Science with (by) Children

-Anish Mokashi[a]

I was a science teacher for 3 months in a school called Vidya Vanam in Anaikatti near Coimbatore. Vidya Vanam[1] is an English-medium school run by Mrs Prema Rangachary. The school follows the NCERT syllabus and the teaching philosophy is to have activity-based classes and to steadily train the students to appear for the National Open Schooling board exams. Anaikatti overlooks the Ooty mountains and it lies on an important elephant corridor in the Nilgiri mountain range. The Sálim Ali Centre for Ornithology and Natural History and the Nilgiri Biosphere Reserve are close by. The children of the school are first generation learners from the villages nearby and most of them belong to the Irula indigenous community. The atmosphere of the school is one of open dialogue between children and teachers and the children also have a good rapport with Mrs Rangachary (whom they call 'PaaTi' or grandmother). I wish to share some of my experiences with the children of Vidya Vanam which made me rethink commonplace notions of children and science.

A student of physics

As a student in IIT Bombay doing a BTech in Engineering Physics, I felt that my studies were fragmented. We were fortunate to have some amazing professors to teach us. But the various courses didn't seem mutually consistent to us, as if each were talking about a different world altogether. We students were insufficiently equipped to draw the connections ourselves and to find the context. The impression we got was that only after scaling the mountain of the accumulated body of knowledge of physics would we get a chance to work on or even glimpse something we find interesting. Only while working on projects was there space for a more explorative learning process.

At the same time, I was also involved in the environmental justice movement. it was difficult to reconcile the firsthand experience of witnessing the social and ecological injustice on adivasi people and the systemic denial of basic human dignity to them, with the placid atmosphere on campus.

On the other hand, going to graduate school in America was quite enriching - with the intense interesting coursework, the relatively democratic academic setup, the teaching and the experience of working full-time on research doing experiments at low temperatures on 2D electron systems. I believe that exposure to research gives us a general approach for grappling with new learning situations - a confidence to start from almost scratch, to face one's ignorance, seek help, troubleshoot, improvise and at times even completely abandon a particular way of doing things. One keeps learning and applying new concepts and in the end, the process leaves you with a ton of patience besides extending existing scientific knowledge.

After my thesis defense, I decided that I would work on something that had bothered me for a long time - on identifying factors that help people find meaning[2] in/make sense of their studies, especially in science which tends to be viewed as static, depersonalized[3] and divorced from all social contexts. I also decided to work on ways to incorporate practices from the culture of doing research in the way science is learnt and taught.

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[1] http://www.vidyavanam.org

[2] Here *meaning* can be understood in the sense of Dr Viktor Frankl's existential philosophy (Viktor E. Frankl, *Man's Search for Meaning,* many editions, 1946) which claims that the drive for meaning is the most fundamental one for human beings as against the drive for pleasure (Freud) or for power (Adler). It could also be taken in the context of the work of Swedish physics education researchers following the phenomenographic approach, e.g. A. Ingerman *et al.*, NorDiNa **3(2)**, 163 (2007) *(Learning physics as a whole - On supporting students making sense of their studies)*

[3] Derek Hodson, *Teaching and Learning Science: Towards a Personalized Approach*, (OUP, 1998), pp. 9.

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No Fear

At Vidya Vanam, I was a teacher for children between the age of 8 to 12 years who had been in the school for 4 to 5 years. Most of them had no inhibitions about speaking to me - they asked me who I was, what I do, where do my parents live and then they told me a lot about themselves, what they like, who is their best friend and how many siblings they have. In my first class, the eight year olds took an on the spot decision to perform a small group dance for me. They took charge of making me feel at home. There was no fear on their faces or in their speech. Whenever they found something of interest or relevance to the class they would immediately point it out. Quite naturally, they named me 'Anish-aNNa'.

Sound Beginnings

I decided to start with sound - since it is something children can easily relate to and it was also in the list of topics in the science syllabus. I referred to activity-based science textbooks prepared by NCERT[4], HBCSE (Small Science series)[5], Eklavya's Hoshangabad Science Teaching Programme (Bal Vaigyanik)[6] and Arvind Gupta's work[7]. By improvising and at times adapting ideas from these sources, we explored a number of concepts related to sound.

