH*.
3. DCFH* reacts with O_2, producing DCF and fluorescent DCF free radical (DCF*).
4. H_2O_2 interacts with heme, forming OH^- and OH*, which further oxidize DCFH into DCF.
5. DCF* emits fluorescence at 530 nm. .

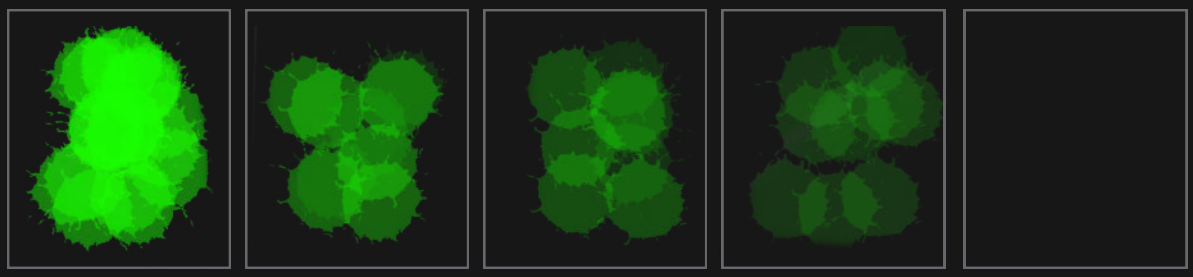
Applications and Insights

It's not as if the blood is on the scene and ready for testing. There are various scenarios in which blood is found at the crime scene and blood is seen at multiple places or surfaces. The dye should be tested in all possible scenarios to determine its effectiveness before being implemented in real-life scenarios. While testing the specificity of the dye, the researchers tested it on various surfaces like wood, textile, sponge, and metal. Along with this, they tested the dye with different fluids possibly found at the crime scene, like pure blood, diluted blood both in fresh and aged conditions, tomato juice, tomato puree, shoe polish, pomegranate juice, saliva, sweat, urine, and animal blood.

The findings suggest that the DCF-DA dye is highly effective in detecting blood stains, even those up to 20 days old or in significantly diluted forms. It works successfully on various surfaces, including metal, textiles, wood, and sponges. However, the dye produced a false positive with ferrous ions ($FeSO_4$) but not with ferric ions ($FeCl_3$). It did not react with other body fluids like saliva, sweat, or urine, showing its specificity to blood. Despite this, the dye did show fluorescence when tested with animal blood, which highlights a limitation in distinguishing human blood from non-human blood.

Positive result indicates presence of blood.

Negative Result indicates Blood is not present.

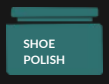


Pure: Fresh blood when tested with DCFDA dye, showed high intensity of green fluorescence under the microscope.

Diluted: Fresh blood when tested with DCFDA dye showed positive result with not very intense fluorescence

Animal blood when tested with DCFDA dye showed positive result.

Aged: Pure and diluted blood showed a less intense fluorescence when treated with DCFDA dye



False positive like shoe polish, tomato sauce, showed no fluorescence when treated with DCFDA dye.

Body fluids like sweat, urine when treated with DCFDA showed no fluorescence

Textile surface - cloth
Positive result indicates presence of blood

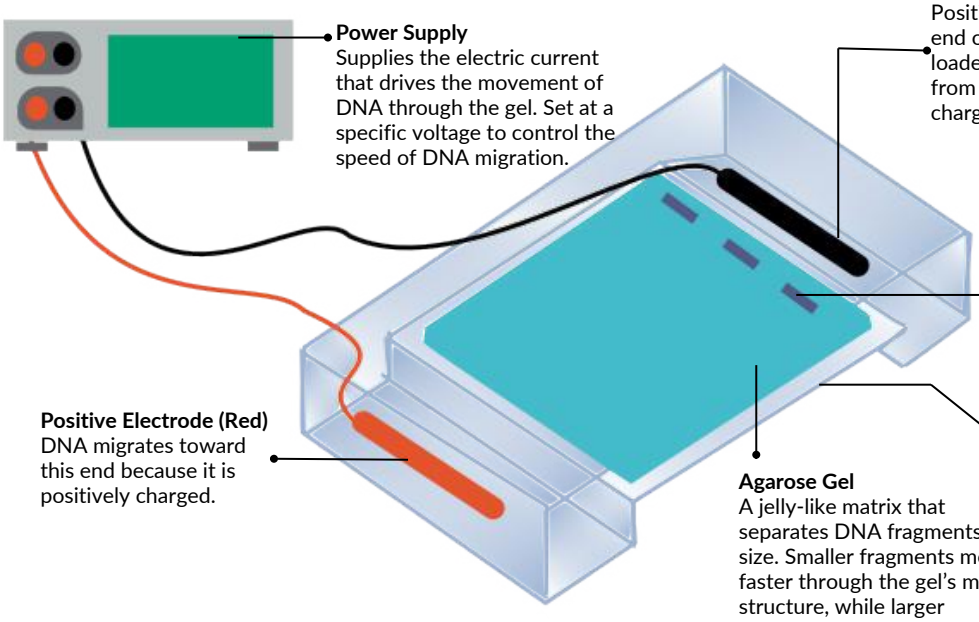
Metal surface
Positive result indicates presence of blood

Wooden surface
Positive result indicates presence of blood

Sponge
Positive result indicates presence of blood

Tracking DNA Degradation

The effect of DCFDA dye on genomic DNA was assessed using Agarose gel electrophoresis. Agarose gel electrophoresis is a technique used to separate DNA, RNA, or proteins based on their size. It uses an electric current to drive molecules through an agarose gel matrix, with smaller fragments traveling faster than larger ones.



Power Supply
Supplies the electric current that drives the movement of DNA through the gel. Set at a specific voltage to control the speed of DNA migration.

Negative Electrode (Black)
Positioned at the opposite end of the gel; DNA is loaded here as it's repelled from the negatively charged cathode.

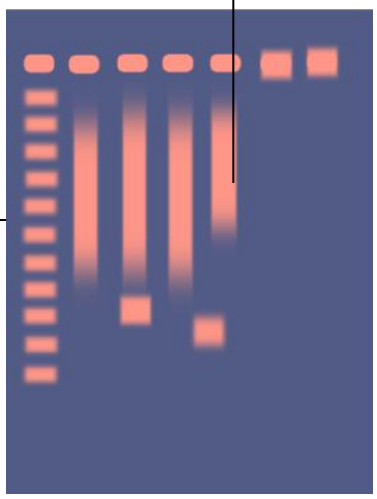
Wells
Small pockets at the negative end of the gel where DNA samples are loaded. These serve as starting points for DNA migration.

Positive Electrode (Red)
DNA migrates toward this end because it is positively charged.

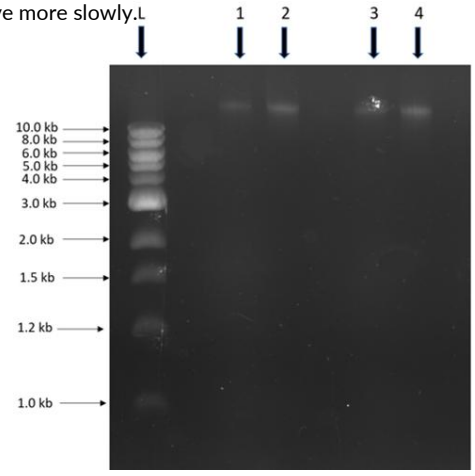
Buffer Solution
Conducts electricity throughout the gel box and maintains pH to keep DNA stable. Surrounds the gel and connects the electrodes.

Agarose Gel
A jelly-like matrix that separates DNA fragments by size. Smaller fragments move faster through the gel's mesh structure, while larger fragments move more slowly.

DNA Bands
DNA Bands: Visible lines representing DNA fragments of different sizes. These bands indicate the relative size of DNA fragments based on their migration distance.



Ladder
A DNA ladder is a reference tool in gel electrophoresis containing fragments of known sizes to help estimate the sizes of DNA fragments in samples.



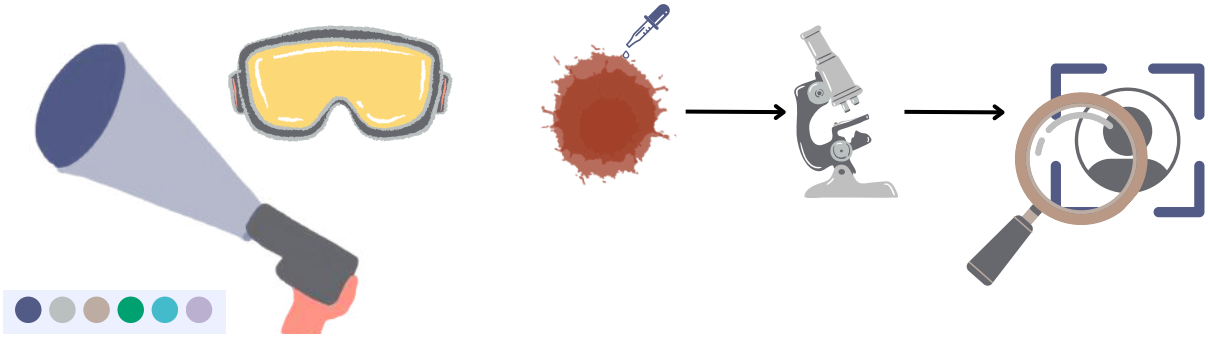
Analysis
L = ladder, which has reference DNA
1 = 1:1 - DNA:DCFDA; 2 = only DNA; 3 = 1:0.5 - DNA:DCFDA; 4 = only DNA
No strands in 1 and 2; 3 and 4 indicate that the DCFDA dye is not creating any DNA breaks; hence, it is not damaging the DNA. The presence of band in lanes 1 and 3 would indicate the breaks in DNA due to dye, which is not the case

Boundaries of Detection

Like every other scientific method developed, this method also has its limitations. One of them is that this method is currently restricted to laboratory settings, requiring a fluorescence microscope to detect the fluorescence. As a result, the samples collected from the crime scene are to be sent to the forensic laboratories for detection. Another limitation is that since fluorescence is an instant phenomenon, it fades away quickly and might lead to some discrepancies while observing under the microscope.

Future Horizons

To overcome the limitations of this method, there are technological advancements like using alternative light sources with goggles for on-field detection. Along with it, the dye could be tested for further profiling techniques to identify the person.



On-field detection

Personal Individualization

Combining an alternative light source and specialized goggles enables effective **on-field blood detection**, providing a practical alternative to traditional lab equipment. The 495 nm light and filtered goggles reveal fluorescent signals that indicate the presence of blood, allowing for immediate visual detection. Moreover, DCFDA preserves DNA integrity, enabling further identification methods, like STR profiling, from the same sample. This dual approach maximizes the efficiency of trace samples, ensuring minimal sample usage while supporting accurate, **personal identification** in forensic investigations.

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Keya Jantrania is a student of Integrated Master of Sciences at Ahmedabad University. She has a deep passion for crime thrillers, which fuels her interest in forensic science. For her, forensic science has always been a fascinating branch of science. Her illustration emphasizes an innovative approach to blood detection, offering a less destructive alternative to conventional reagents. She feels that forensic science, when explained correctly, can be fascinating to everyone.

Ritesh Shukla is an Associate Professor at the School of Arts and Sciences at Ahmedabad University. His research spans nanobiotechnology, toxicology, DNA forensics, food forensics, and the development of point-of-care diagnostic devices. He focuses on genetic toxicology and forensic science, particularly forensic nanotechnology and DNA forensics. He specializes in developing innovative forensic tools, such as a nano-based blood detection device—his work bridges toxicology and forensic science with applications in criminal investigations and public health.

Environment's Natural Defence

Bioremediators' Protective Role on Zebrafish Larvae

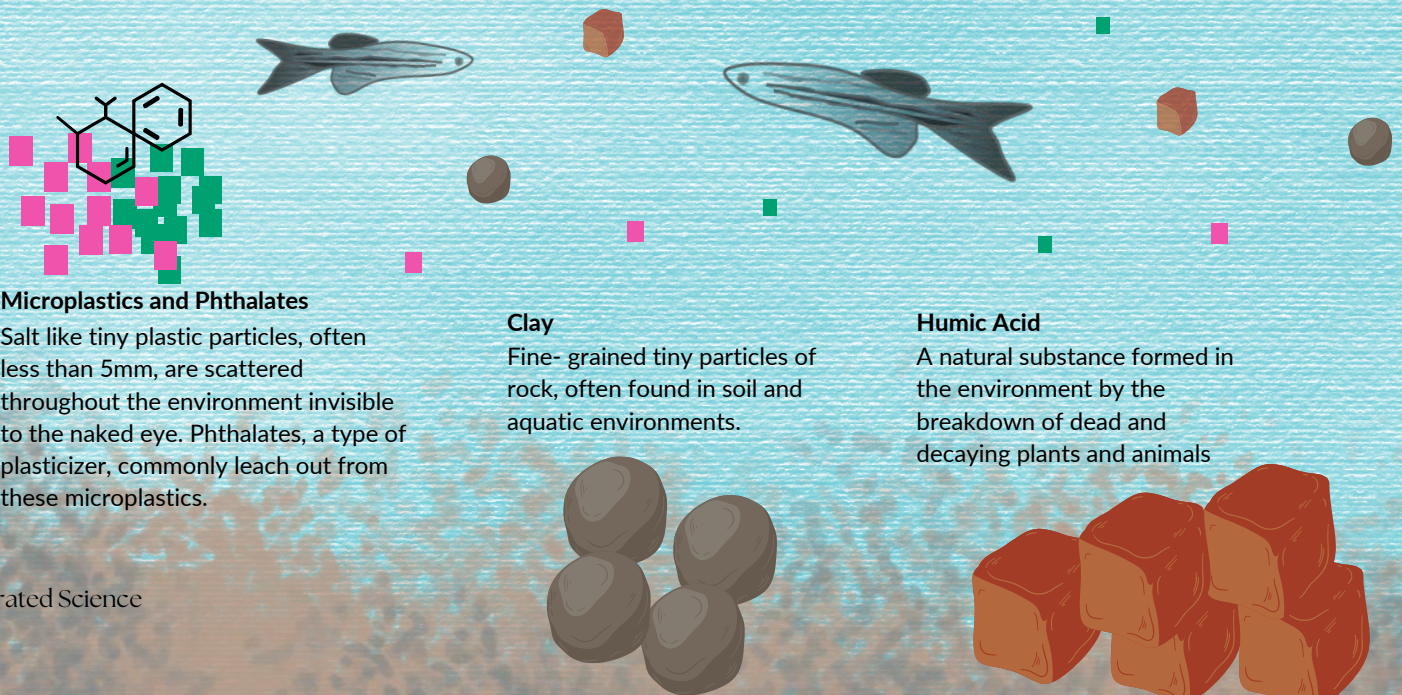
Writer and Illustrator **Shaivee Chokshi** | *Science Mentor* **Ashutosh Kumar**

Plastics have become an inevitable entity on Earth and have woven into our lives to an extent where they have now made their way into the human body. Plastic is a common environmental pollutant. It is estimated that global plastic production will reach approximately 33 billion tons by the year 2050. It is also estimated that about 12,000 million tons of plastic will end up accumulating in the environment. Plastics do not degrade quickly and remain in the atmosphere for a long time. Their accumulation in the environment has posed a threat to the environment and living beings. Plastics, once appreciated for their durability, now become a long-lasting contaminant in the atmosphere and affect the carrying capacity of the ecosystem. The environment responds to plastic contaminants with mechanisms that help to mitigate their adverse effects, like humic acid and clay work to reduce the effects of toxicants. These effects and mitigation pathways of the environment are being explored and studied using Zebrafish as a model organism.