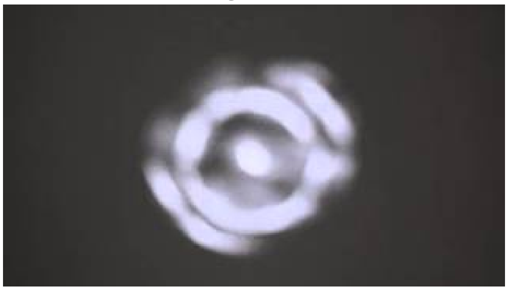
We began with observing environmental sounds in the school - listening intently we noted their direction, traced down their source and drew a soundscape. Some children repeated this observational exercise at home and drew elaborate soundscapes with pictures. A boy of 8, Sabareesh even listed "the sound of a tube-light when it is quiet at night".

The next day, we made drums by tying plastic bags over coconut shells. Some children put a few seeds and small stones within these and made a rattling drum. We explored things around us to make different sounds and also imitated many bird-calls. We could arrive at the idea that behind every sound there is something that vibrates be it our throats or things like a tabla, a guitar string, a rubber band, a leaf/paper whistle. We saw how the pitch changes when we fill water in a bottle up to different levels and blow at the bottle's mouth (Helmholtz Resonator). Once, we used a flute to talk about pitch by playing different notes. They loved to listen to it and literally forced me to play on for a while. I found them quite single-minded in pursuing what they find beautiful.

Bucket art

In the next class, I got a bucket of water to claim that just like waves travel in water, vibrations from an object travel in air and we hear sound, i.e. sound is vibrations that travel.

(click on the image to watch the video)



Coincidently, that day the early morning sunlight was falling on the surface of the water and its reflection was projected on the ceiling. A slight push to the bucket or drops of water dripping from my hand would be enough to create very dramatic and surprising patterns in the projected image.

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[4] http://www.ncert.nic.in/ncerts/textbook/textbook.htm
[5] http://coglab.hbcse.tifr.res.in/download-books
[6] http://www.eklavya.in
[7] http://arvindguptatoys.com

The ripples would show up very clearly in the light and shadow of the image amid excited gasps from the children. We spent some time observing and appreciating this spectacle and I tried to stress on the fact that we were looking at waves.

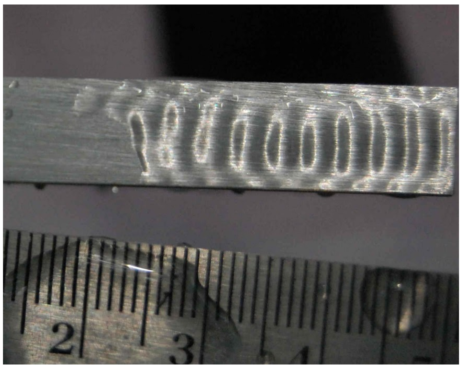
Tuned in

We heard and felt the vibrations of a tuning fork and listened to its monotonic hum. It was a very popular toy among all the children and everyone loved to be tickled when a friend would bring it close to their ears. They made it touch different objects like a plastic bag, a tiffin box, a coconut drum, a pencil box, clothes and so on and listened to the sound due to the induced vibrations. A child described induced vibrations as - “when we touch the tuning fork, the vibrations enter our hands”.

I thought that if we can see the tuning fork making waves in water, it will be easy to connect it to sound waves in air. I held it on the water surface in the bucket and we saw that the ripples it made were very close to each other. This was easier to visualise because of the projected image but it was not as clear as I had expected. In fact, the children were more taken by the way the tuning fork splashed water.

A child named Prasanna Venkatesh (age 12 years) took hold of the tuning fork and while the rest of the class moved on, he kept splashing water. After about half an hour, Prasanna called me, “aNNa, I want to show you this”. He was sitting next to the bucket with water all around. He hit the tuning fork with a rubber mallet and instead of dipping it in water, he poured water over it! I could not believe what I saw. Extremely intriguing-looking patterns were formed on this water as the fork continued vibrating.

(click on the image to watch the video) (Clearly visible crests of the surface gravity waves)



Prasanna was observing gravity waves on the surface of water on the tuning fork which itself vibrates and drives these waves. A high shutter-speed photo revealed these surface gravity waves.

Every year, scores of 11th grade students in India routinely perform the experiment of holding a tuning fork at the mouth of a partially filled water column to find the resonance. But does no one think of simply pouring water on the surface of a vibrating tuning fork? Or no one expects them to?

Can we see sound?

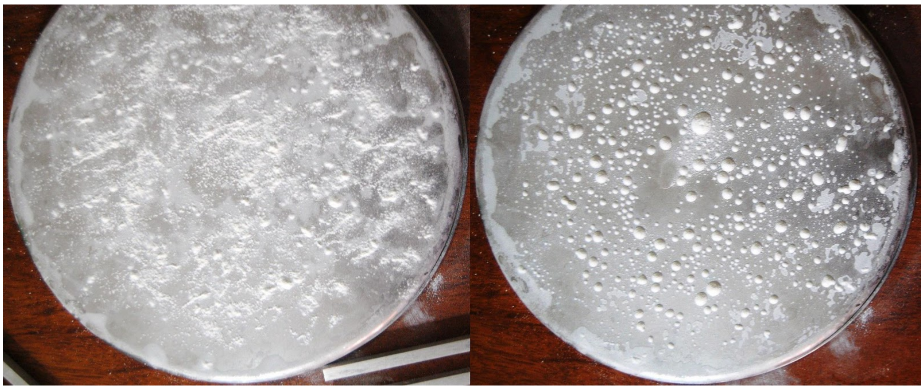
One day I was thinking out loud in class that we can of course hear sound but is there a way we can see it? Someone thought of making smoke and we burnt some paper and held the tuning fork in the smoke. But the tuning fork’s vibrations were probably too feeble to create a visible effect[8]. We didn’t think of plucking a guitar string in smoke which might have been observable. Then out of nowhere, Hrishikesh (age 12) had a Eureka moment and shouted, “aNNa, powder! Powder!”. We got some talcum powder and spread it on an upside down glass. We touched the tuning fork to it but the glass was too massive and nothing happened. Then we used a steel lunch plate instead. This time

[8] Smoke has been used for visualising acoustic waves - e.g. Ming K. Tan *et al.*, Appl. Phys. Lett. **91**, 224101 (2007). *(Direct visualization of surface acoustic waves along substrates using smoke particles)*

the powder moved everytime we touched the tuning fork to the plate. Progressively, the powder collected in patterns of small and large heaps on the surface of the plate and Pavin Kumar (age 12) remarked, "It looks like a butterfly!"

It was a simple way of getting *Chladni patterns* in which we are able to find the anti-nodes[9] of the 2-dimensional standing wave due to reflections from the circular boundary and by observing the positions of the heaps (of varying size) of talcum powder. Later we put powder on a Tabla Baayaan/Dagga and saw the heaps being formed when we make the diaphragm vibrate.

It looks like a butterfly!



After a few days, Prasanna extended Hrishikesh's idea by putting some powder directly on a vibrating tuning fork. The powder collected in heaps that shimmered and moved to the centre line of the tuning fork. It is remarkable to note that Michael Faraday had done the same experiment in the 1830's using lycopodium powder[10] and that it is also a subject of current research.[11] The following passage from Jearl Walker's The Flying Circus of Physics is very instructive in this context: *Dust, being lighter than sand, is affected by air currents that are set up just above the plate when it oscillates. Next to the plate, air tends to move from a node to an adjacent anti-node and then upward away from the plate. Thus, this airflow tends to carry dust from a node to an adjacent antinode, depositing it there as the airflow turns upward.*

[9] J. R. Comer *et al.*, Am. J. Phys. **72**, 1345 (2004). *(Chladni plates revisited)*

[10] Michael Faraday, *Experimental Researches in Chemistry and Physics,* (Taylor and Francis, London 2005, originally published in 1859), pp. 227. *"If a tuning-fork be vibrated, then held horizontally with the broad surface of one leg uppermost, and a little lycopodium be sprinkled upon it, the collection of the powder in a cloud along the middle, and the formation of the involving heaps also in a line along the middle of the vibrating steel bar, may be beautifully observed"* (He notes that it is caused due to induced air currents - the modern term is *acoustic streaming*) Lycopodium powder and talcum powder are of the same particle size range ~ 20 to 40 microns.