The durability and flexibility of plastics are conferred on them by 'plasticizers,' a specific chemical coated on plastics. When these plasticizers are odourless, oily, and colourless, they are called 'phthalates.' Phthalates are commonly used in cosmetic products and medical equipment. They harm the human body as they enter through skin pores. These known endocrine disruptors can cause several hormone-related imbalances in the human body, especially affecting females. These plasticizers also greatly affect the biological processes in the environment.

Environment's protective role

While plasticizers interfere with the biological processes in the environment, nature has ways to mitigate its effects. To assume that the environment is functioning normally, certain naturally occurring materials in the environment, like humic acid and clay, help reduce the toxic effects of these plasticizers in the environment. Since these agents are naturally occurring and remediating a threat to the environment, they are termed 'bioremediators'. Ashutosh Kumar, a professor at Ahmedabad University, carried out research on the mitigating role of humic acid and clay in the environment. An experiment is set up in the laboratory to know the effect of these on aquatic organisms.



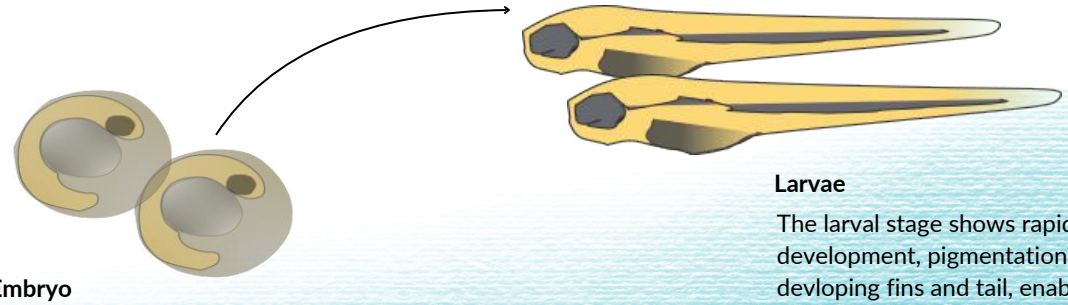
Microplastics and Phthalates
Salt like tiny plastic particles, often less than 5mm, are scattered throughout the environment invisible to the naked eye. Phthalates, a type of plasticizer, commonly leach out from these microplastics.

Clay
Fine- grained tiny particles of rock, often found in soil and aquatic environments.

Humic Acid
A natural substance formed in the environment by the breakdown of dead and decaying plants and animals

Developmental phases of Zebrafish

Zebrafish are a preferred model organism due to their rapid growth stages. Fertilized eggs from a batch undergo growth and enter the Embryonic stage in 24 hours, which develop into larvae in about 48 hours, and some larvae live on to become adult fish. This study was based on the larval stage. It is ideal due to the larvae's transparency making it easier for observation of internal structures and real-time developmental studies.



Embryo

Fertilised eggs develop into the embryo in 24 hours showing key organs and signs of development.

Larvae

The larval stage shows rapid development, pigmentation and devloping fins and tail, enabling it for independent motility.

Adult Zebrafish

The larvae become adult Zebrafish in about 4-5 months, they show sexual dimorphism and are capable of reproduction.

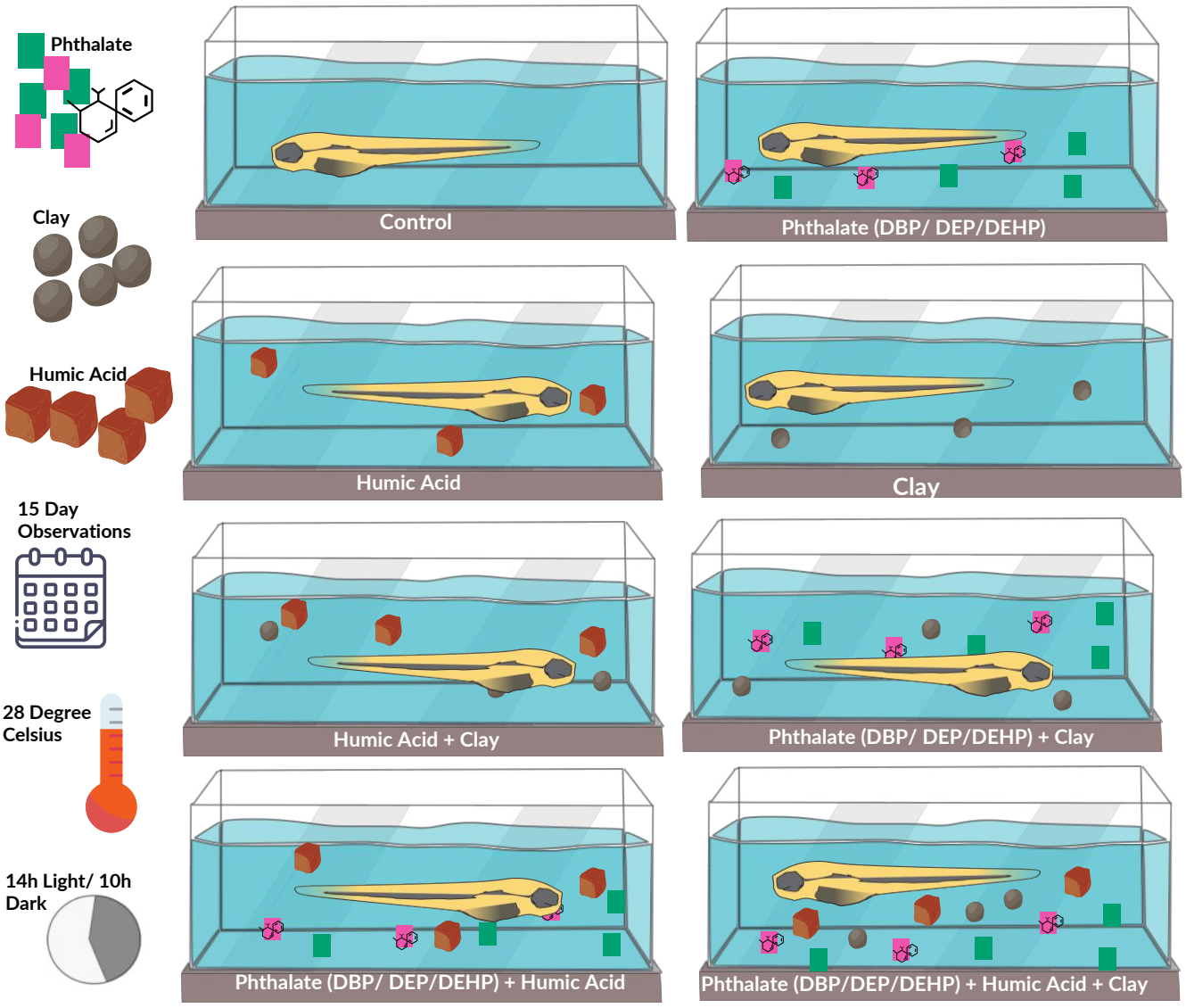
Interaction with Humans

Humans are closely related to some aquatic species, like the Zebrafish, which shares 70% sequence similarity with our genome. This means that most factors affecting its organs and tissues might similarly affect humans. It is known that the effects of plasticizers seen in Zebrafish are mimicked in humans. Since humans have closely woven plasticizers into their lives, there is a chance they may be affected by these endocrine disruptors. Furthermore, ICAR states that **72.1%** of Indians are pescatarians, meaning that toxicants ingested by fish could end up in the human system. Since it is not ethical to study how these plasticizers affect the human population, scientists examine how they affect Zebrafish development. By observing the effects of these phthalates on Zebrafish, analogies can be drawn about how they might affect the human body.

Experimental Set up

The research hypothesizes that bioremediators significantly reduce the toxic effects of phthalates—namely, DEP, DBP, and DEHP—on Zebrafish larvae. It is observed that these help reduce the death rate and malformations in the larvae. Furthermore, it is also observed that when humic acid and clay are introduced, the growth and organ development of the larvae are enhanced. Adult wild-type Zebrafish from Assam are bred in the laboratory, and the collected eggs grow into larvae. These larvae are kept in optimal conditions, and their growth is observed. The larvae are given a sufficient growth environment similar to their natural surroundings. Healthy larvae from a batch are selected and introduced to three phthalate solutions—DBP, DEP, and DEHP, which are most abundant in the environment. The concentrations of these phthalate solutions are kept similar to those in the environment. The larvae are observed for 15 days. Separate batches of healthy larvae are introduced to a combination of humic acid, clay, and phthalates. A batch of larvae is not introduced to any of the chemicals and is known as the 'Control.'

These larvae are observed for death, growth, and cellular stress due to oxidants. One batch of larvae exposed to humic acid, clay, and phthalates is grown into adult fish for 6 months to observe developmental differences in various combinations. The liver and intestine of these adult fish are studied under a microscope to identify developmental differences. For this experiment, researchers used a standardized clay called montmorillonite clay, and humic acid was sourced from a company. It is not possible to give exact environmental values, as humic acid and clay vary in amount by location.



Observations

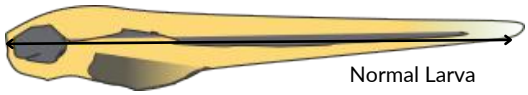
These larvae are observed for death, growth, and stress on cells due to oxidants. One batch of larvae exposed to humic acid, clay and phthalates is grown into adult fish for 6 months to see how it has affected the development of organs. The liver and intestine of these adult fish were studied under a microscope to see developmental differences in various combinations. A typical Zebrafish larva has a straight tail and a flexible spine for movement. It has a flat belly, which provides a streamlined shape that helps it in swimming. The larvae are generally of 3-4 cm in length.

1 Death

Death in a Zebrafish larvae is commonly characterised by a curved, spiral shaped body, eventually turning into a darker grey colour.

2 Larvae Length

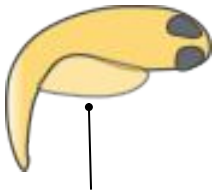
The distance from the head to the tail of the larva.



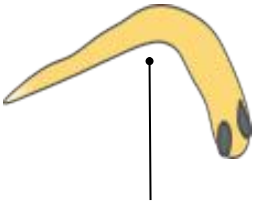
Normal Larva

3 Malformations

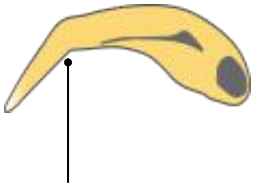
As mentioned, normal Zebrafish larvae has a straight tail and a flexible spine for movement. Sometimes, there is disruption in development which leads to abnormal growth in the larvae. This is termed as 'malformations'. They are of the following types:



Pericardial Malformations
Bulge near the heart due to fluid accumulation



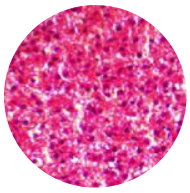
Spinal Malformation
The spine bends and becomes crooked.



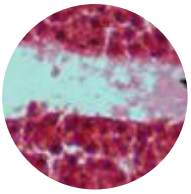
Tail Malformation
The tail bends in a different direction

4 Organ development

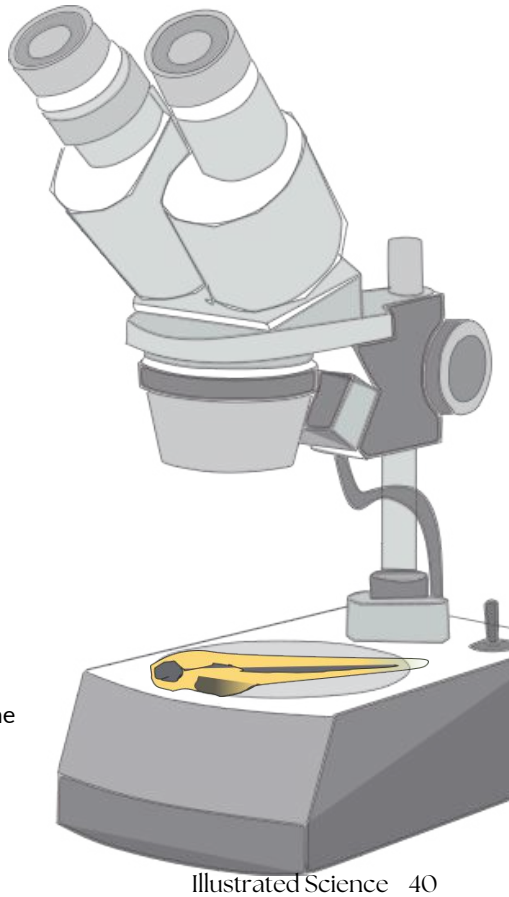
Histopathology of the liver and intestine were observed to see differences in development



Intact cells in Zebrafish liver.