[11] M. Dorrestijn *et al.*, Phys. Rev. Lett. **98**, 026102 (2007). *(Chladni Figures Revisited Based on Nanomechanics)* A related phenomenon using micro and nano-sized beads on a cantilever of length 1⁄2 mm length that is vibrated in an aqueous environment. The microparticles accumulate at the antinodes while the nanoparticles at the nodes.

Motion against gravity
Prasanna found that even if we tilt the tuning fork by small angles, the heaps of powder steadily move up the tuning fork against gravity!

(click on the image to watch the video)

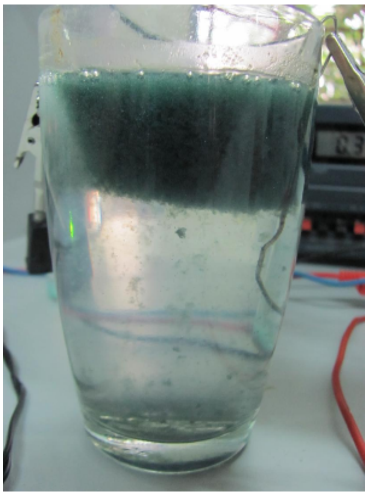
Chemistry and Poetry

Once, preparations for a cultural programme were going on and children who were not taking part were hanging out in the library. Some of them came to the science classroom and excitedly showed me something in a book and told me that they want to try it out.

The children got some water in a beaker, batteries, a small electric bulb, some salt and copper wires. They wanted to do an experiment to see that salt water conducts more electricity than normal water. We wondered what to dip in the water as electrodes and I straightened some paper clips and tied the wires to them. After mixing some salt, we saw tiny bubbles of gas forming around one electrode but the bulb did not glow. Some children joined two batteries in series reasoning that a torch light needs two of them and then the bulb glowed dimly. Now some of them added more salt to the water. The bulb grew brighter and more bubbles were seen. At this point, Pavin Kumar exclaimed, "aNNa, it looks like a waterfall, but upside down!"

A waterfall, upside down

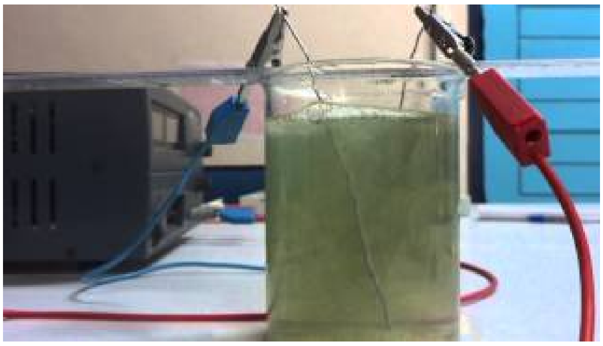
Magic water



We had already verified what we had started out to and I was hoping they would wind it up. But this wasn't enough for them. They were completely involved now. Someone got more salt from the kitchen and kept on adding it and mixing it in and observed that bubbles are produced more vigorously. After a while, the solution got saturated and they stopped adding salt. Then it started changing colour! Amid loud cheers, gasps and exclamations of "magic water", first the solution turned dull yellow, then a faint olive green and finally a dark green (a precipitate that fell off the anode and slowly settled at the bottom as sediment). The next morning, we saw an orange-brown sediment at the bottom of the beaker with clear solution above and a badly corroded anode.

Hydrogen gas is liberated in the form of bubbles at the cathode (confirmed by popping sound produced when a burning matchstick is held over it) and ionised iron atoms from the paper-clip anode enter the salt solution.[12]

(click on the image to watch the video ~3 minutes)



Light and Charges

We made pinhole cameras to show that light travels in a straight line and we saw the inverted image of a candle using paper dipped in oil and dried, as a translucent screen. Some children pierced more than one holes and saw multiple images of the candle on the screen like the effect that is used in movies. We made an aluminium-leaf electroscope using a tiny piece of foil (from a cheese wrapper), placed it on a thick copper wire hook inside a beaker and saw the folds of the foil move apart when we bring a vigorously rubbed comb near the wire. Using strands from old cement bags (Mr Rajeev Vartak's idea), we could understand a lot about static charges. Holding together a number of these strands at one end and rubbing them in a pulling action makes them move away from each other - exhibiting repulsion of like charges. A rubbed strand would be attracted to an 'unrubbed' one as it induces charges on the latter. The rubbed strands are attracted to our hands too and the strands stick to our body like a giant spider or an octopus.