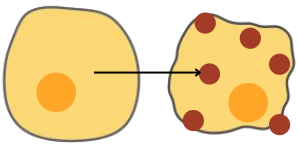


Damage in cells in Zebrafish liver.

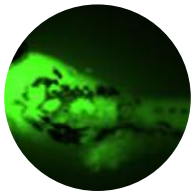


5 Oxidative Stress

Just like humans deal with 'mental stress', at the molecular level, cells face 'oxidative stress' due to oxidants.



Free radicals

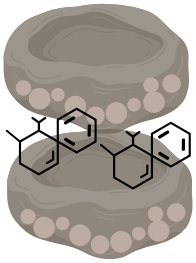


Oxidative stress (indicated by green colouraiton) shown by cells in the larvae.

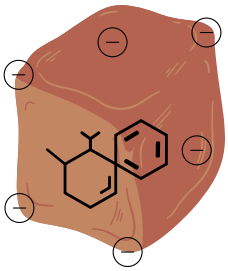
No oxidative stress shown by cells in the larvae.

Remediating role of Humic Acid and Clay

Humic acid has a negative charge, binding with phthalates and engulfing them, leading to the sedimentation of phthalates. Moreover, clay has porous sheet-like structures that trap phthalates between layers. These materials have adsorbing surfaces, which means that toxicants easily adhere to their surface, reducing their availability in the environment. Does this help reduce the toxic effect on the Zebrafish larvae?



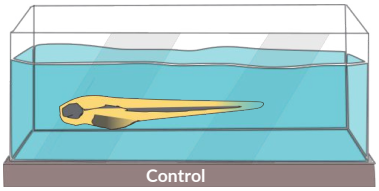
Clay
The porous-sheet like structure of clay helps in the trapping of toxic substances between those layers.



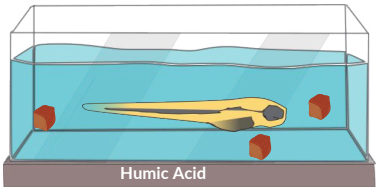
Humic Acid
The negatively charged particles of humic acid, engulf the phthalates.

Yes, indeed. It is found that larvae exposed to individual phthalates have a high death rate compared to those exposed to humic acid and clay. Larvae exposed only to phthalates show an 87.33% death rate, while those exposed to humic acid and clay show a reduced rate of 9.3%. Similarly, abnormal growth intensity in larvae treated only with phthalates is high, but this is reduced in the presence of humic acid and clay. The length of the larvae also reduces from 4.5 mm to 3 mm when treated with phthalates. Oxidative stress levels are almost halved in larvae exposed to humic acid and clay, implying an impact on cellular activity. Furthermore, when these larvae grow into adult fish, studies of the liver and intestine reveal significant degeneration and cell death in larvae treated with phthalates but comparatively lower damage in those treated with humic acid and clay.

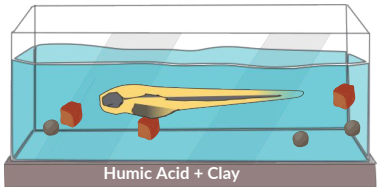
When the water in these tanks is tested using High-Performance Liquid Chromatography, tanks with phthalates alone show higher phthalate levels, while those with humic acid and clay show significantly lower levels. This indicates a lower bioavailability of phthalates in the presence of bioremediators.



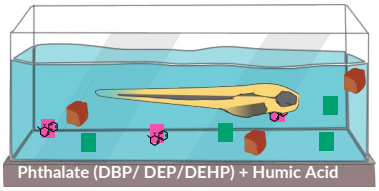
Tank 1
Normal death rate and malformation



Tank 2
Slight increase in death rate and malformations than Tank 1.

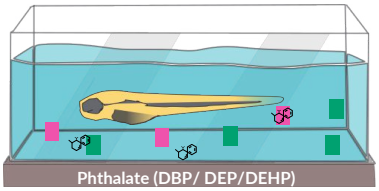


Tank 3
Reduction in death rate and malformations as compared to Tank 2 and 6.

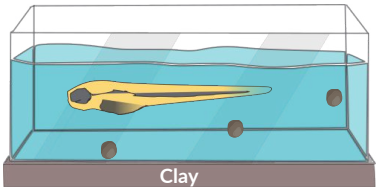


Tank 4
Death rate and malformations intensity similar to Tank 7.

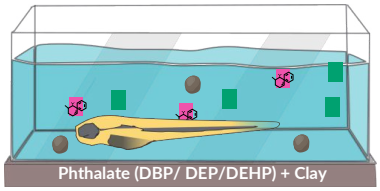
Tank 5
Very high death rate and malformation intensity.



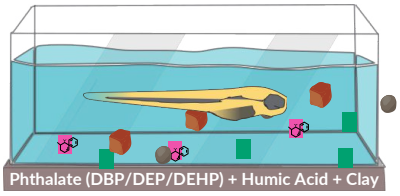
Tank 6
Death rate and malformation intensity similar to Tank 2.

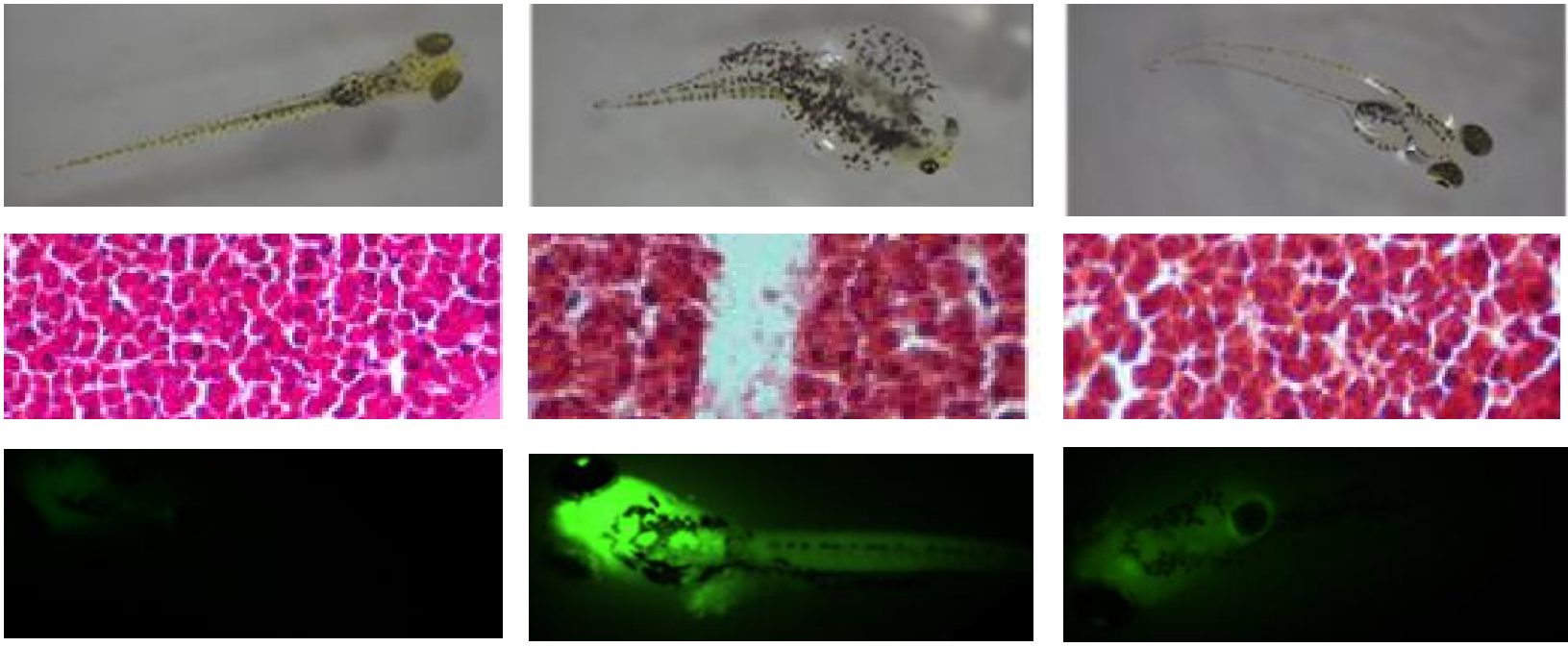


Tank 7
Death rate and malformation lower than Tank 5.



Tank 8
Higher death rate and malformation compared to Tank 1,2,6,3 but lower compared to Tank 4,5,7.





Control **Phthalate treatment** **Humic Acid and Clay exposure**

Nature's own defenders are helping protect the environment, which is slowly being invaded by plastics. Plastics, once deemed useful for their durability, are now embedded in organisms' bodies, including humans. These studies on humans' genetic relatives, Zebrafish, show the adverse effects of plastics and plasticizers, like phthalates. They further demonstrate how humic acid and clay play a mitigating role in reducing these environmental toxicants' effects.

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Shaivee Chokshi is a student of Integrated Master of Science at Ahmedabad University. She loves nature, solitude, and creativity. She finds joy in drawing, painting, and writing, especially when the natural world around her inspires these passions. This illustration is an insight into the field of environmental toxicology. It shows how tiny organisms, like Zebrafish, help us understand the hidden impacts of plastics on ecosystems, reminding us that nature has its own ways of healing, which we can learn from.

Ashutosh Kumar is an Associate Professor at the School of Arts and Sciences at Ahmedabad University. His research group works at the intersection of biology and nanotechnology, with a specific emphasis on advancing nanomedicines tailored for the therapy of breast cancer and rheumatoid arthritis along with environmental nanotechnology. His lab is involved in developing novel drug delivery systems, including lipid-based particles (such as nanoliposomes and solid lipid particles) and polymer-based particles (including chitosan and PLGA) for the delivery of therapeutic agents to various tumours and diseases.

Bee-hind the scenes

Uncovering the impacts of heat stress on honeybees

Writer and Illustrator **Rithu Vijayabaskar** | *Science Mentor* **Jitesh Jhawar**

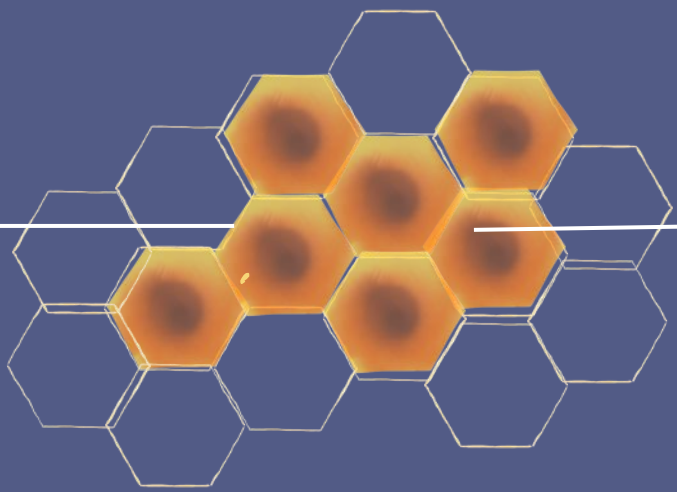
In the golden light of a warm afternoon, the delicate dance of bees among flowers is a familiar and cherished sight. These pollinators, vital to the well-being of ecosystems, seem tireless in their quest. Despite their graceful toil, long-term exposure to a particular environmental factor becomes a stressor: heat, the absolute test of adaptability. As temperatures rise, bees face a battle that imperils their ability to forage, reproduce and ensure continuity of the natural world. Delving into how bees and their colony respond to heat stress reveals a story of resilience.

Collective systems: The creation of a Superorganism

A single bird would be helpless against harsh winds, but when they fly together as a singular unit, they weave through the sky harmoniously. A collective system operates similarly. Individual parts of the system interact, resulting in a more extensive, coordinated behaviour, thus creating a superorganism. Across nature, different species exhibit unified behaviours that are seamless in nature. This form of unified coordination is termed a collective system.

A more straightforward way to understand the importance of a collective system can be explained by imagining a flock of birds flying in the sky. Superorganisms exist across the natural world, with one of nature's most formidable workers, the humble honeybee, being an excellent depiction of a collective system. Honeybees depict their resilience through their incredibly coordinated work, making behaviours seem like it is the work of one superorganism. Collective systems are the hallmark of social insects, like bees, who have developed a remarkable ability to regulate and maintain a stable temperature within their nests. Honeybees can adapt their colony or nests to counteract changes in the external environment and maintain an optimum temperature inside the hive - this phenomenon is termed Nest Homeostasis.

Honeybee brood:
Usually in the middle of the hive. The honeybee brood is maintained at 34.5 degrees Celsius.

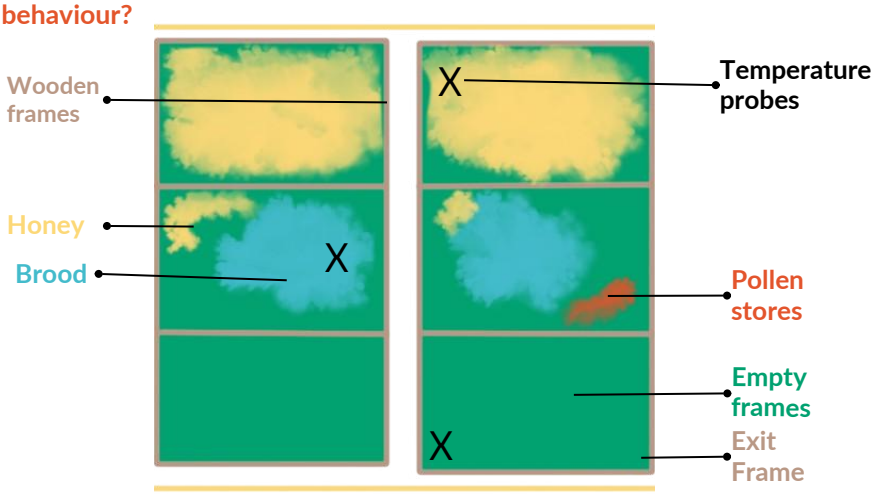


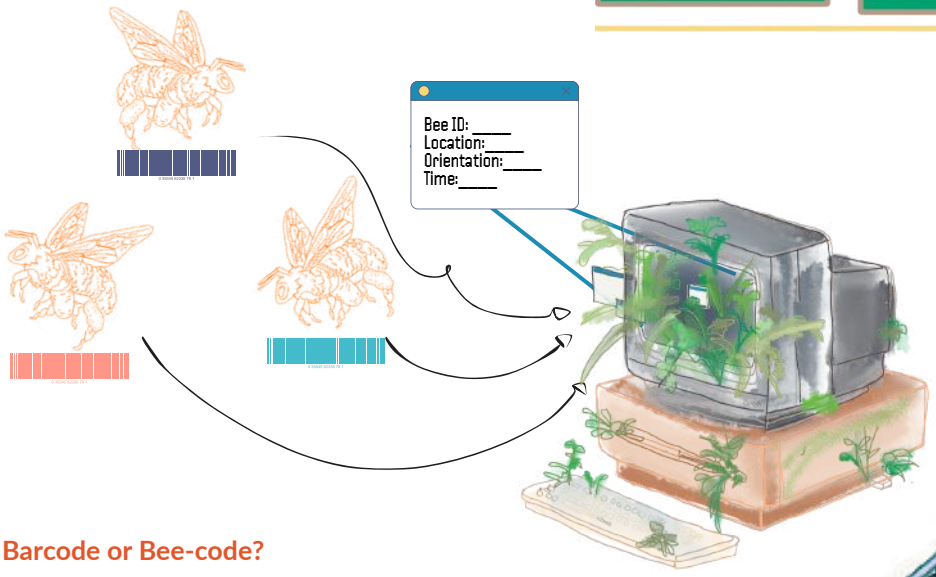
Behaviours observed:
When the temperature rises, bees use diverse behaviours to cool the nest. This includes fanning air around the nest, collecting and spreading water, heat shielding and even evacuation.

Social insects, like honeybees have developed a remarkable ability to regulate and maintain a stable temperature within their nests. This skill isn't just a matter of comfort - It's crucial for their survival and success. Any fluctuation in nest temperatures can prove detrimental to the developing young, known as the brood. If the brood's development is impacted, it begins to develop in a weaker and less fit manner.

How do scientists observe honeybee behaviour?

The **observation hive** is a unique method developed that enables researchers to observe the day-to -day activities of the hive without disrupting or irritating the bees. Made with glass walls, the observation hive allows a researcher to fully analyse the behaviours of a honeybee and its colony.





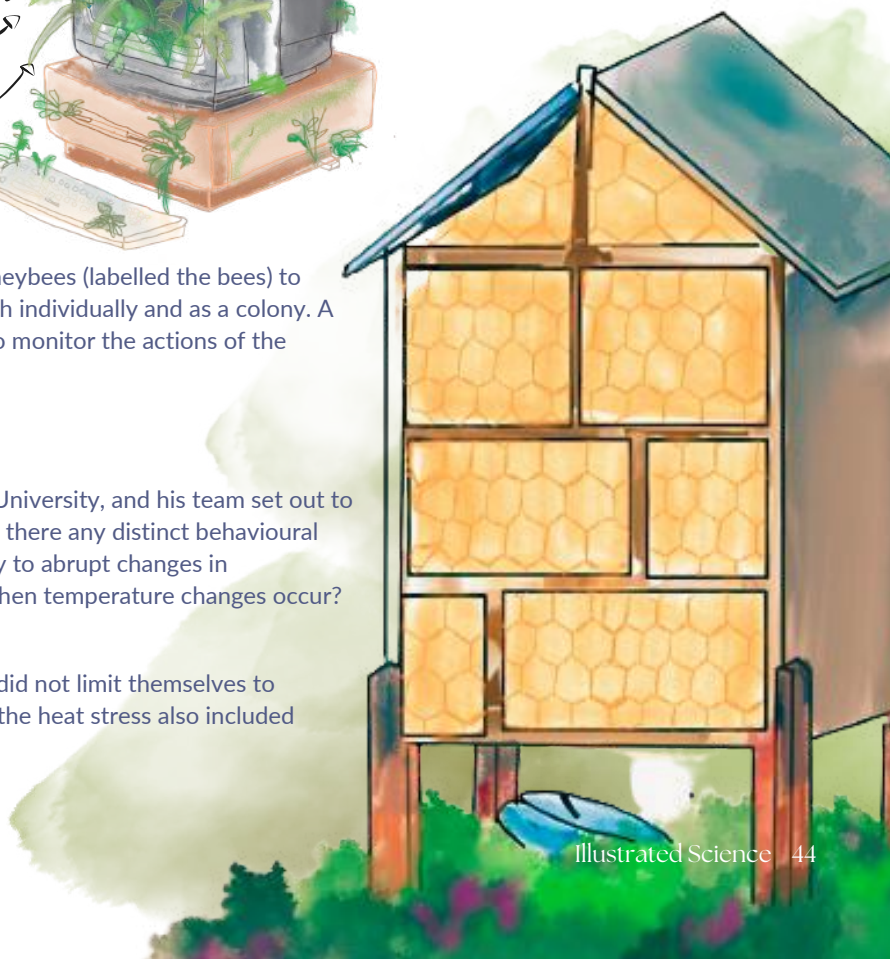
Barcode or Bee-code?

In this study, the researchers individually tagged honeybees (labelled the bees) to examine how the colony responds to heat stress both individually and as a colony. A marker like a QR code was fitted on the honeybee to monitor the actions of the bees.

Buzzing with purpose

Jitesh Jhawar, an ecology Professor at Ahmedabad University, and his team set out to answer questions about honeybee organization. Are there any distinct behavioural clusters responsible for distinct responses, especially to abrupt changes in temperature? Do specific bees have specific roles when temperature changes occur? Can honeybee behaviour be predicted?

An important aspect to note is that the researchers did not limit themselves to collecting just heat stress data; observations during the heat stress also included speed, space usage, dispersion, and more.



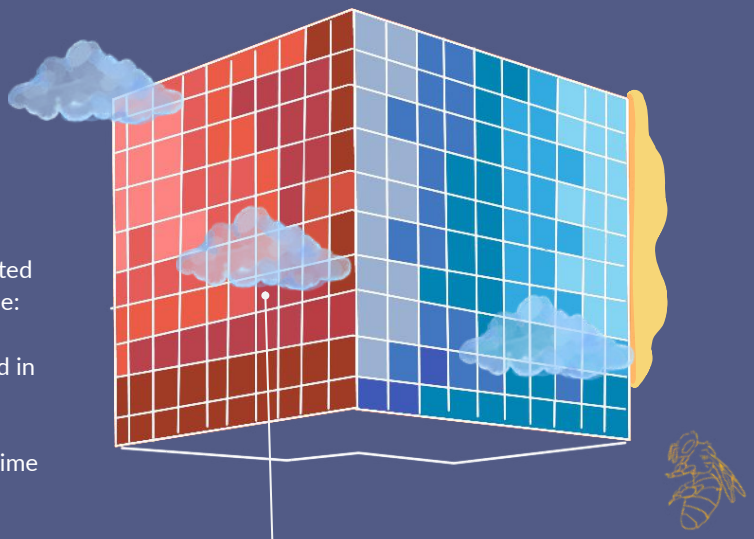
Principle Component Analysis: A tool to simplify the complexities

Numerous behaviours recorded in the data can be correlated when analysing multiple attributes in the data. For example:

Negative correlation: if honeybees are specialised (situated in one area more), their speed and dispersion reduce.

Positive correlation: honeybees near the exit spend more time outside the nest, displaying a positive correlation.

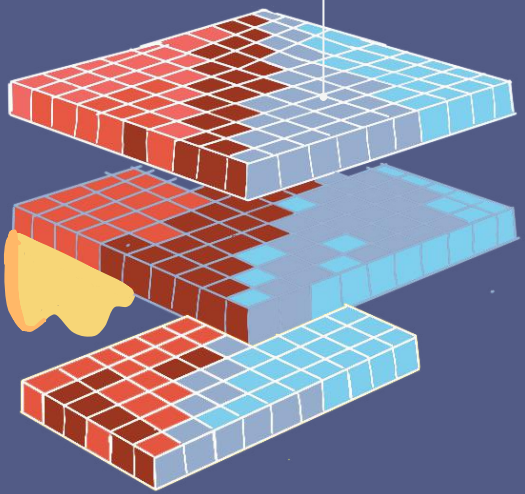
The presence of these numerous layers of data makes it difficult to analyse a single honeybee's behaviour from one dimension. The ingenuity of the analysis lies in how the analysis of these multiple layers of data can been simplified.



1 *Imagine a hyper cube with multiple dimensions, each representing a data point being measured, and each colour is a different feature such as height, weight or width.*

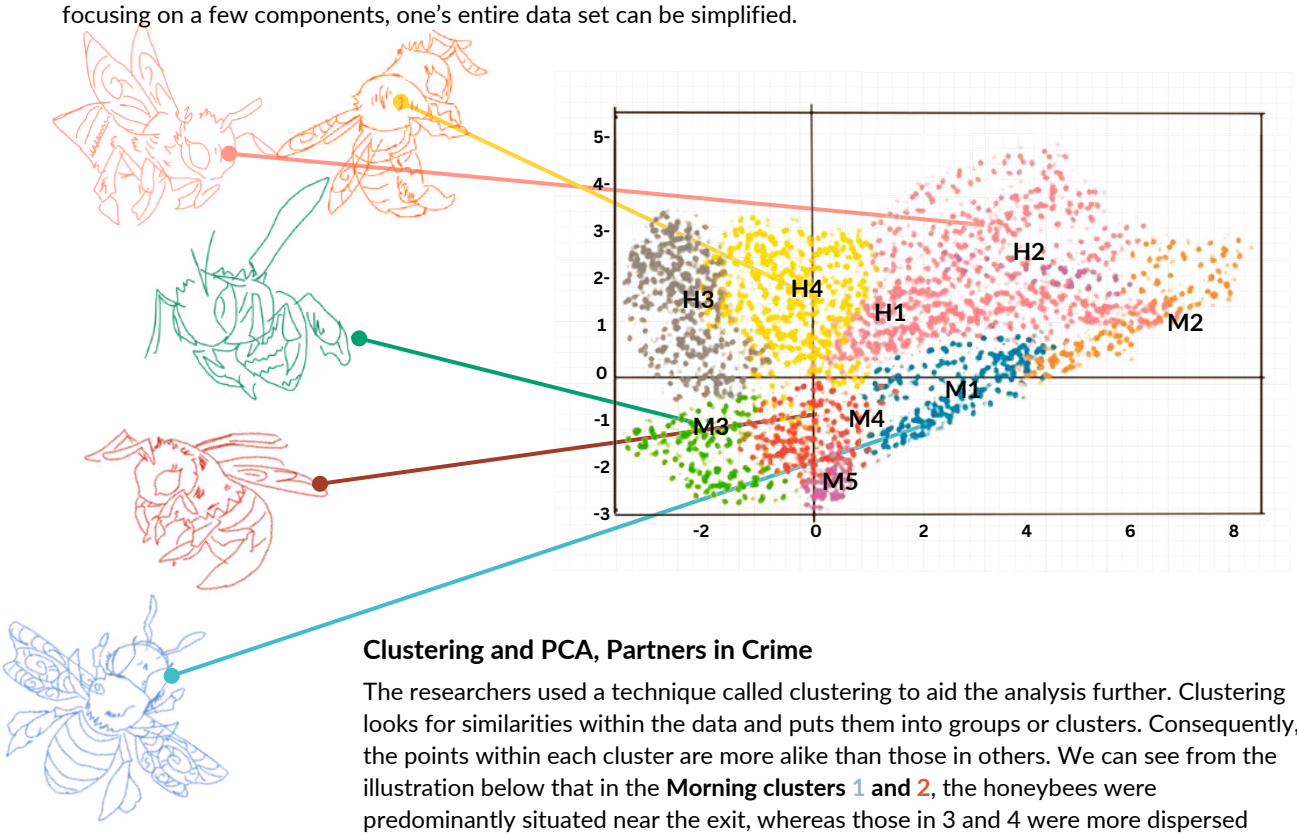
2 *Now imagine any 2 random directions in the hypercube, and these are the behaviours that were monitored . If these two behaviours are highly correlated, then any one of these behaviours can be used to describe both.*

3 *Such correlated behaviours can be compressed into single behaviours. Thus reducing the dimensionality of the system.*



4 *This process continues until only one axis remains, therefore the multidimensional dataset can been condensed to fewer dimensions starting from the multiple in the first cube.*

This is where PCA (Principle Component Analysis) comes into use. PCA looks at the data and finds the principal components where most of the action happens. PCA provides us with uncorrelated behaviours along different vectors. Each vector is a representation of of the underlying correlated behaviours. This plot below represents each honeybee's behaviours mapped onto the first two PC vectors, which has the maximum variation in data. By just focusing on a few components, one's entire data set can be simplified.