Science in everyday life

Meanwhile, we moved on to other topics. We drew leaves, seeds, flowers, fireflies kept in matchboxes and once a baby lizard which we trapped in a glass. A child got seeds that were called 'helicopter' and showed me how thrilling it is to throw a bunch of them up in the air and watch the spectacle of them descending slowly like helicopters. Another child got a big shiny seed called SooDkaTi (literally 'hot-seed') which gets really hot when we rub it on the floor. Sudharma (8 years) showed me how to make a big bubble by peeling the leaf from the stem of a certain plant and blowing at the sap between the stem and the leaf.

Perceptions of Children and Science

Having gone through graduate school, I didn't expect that school children would have something to teach me. I had arrived with the idea that I will try to bring in elements of research into science-teaching. To observe that children are capable of stumbling upon non-trivial phenomena turned all my notions inside out and upside down. Looking back, I feel that it wasn't just a coincidence that many of the senior Emeritus professors whom I admired for their beautiful work and their undying curiosity seemed to have a child-like playful approach towards doing research.[13]

Probably children are *unassuming scientists*. Even if they can't articulate their findings in scientific terminology, they already possess many qualities that are conducive for doing research. They can

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[12] The precipitate gave a positive test for iron in potassium ferrocyanide + acid solution which changed from colourless to blue. The dark green ferrous hydroxide/chloride precipitate (depending on pH) is slowly oxidised to an orange-brown ferric. There is a risk of chlorine gas being produced at the anode for electrodes of some materials. Thanks to Dr Ambili Menon and Ms Deepthi D R from the Chemistry Section of IISc UG Programme.

[13] Pierre Laszlo, American Scientist **92** (5), 398 (September-October 2004). *(Science as Play)*

think laterally and draw connections, they have patience and persistence, they are neither disheartened by failure nor are they afraid of committing mistakes, they can think as they do and take the next logical step, they can tinker around and they can see things as they are with a very keen observation. Also, they do not have a compartmentalised notion of knowledge enabling them to integrate even science and poetry like Pavin Kumar.

The fact that sometimes children can almost independently uncover or stumble upon complex scientific phenomena makes me wonder whether science should be learnt like the arts[14] where students are expected to do something new. However, 'something new' need not be a discovery every time. It could as well be a new interpretation/explanation, an observation or a novel way of looking at a phenomenon and relating it to other effects.

Now I doubt my original premise. Maybe there is no need to artificially reconcile the pedagogy of science with the actual process of doing science (viz. research). In a way, children already have an inherent scientificness[15] and it is a problem of grown-ups not having recognised and acknowledged it. In fact, many of their sometimes accidental and at times intentional explorations lead to opportunities for new learning. Probably children are often underestimated and grown-ups need to appreciate their abilities. Also, a genuine dialogue between teachers and children in the science classroom[16] can make learning truer to the scientific spirit and also more meaningful for everyone.

Challenges and Hope

Teachers work under tremendous pressures to complete the syllabus. They don't receive much societal appreciation for the hard work they do. In fact, urban India ranks teaching as a low-status job. Schools do not have an atmosphere of (neither the time for) continuous learning and of sharing and discussing ideas and concepts (like that in academic science departments). As a result, teachers have very few opportunities for professional development and intellectual growth.

On the other hand, the conventional approach of teaching science is one of an information deluge of facts. It leaves no time or mindspace for understanding how these facts came to be known in the first place, forget negotiating/testing them out or applying them (not merely in the form of solving numerical problems). The scientific method(/s)[17] is an orphaned concept in the science classroom[18].

For that matter, teaching activity-based science itself is quite challenging as one has to continuously connect the activities to the language of science in written exams. Maybe remaining open to relevant explorations without digressing too much is a fine balance.

Given these multiple challenges, children themselves might help us find a way out. If we choose to listen to them (and modify our attitudes and methods in the light of findings of research[19]).