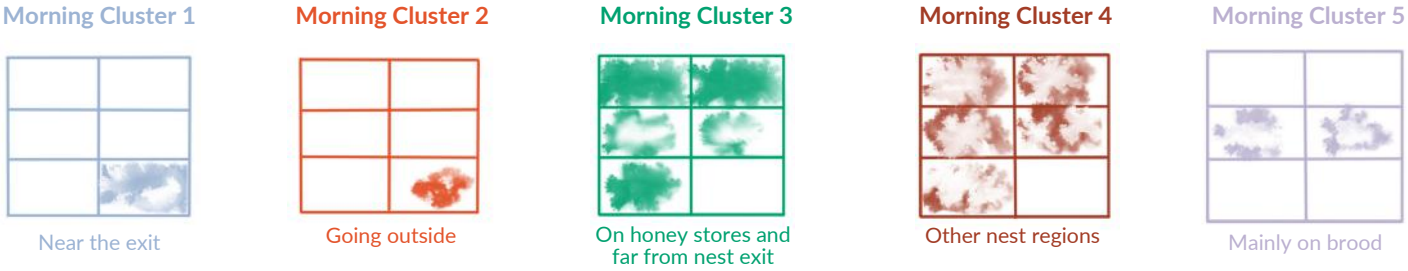


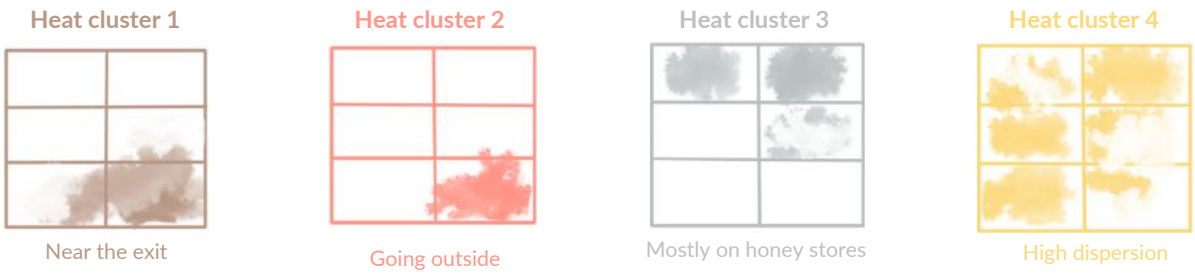
Clustering and PCA, Partners in Crime

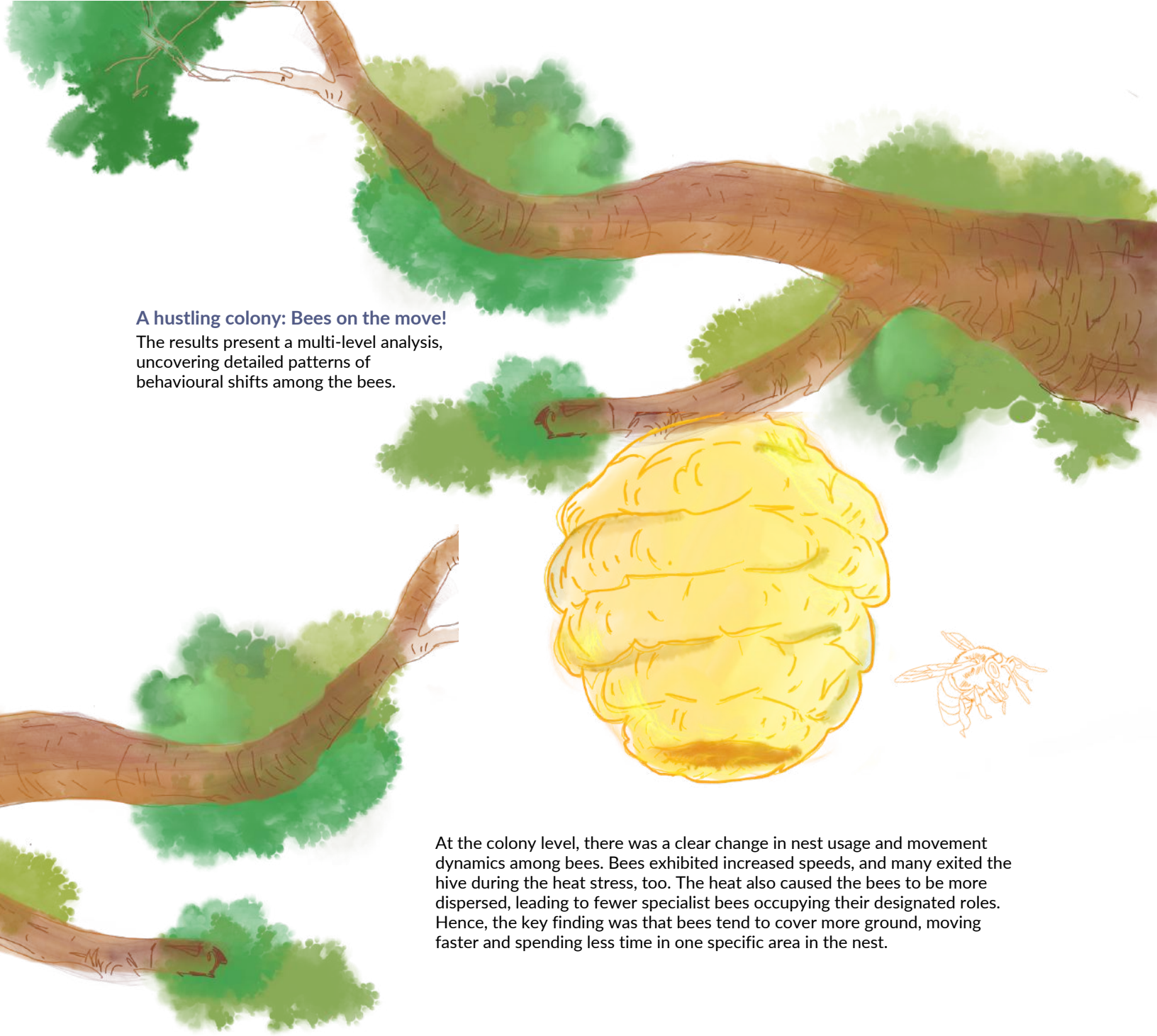
The researchers used a technique called clustering to aid the analysis further. Clustering looks for similarities within the data and puts them into groups or clusters. Consequently, the points within each cluster are more alike than those in others. We can see from the illustration below that in the **Morning clusters** 1 **and** 2, the honeybees were predominantly situated near the exit, whereas those in 3 and 4 were more dispersed along the hive. Similarly, in **Heat Clusters** 1 **and** 2, the bees are mostly situated near the exit. **Cluster** 5 during the morning was absent during the heat stress period. .

Depiction of the clusters within the hive

Combining PCA and clustering led to the identification of 5 clusters in the morning and 4 during the heat stress.







A hustling colony: Bees on the move!

The results present a multi-level analysis, uncovering detailed patterns of behavioural shifts among the bees.

At the colony level, there was a clear change in nest usage and movement dynamics among bees. Bees exhibited increased speeds, and many exited the hive during the heat stress, too. The heat also caused the bees to be more dispersed, leading to fewer specialist bees occupying their designated roles. Hence, the key finding was that bees tend to cover more ground, moving faster and spending less time in one specific area in the nest.

Final conclusions

1. The older bees evacuated the nest first. and were already predominantly situated near the exit before the heat stress

2. Before heat stress, bees near the exit remained in the same place even during the heat stress

3. Brood specialists predominantly moved to the top of the nest, which showcases the importance of the brood care as moving reduces the heat exposure from their own metabolism .

4. Researchers speculate that bees that were already near the exit, or outside the hive participated in collecting and bringing water back for cooling.

5. Many of the behaviours during the heat stress returned to the pre-heat stress levels, suggesting that these behaviours can be retained.

6. In conclusion, the response to heat stress, analyzed as movement and space-use measures, correlated strongly with what the bees were doing just prior the heat stress.

Future of Research into Bee Behaviour

We return to the warm afternoon, to the honeybee colony, where the bees have just returned their hive to the normal temperature, a task often taken for granted. These shifts and delicate balances in honeybee behaviour during periods of incredible stress reveal the constant struggle for survival. Future research could use more fine-skilled and targeted manipulations to investigate specific correlations between behaviours other than heat stress alone. For example, the behaviours of specialist bees could be studied, such as the tasks they carry out and whether they can be denoted as collective or individual tasks.

Moreover, the behaviours of the bees in different environments can also be explored. While the study of bees is already well established, integrating future technologies could help us further understand the humble honeybee's complex, multi-dimensional behaviours.

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Rithu Vijayabaskar is a student of Integrated Master of Science at Ahmedabad University. From a young age, her curiosity about the natural world has pushed her to delve deeper into understanding how things work. Her love for illustration also shines through, whether it's a simple sketch in class or a detailed drawing. She firmly believes that art and science should not be seen as separate entities but rather should be understood together, using visually striking illustrations to help explain science.

Jitesh Jhawar is an Assistant Professor at the School of Arts and Sciences at Ahmedabad University. His research focuses on understanding group dynamics and underlying mechanisms that also fall under self-organisation in biological systems. His research is driven by fundamental proximal questions on animal behaviour while they are in groups. His research is also highly interdisciplinary, as he uses computer vision, motion detection, and machine-learning-based techniques for data collection from videos of animal groups. He completed his PhD at the Indian Institute of Science, Bengaluru (2019) and moved to the Max Planck Institute of Animal Behaviour and the University of Konstanz, Germany for postdoctoral work

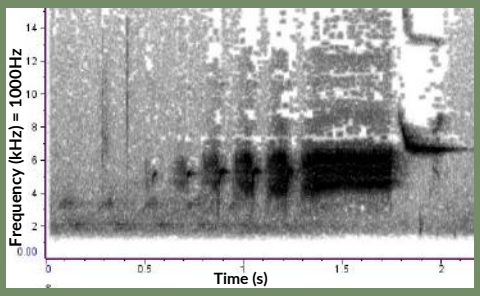
Echoes of the Past

Variability in the B Song of the Golden-Cheeked Warbler

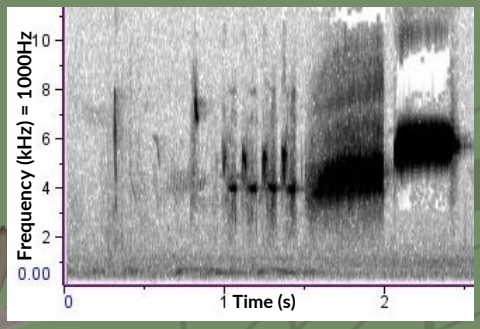
Writer and Illustrator **Chinmayee B.** | *Science Mentor* **Rama Ratnam**

Greetings, human! I am the Golden-cheeked Warbler (*Setophaga chrysoparia*), a bird known for my striking yellow cheeks and a voice that carries through the oak-juniper forests of central Texas. I may be small, but my song is a powerful tool in my life—constantly changing. My kind relies on these juniper trees for much more than just shade. In fact, we collect strips of bark from the juniper tree and use spider webs to weave it all together to build our nests within the oak trees. This place provides not just shelter but also the acoustics that shape my song.

Let us now fly higher into my world!



The spectrogram illustrates Type A song, commonly used by GCWA for courtship, recorded in 2010.



The spectrogram illustrates Type B song, commonly used by GCWA for territorial defense recorded in 2009.

As a songbird, my vocal journey starts with what's called a "plastic song." This is the phase where young birds like me learn the art of communication, and our song is highly variable as we practice and perfect it. Over time, this plastic song transitions to a "frozen song", which remains mostly unchanged throughout adulthood. For many songbirds, once the song is learned, the chance of variation is extremely low.

So, you might ask, what explains the change in my song over the years? Is it a natural cause? Given that songs usually remain consistent after learning, this seems unlikely. Or is it a deliberate change driven by shifts in my environment or the need to adapt?

The Two Songs I Sing

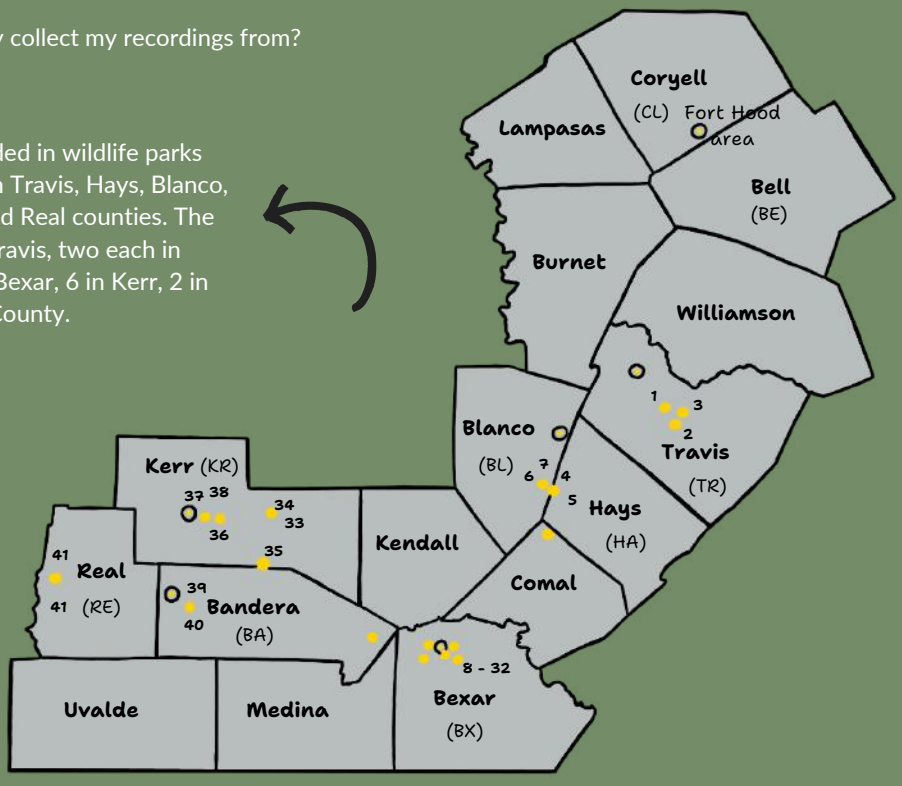
Like many of my fellow warblers, I communicate using what scientists call a "two-category song system." Each of these songs serves a distinct purpose.

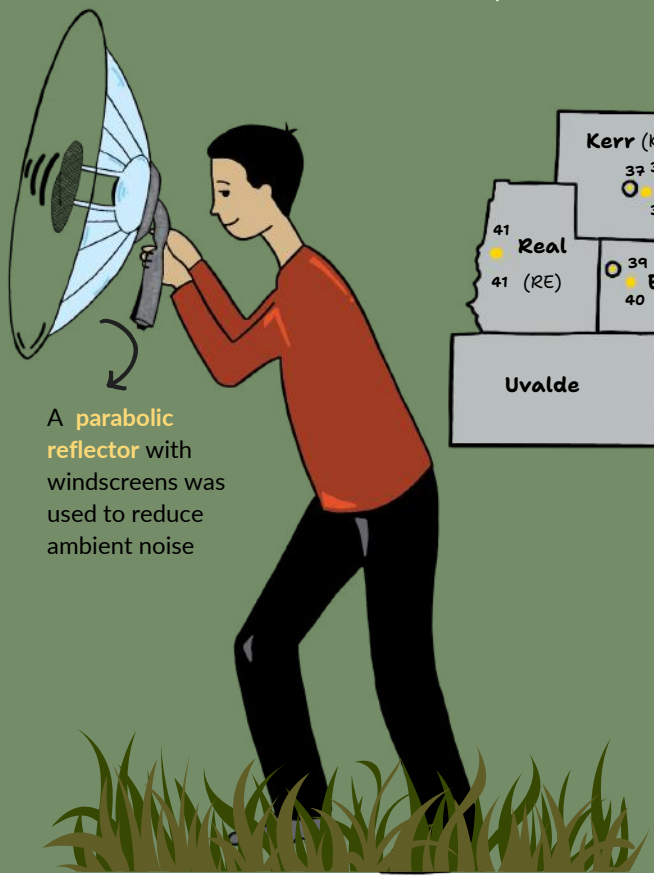
First, there's "**A song**". This is my simple, stereotyped tune, sung at a low pitch and usually used to attract females. Early in the spring, when I'm focused on finding a mate, you'll hear me singing the 'A song' during sexual interactions. It's a reliable melody, with little variation over time, as keeping it consistent helps female warblers compare the songs of different males. In this sense, my 'A song' is crucial in ensuring reproductive success. Researchers have noted that the 'A song' shows minimal change in its "modal frequency"—the frequency where the song's energy is strongest—between the recordings made in the 1990s and more recently.

Now, let me tell you about the "**B song**" that interests scientists most. The 'B song' is far more dynamic and varied than the 'A song' (as shown in figure 1). B song contains 4 syllables, namely, a, b, c and d. Syllables are just like different letters that make up a word and here, different syllables make up the B song. I use this song later in the spring, once the nesting season begins, primarily to engage with other males. You see, the 'B song' is my battle cry. It helps me defend my territory and assert dominance when rival males come too close. Unlike the 'A song,' which needs to remain stable for females, the 'B song' is more flexible and prone to change. And it is this very adaptability that has piqued the interest of researchers.

So, where did they collect my recordings from?

41 warblers were recorded in wildlife parks and private properties in Travis, Hays, Blanco, Bexar, Kerr, Bandera, and Real counties. The sites included three in Travis, two each in Hays and Blanco, 25 in Bexar, 6 in Kerr, 2 in Bandera, and 1 in Real County.

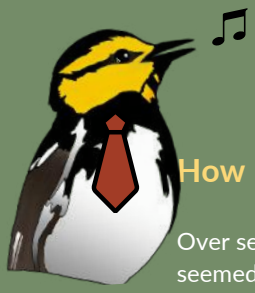




A **parabolic reflector** with windscreens was used to reduce ambient noise

Want to track the journey of my 'c*' syllable in the B song?

Scan the QR to hear the change from 1993-94 to 2010-11.



How Humans Collected My Song

Over several springs, from 2009 to 2011, humans came to my home in the oak-juniper forests of central Texas. They seemed especially interested in the songs of my fellow warblers and me. I'd see them early in the morning, right at dawn, setting up their strange equipment to capture our voices. To capture my voice, they used two types of microphones. One picked up sound in all directions (omnidirectional microphone), while the other focused more directly on me (super-cardioid shotgun microphone), filtering out other noises. Some of my friends living in more remote parts left automatic recorders (autonomous recorders) to capture our songs after dawn without being there. I noticed them record my song repeatedly until I stopped singing for the day.

These humans didn't just record any song. They paid special attention to my 'B song,' the one I sing to other males when they come too close. Over three seasons, they recorded more than 1700 of my B songs from across the seven counties. They even compared my recent songs to older ones recorded in 1993-1994—before I was born! The older recordings were stored at a place called the Cornell Lab of Ornithology.

The **omnidirectional microphone** captured sounds from all directions, ensuring the full range of the warbler's song and surrounding sounds.

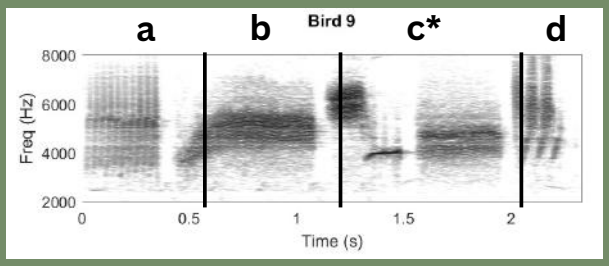
The **super-cardioid shotgun microphone** was used to capture the song clearly while minimizing background noise.

The **autonomous recorder** was placed at remote sites to record bird songs independently, without requiring a researcher on site.

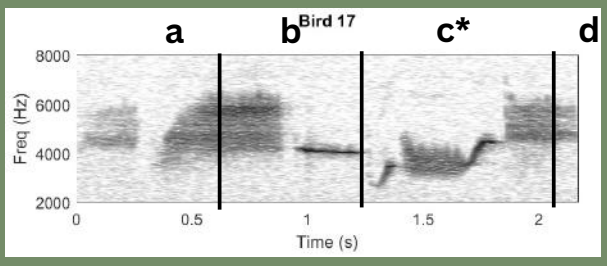
Once they gathered my songs, they processed them using a special tool that filtered out unnecessary noise. They created visual representations of my song—called spectrograms—that showed the frequency of my voice over time. From these spectrograms, they figured out the "modal frequency," the part of my song that carries the most power. They did this for all the males they recorded, both for our 'A songs' and 'B songs.' The researchers compared my modal frequencies to those of older generations to see how my song has changed over the years. Using a statistical tool, they confirmed that my B song had shifted, especially in the modal frequency. Even though we learn our songs carefully, and they don't change much after we perfect them, something in my environment has made me adjust how I sing.

A Shifting Melody: The B Song Over Time

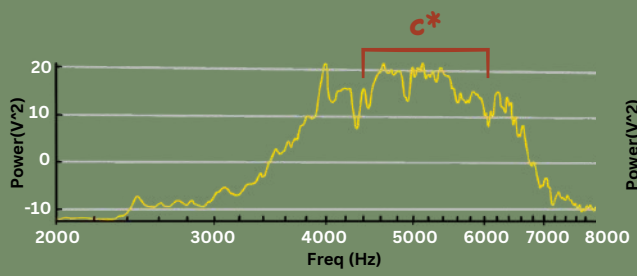
The two spectrograms display data from two different time periods for two different GCWA. Notably, syllable "c" has undergone a significant shift over time, with a frequency decrease of approximately 600 Hz. The charts at the bottom provide a simplified view to clearly illustrate this change.

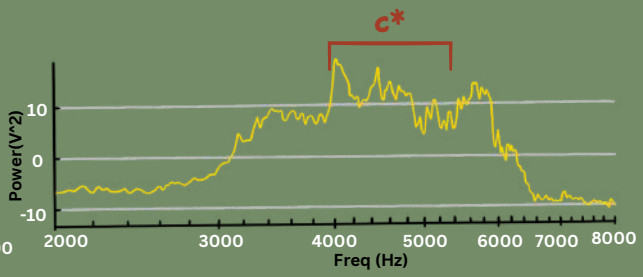


B Song collected by Andy Bolsinger in 1993-34



B Song collected by Ratnam, Cozort and Leonard in 2010-11





Ratnam and his fellow researchers conducted a study comparing my songs recorded between 2009 and 2011 with older recordings from 1993-1994. They focused specifically on the 'B song' because it showed the most variation over time and across different regions. Using advanced tools like "spectrogram" to create visual representations of sound frequencies over time, they could closely analyze my song's structure.

What they discovered was fascinating: the "modal frequency" of my 'B song'—the frequency where the song carries the most power—had shifted significantly over the years. In the older recordings, my 'B song' peaked to around 4600 Hz, but this frequency had dropped to about 4000 Hz in the more recent recordings. A subtle shift, perhaps, but significant in bird communication.

But what's responsible for this change? Researchers found that the key to this shift lies in one specific part of my 'B song,' the "c*" syllable (the star is used to show that this particular syllable had a significant variation). While syllables a, b, and d remained relatively stable between the two time periods, the c* syllable underwent the most noticeable variation, as we can see in graphs above. This part of the song showed "frequency modulations"—changes in pitch that create slurs (upward or downward sweeps of sound)—that were not as prominent in the 1990s recordings. It was these changes in the c* syllable that caused the overall shift in modal frequency.

This variability in the 'B song' may not just be a random noise—it's a systematic change. The 'B song' plays a crucial role in male-male interactions, helping me communicate with neighbouring males and maintain my territory. Researchers believe this part of my song is more flexible because it needs to adapt to the challenges of defending my territory, which can vary depending on environmental conditions, population density, and other factors.

Spatial Differences: My Song Across Texas

Interestingly, researchers also noted that the greatest differences in my 'B song' occurred between two specific locations: Bexar County in the 2009-2011 recordings and Bell County in the 1993-1994 recordings. These two counties are located in different parts of my breeding range in Texas, and while the reasons for this geographic variation aren't entirely clear, it suggests that my song is influenced not just by time but also by place.

We warblers are territorial creatures, and the dynamics of male-to-male interactions can vary from one region to another. In areas with high population density, my 'B song' might need to be more assertive or lower in frequency to stand out. Alternatively, changes in the acoustic environment—such as increased background noise from human activities—might force me to adjust my song so it can still be heard. Researchers refer to this as "anthropogenic noise"—noise generated by human activities like construction or traffic, deforestation for development which can interfere with my ability to communicate with other males.

Understanding the Shift

You might wonder: Why does this change in song frequency matter? Well, in the world of birds, communication is everything. My 'B song' is critical to establishing dominance and defending my territory. If my song can't be heard or understood by other males, I risk losing my territory, which could impact my ability to reproduce and ensure the survival of my species. The drop in modal frequency could reflect an adaptation to environmental factors. For example, lower-frequency sounds travel farther and are less likely to be drowned out by noise, making them more effective for long-distance communication. This could explain why the frequency dropped in my 'B song' —perhaps I'm adjusting to new challenges in my environment, whether they come from other males, changes in habitat, or increased noise levels.

Researchers used statistical tools to confirm that the changes in modal frequency were significant. This test compares two groups of data that don't follow a normal distribution—in this case, the older and more recent recordings of my 'B song'. The results showed a clear difference in modal frequencies between the two time periods, confirming that my song had indeed evolved.

The Stable A Song

While my 'B song' has changed, my 'A song' remains remarkably stable. In both the older and more recent recordings, the modal frequency of my 'A song' hovered around 4600 Hz, with no significant shifts over time. This stability makes sense because the 'A song' is primarily used for attracting mates, and too much variation could make it harder for females to compare potential partners. The consistency of the 'A song' helps females select the best mates based on familiar patterns, ensuring reproductive success.

The Road Ahead

So, what's next? Researchers are eager to continue studying my systematically changing song, particularly to understand the causes of these changes and their potential impact on my species. They're investigating whether environmental changes, population pressures, or human interference drive the shift in my 'B song.' Scientists can better understand how my species and other birds adapt to a rapidly changing world by learning more about these factors.

For now, my song continues to change with my environment. It's not just a melody—it's a living, evolving tool that helps me survive. And as long as I sing, my story will continue to unfold.

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Chinmayee B is a student of Bachelor of Arts (Honors) in Economics at Ahmedabad University. With a flair for scientific illustration and a strong interest in avian studies, she illustrated a paper on the Golden-cheeked Warbler, focusing on the shifts in its B Song over time. Drawing from her skills in visual storytelling, Chinmayee crafted detailed yet accessible illustrations, helping readers grasp the nuances of this bird's changing vocal patterns. Her passion for art and ecology intertwines to bring complex research findings to life, making science approachable and engaging.

Rama Ratnam is a Professor at the School of Arts and Sciences at Ahmedabad University. He is a neuroscientist with a broad interest in brain and behaviour, particularly in neurobiological mechanisms of sensory processing that give rise to perception. His research interests include Neuroscience, Brain And Behavior, Sensory Processing, and Neural Engineering. He obtained his doctoral degree from the University of Illinois at Urbana-Champaign. His engineering roots from IIT Delhi have deeply influenced his research in biology to combine biology and engineering to explore how natural selection mirrors optimal design.

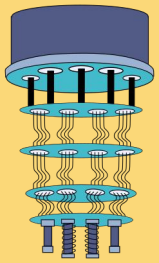
Quantum Computers Surpassing Classical Boundaries

Writer and Illustrator **Freya Shah** | *Science Mentor* **Alok Shukla**

Are there problems so complex that even the most powerful computers we use today can't solve them? While classical computers can predict climate change, their precision is limited in modelling complex, long-term scenarios. For challenges like improving these predictions or discovering new medicines, conventional computing falls short. But what if a new type of computing, one that harnesses the strange rules of quantum mechanics, could tackle these seemingly impossible tasks? Quantum computing, an emerging technology, might just hold the key to solving problems that would take classical computers millions of years to crack.

Classical computers, the ones we use every day for browsing the web, sending emails, or playing games, operate using bits, the fundamental units of information. A bit can be either a 0 or a 1, like a tiny switch that can be turned on or off. By combining millions or billions of these bits, classical computers perform a wide range of tasks, from simple calculations and streaming high-definition videos to running sophisticated code, advanced data analysis, etc. However, while classical computers are highly effective for several tasks, they face serious challenges when it comes to solving extremely complex problems. These problems often involve taking into account an enormous number of parameters, variables, and interactions, which quickly overwhelm the capabilities of classical computing.

One example of this complexity arises in cryptography, the science of securing information. Many encryption methods used today rely on the fact that classical computers struggle to factor large numbers efficiently. For instance, breaking an encryption key could require factoring a number with hundreds or thousands of digits, a process that becomes exponentially more difficult as the number grows. While classical computers can easily factor in small numbers, when they face large numbers, the sheer number of possible combinations is so vast that it could take them millions of years to solve. This enormous difficulty is what keeps encryption methods secure, at least for now. Similarly, in fields like drug discovery, climate modelling, and optimization, classical computers hit a wall due to the complexity involved.

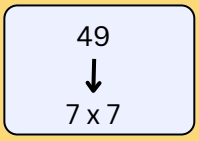


Quantum computers are different form of computations that uses the principles of quantum mechanics

Several **complex problems** take millions of years for computers that we use daily to compute. These are even difficult for state-of-the-art supercomputers.

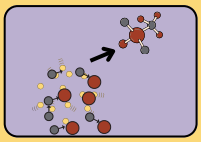
Classical computers are computers that we use daily for several tasks.

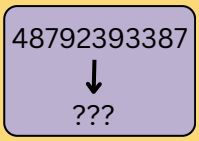
Searching a word in a dictionary is easy



For eg: Factoring 49 is very easy for classical computers

Finding a new medicine that caters to specific properties from different atoms and molecules is very hard.

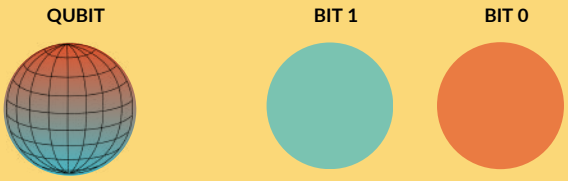




Factoring such a large number can take millions of years and that is what the modern cryptography is based on. That is classical computers cannot factor such large numbers

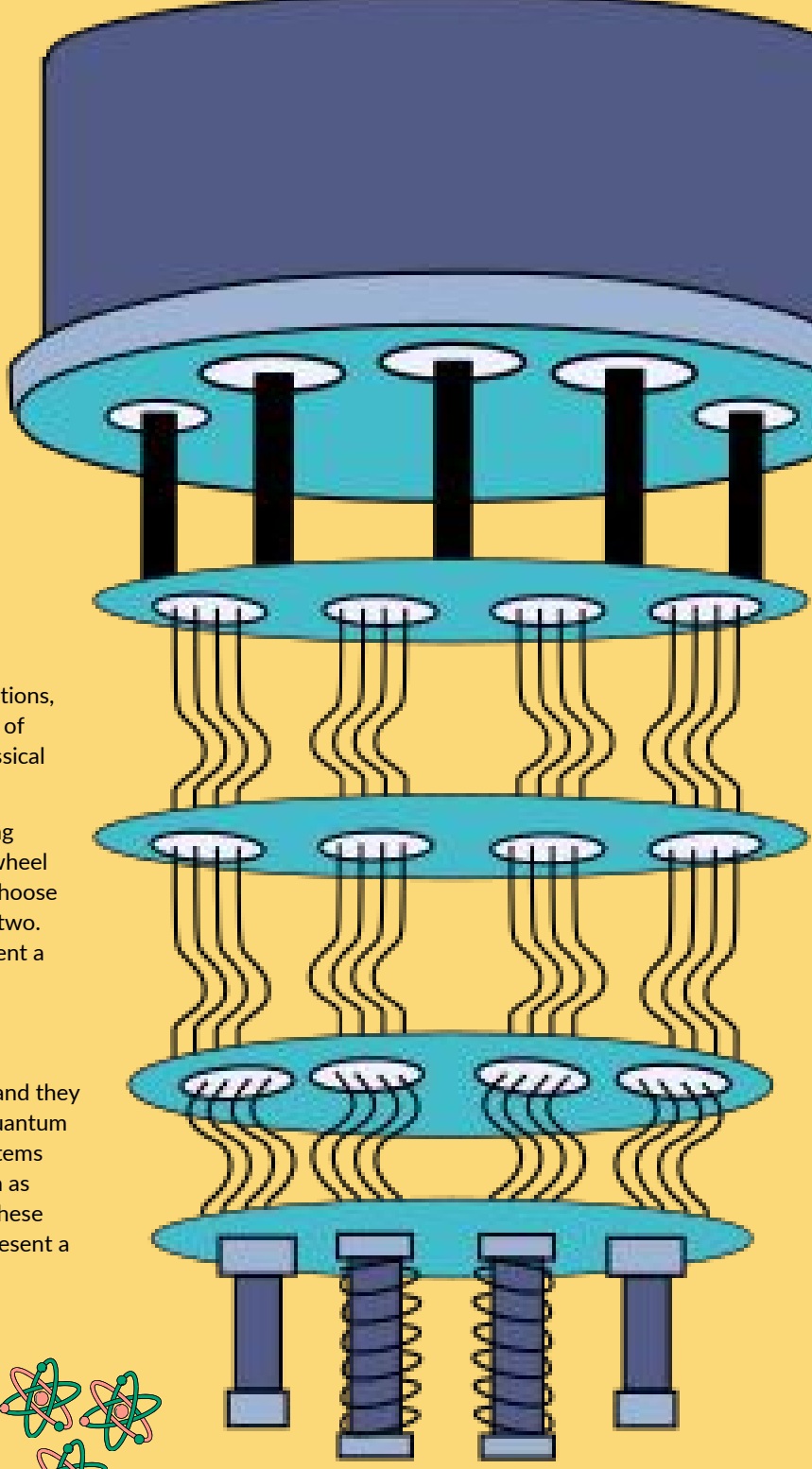
An Alternative Approach

Quantum computers process information differently. It operates on the principles of quantum mechanics, a branch of physics that governs the behaviour of particles at the smallest scales, such as electrons, photons, and atoms. Let us first understand how classical computers work. Every classical computer is made up of a fundamental unit called a bit.



Think of bits like colors: either red or blue. In a classical computer, each bit must choose between these two options, meaning it is either a **bit 0** or a bit 1, with no possibility of anything in between. This is the foundation of how classical computers process and store information.

Quantum computers use qubits as their basic processing unit. To understand how qubits work, imagine a color wheel rather than just two fixed colors. Instead of having to choose only red or blue, qubits can be any shade between the two. They aren't restricted to a single state; they can represent a whole spectrum of possibilities at once.



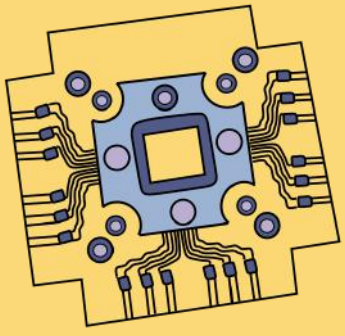
What are qubits made of?

Qubits are the building blocks of quantum computers, and they are made from various materials that exhibit specific quantum mechanical properties. These materials can include systems composed of atoms, ions, and subatomic particles, such as electrons and photons. The information is encoded in these materials through their quantum states, which can represent a variety of values simultaneously.

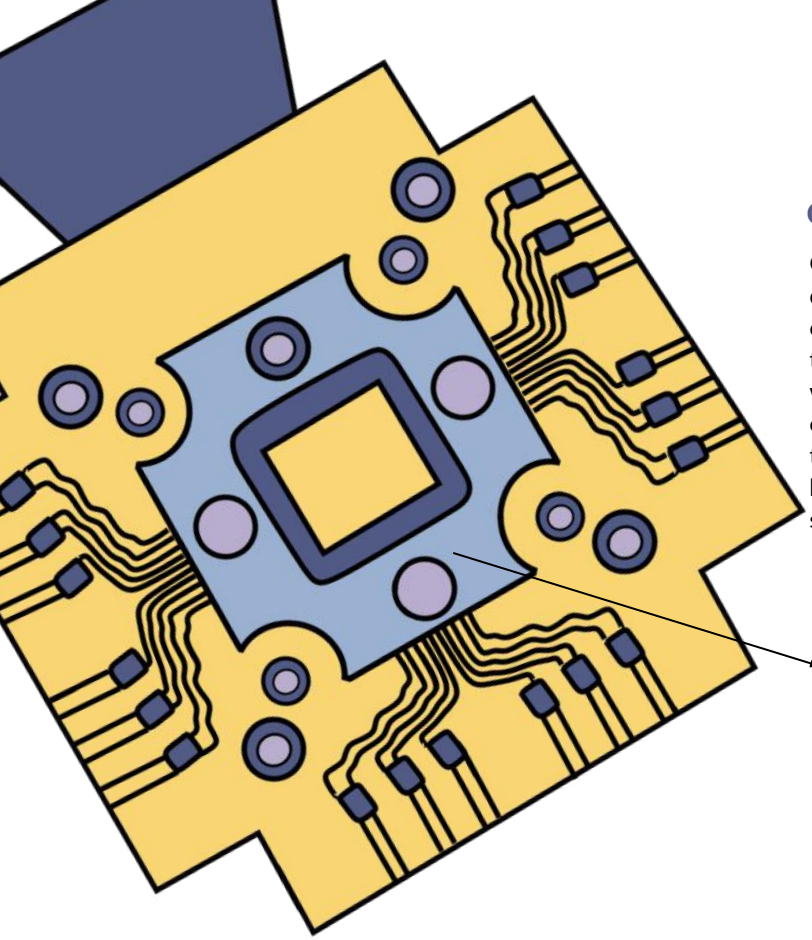
Neutral atom qubits

It consists of individual neutral atoms, such as rubidium or caesium, that are held in place using laser beams. When these atoms are cooled to extremely low temperatures, they exhibit unique quantum properties, allowing them to be used as qubits.

Superconducting qubits

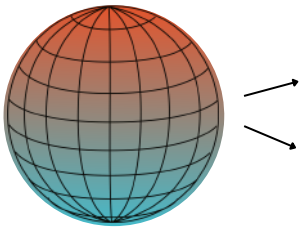


One of the most popular qubits used by IBM. Superconducting qubits are tiny circuits made from special materials like niobium or aluminium. These materials can conduct electricity without any resistance when cooled to very low temperatures (below 20 millikelvins). In superconducting qubits, quantum mechanics comes into play through a component called a Josephson junction. This junction allows the qubit to oscillate between two energy states, which represent the 0 and 1 values of a bit. By applying microwaves, scientists can control these oscillations, enabling the qubit to perform calculations.



Qubit Properties

Qubits exhibit distinctive quantum properties, such as quantum superposition and quantum entanglement, which contribute to their potential for significantly speeding up the solution of complex problems. Unlike classical bits, which can only represent a single value of 0 or 1, qubits can exist in multiple states simultaneously, much like a wave that can be in various locations at once. When measured, however, qubits behave like particles, collapsing into a single state.

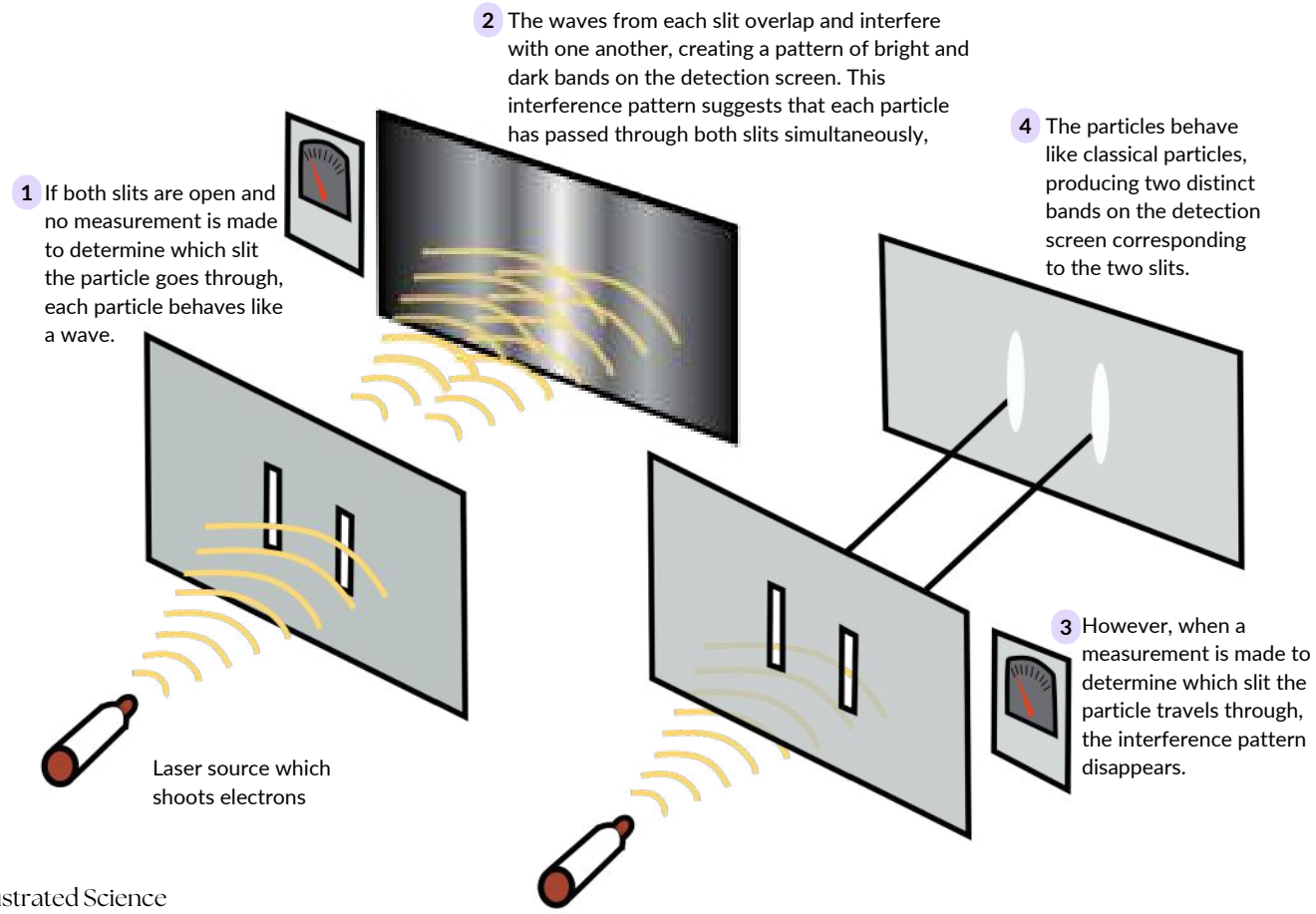


The qubit behaves like a wave in some cases and like a particle in others!

Particle-wave duality, fundamental concept in quantum mechanics that describes how every particle, such as electrons or photons can show wave as well as a particle like properties.

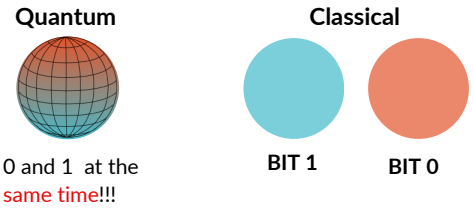
Double Slit Experiment: A Quantum Revelation

Particle-wave duality can be understood by double slit expriment. The experiment consists of a particle source, like electrons, a barrier with two slits, and a detection screen. When particles are fired toward the barrier, they can pass through one of the two slits.



Quantum Superposition

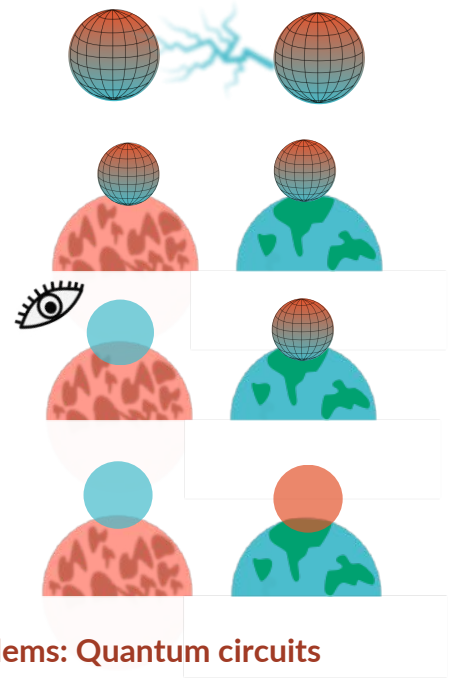
While bits can be either 0 or 1, qubits can be both at the same time. This phenomenon of qubits existing in multiple states at once is called quantum superposition.



Imagine you're trying to solve a maze. A classical computer would try every path one after the other, but a quantum computer could explore all the paths at once! This makes quantum computers potentially game-changing for solving really complex problems that would take regular computers ages to figure out.

Quantum Entanglement

Multiple qubits can also be entangled with each other. In the quantum world, entanglement describes a special connection between qubits in which the state of one qubit is directly linked to the state of another, no matter how far apart they are.



Imagine two light bulbs, both in states of superposition and entangled.

The entangled bulbs are separated—one bulb is on Earth, and the other is on Mars.

The state of one bulb is measured.

Then, the state of the other bulb instantly changes, even though there's no physical connection!

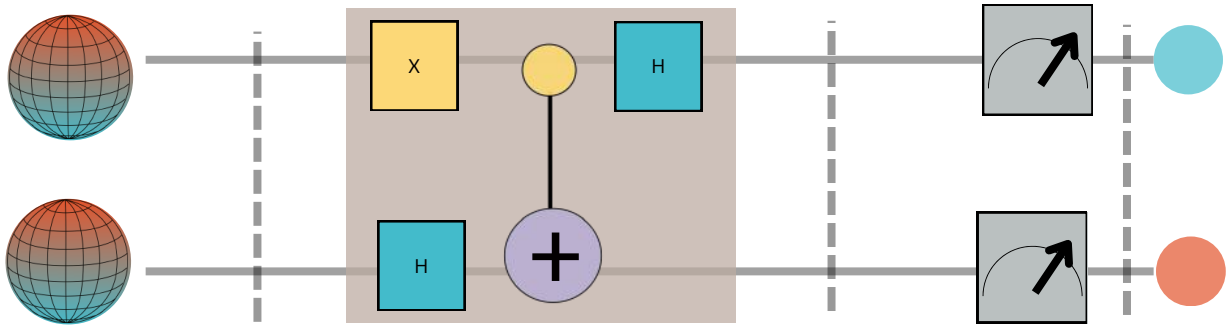
Quantum framework for solving problems: Quantum circuits

The quantum framework for problem-solving involves encoding information in qubits, manipulating their states through quantum gates arranged in algorithms, and finally measuring the states to extract useful results.

1. The first step is state preparation, where qubits are initialized to a specific state based on the problem at hand.

2. To manipulate the states of qubits, quantum circuits use quantum gates. Think of these gates as tools that perform specific operations on the qubits, similar to how classical logic gates work in regular computers. These gates can be combined in sequences to create what is known as a quantum algorithm. Each algorithm is designed to solve a specific problem by cleverly arranging these gates to manipulate the qubits' states in a way that optimally addresses the task at hand.

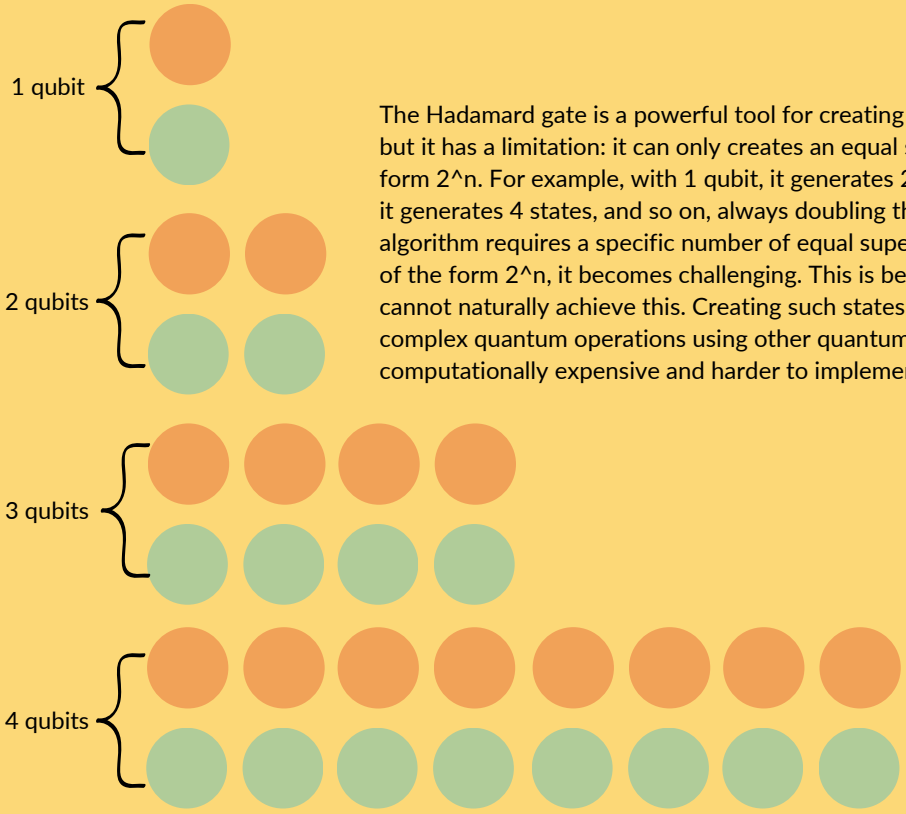
3. Once the quantum algorithm has processed the information, the final step is measurement. This involves observing the states of the qubits, which causes their superposition to collapse into definite values of either 0 or 1. The result of this measurement gives the output of the quantum computation, providing a solution to the original problem.



Equal Superposition States

Most quantum algorithms begin by preparing all qubits in an equal superposition state. This initial setup is crucial because it allows the qubits to represent all possible combinations of states simultaneously, rather than starting from a single predetermined state.

This is achieved using the Hadamard gate, which allows each qubit to represent both 0 and 1 at the same time, instead of being limited to just one state like classical bits. When multiple qubits are placed in this superposition, they collectively represent a vast number of combinations simultaneously.The number of possible states grows exponentially with the number of qubits and follows 2^n where n is number of qubits.



The Hadamard gate is a powerful tool for creating equal superposition states, but it has a limitation: it can only creates an equal superposition states of the form 2^n. For example, with 1 qubit, it generates 2 equal states, with 2 qubits, it generates 4 states, and so on, always doubling the number of states. If an algorithm requires a specific number of equal superposition states that is not of the form 2^n, it becomes challenging. This is because the Hadamard gate cannot naturally achieve this. Creating such states would require more complex quantum operations using other quantum gates which can be computationally expensive and harder to implement efficiently.

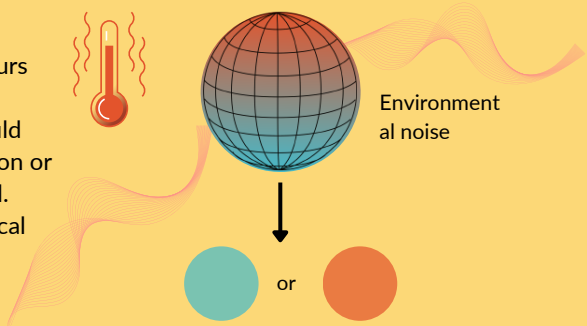
Alok Shukla, a professor at Ahmedabad University and his collaborator, Prakash Vedula from the University of Oklahoma, have recently developed an innovative algorithm that can create arbitrary uniform superposition states with a significant reduction in the number of gates required. Compared to existing state-of-the-art methods, this algorithm achieves an exponential reduction in the number of quantum gates, making the process more efficient and practical for quantum computing applications. The algorithm is deterministic and does not require any additional qubits.

Previously, generating a superposition of M quantum states required O(M) gates, demanding thousands or millions for large M. Now, with just ⌈log(M)⌉qubits and O(logM) gates, the same superposition is achievable. For instance, it can now generate a superposition of over a million states with fewer than 20 gates—an exponential boost in efficiency!

Why is the proposed algorithm useful for quantum computation?

Despite their immense potential, quantum computers are not yet widely used due to several major challenges. First, quantum computers are still in their infancy, with only small-scale prototypes available. These machines can handle a limited number of qubits, and scaling them up to tackle real-world problems is extremely difficult. Scalability refers to how well we can increase the number of qubits in a quantum computer while maintaining their performance. Right now, building quantum computers with many qubits (in the millions or billions, like classical computers have bits) is extremely difficult due to several problems.

Decoherence is also one of the biggest challenges in quantum computing. It occurs when a qubit loses its quantum state due to interactions with the surrounding environment. Vibrations, temperature fluctuations, or electromagnetic noise could cause this. When a qubit interacts with its environment, the delicate superposition or entanglement can break down, and the quantum information is lost or corrupted. The quantum state, after interacting with the environment, changes into a classical bit and loses its quantum information.



Creating uniform superposition states is essential for many quantum algorithms as they rely on the creation of uniform superposition states. The proposed algorithm, with its O(log(M)) gate and space complexity, brings substantial advantages, allowing efficient preparation of superpositions over very large numbers of states with far fewer gates. This efficiency makes the algorithm highly promising, with the potential to impact fields like cryptography, optimization, and search. The quantum computing platforms developed by IBM (Qiskit) [3] and Google (Cirq) [2] have integrated this algorithm as a dedicated gate. Due to the importance of creating uniform quantum superposition states in quantum computing, it is anticipated that the UniformSuperpositionGate will play a key role in a variety of quantum algorithms and applications.

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Freya Shah is a student of Bachelor of Science (Honors) majoring in Computer Science with minors in Physics and Mathematics at Ahmedabad University. She is interested in pursuing research in quantum information. This illustration provides an overview of the quantum computing field, highlighting types of problems where quantum computers could outperform classical ones. It also explores exciting research on a new algorithm for creating uniform superposition states.

Alok Shukla is an Assistant Professor in the Mathematical and Physical Sciences division of the School of Arts and Sciences at Ahmedabad University. He holds a Ph.D. in mathematics from the University of Oklahoma, USA, and served as a postdoctoral fellow at the University of Manitoba, Canada, before joining Ahmedabad University. He has expertise in quantum algorithms and their applications. His notable contributions include the development of efficient algorithms for preparing uniform quantum superposition states, achieving exponential improvements over existing methods.

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