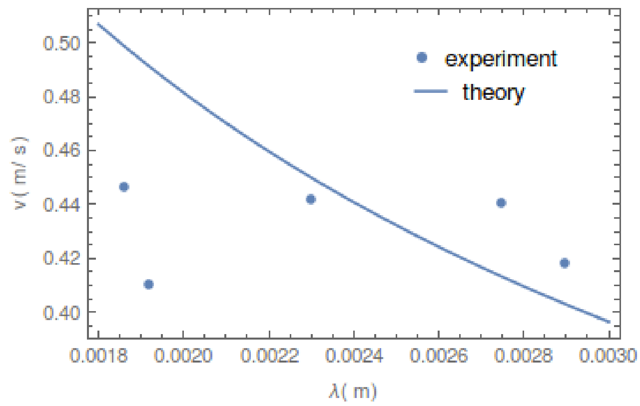
I thank my colleagues at Vidya Vanam and the children for their love and for all that they have taught me.

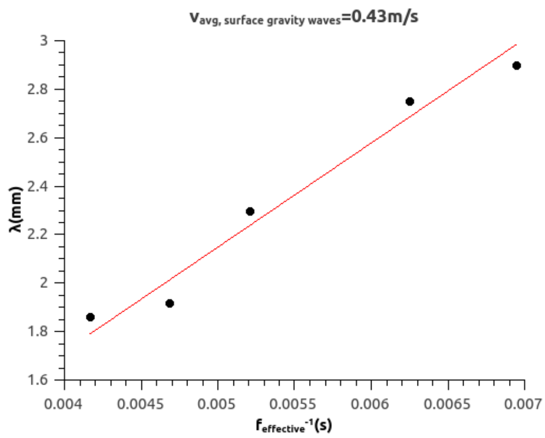
[14] Pablo Picasso's perspective on art and children: *"It took me four years to paint like Raphael, but a lifetime to paint like a child.", "All children are artists. The problem is how to remain an artist once he grows up."*
[15] Christina Siry, Res. Sci. Educ. **43**, 2407 (2013). *(Exploring the Complexities of Children's Inquiries in Science: Knowledge Production Through Participatory Practices)*
[16] Jyotsna Vijapurkar, Learning Curve (Azim Premji Foundation) **12**, 15 (April 2009). *(Listening to Children's Voices in the Science Classroom)*
[17] It is inaccurate to talk of a unique scientific method, e.g. The *real* process of science
[18] Jyotsna Vijapurkar, The Hindu, Mar 2 2007 *(Are we really teaching science in our schools?)*
[19] Kamala V. Mukunda, *What did you ask at school today?: A handbook of child learning* (HarperCollins India, 2009)

Appendix

Surface gravity waves in water on a tuning fork

The frequency of waves set up on a vibrating surface (in which case, the effective gravitational acceleration is periodically varied) is half the frequency of the excitation- a result first noted by Faraday[20] (parametric oscillations). The experimental velocities[21] (with $f_{effetive}=f_{tuning\ fork}/2$) are close to the numerical values of the expected phase velocity of surface gravity waves[22], $v^2(k) = \left[\frac{g}{k} + \frac{Tk}{\rho}\right] tanh(kh)$, where T is the surface tension, ρ density, h water depth (~ 3mm), k wave number. The term, $\sqrt{\frac{Tk}{\rho}}$ dominates given the parameters of this situation. We get a constant velocity for the range of tuning fork frequencies investigated (a good linear fit; R^2=0.96). More systematic measurements are needed as well as theory that incorporates the particular boundary conditions of the tuning forks used.





Motion of powder heaps against gravity

A simplistic way of reasoning could be that the free end of the tuning fork that moves with more amplitude than the rest of the fork (in the principal vibrational mode[23]) represents a higher energy state that more than offsets the difference in their gravitational potential energies. But this cannot account for the formation of the heaps of powder.

On the other hand, the motion of induced air currents (acoustic streaming[24] in the Stokes boundary layer) along the surface of the tuning fork manifested by the motion of the powder heaps (located at antinodes that shift), might inherently be a strong effect compared to the feeble component of the powder's weight down the incline, mgsinθ. This seems to be a more acceptable explanation as heavier sand particles (that should collect at the nodes) are thrown off from the surface of a vibrating tuning fork and only the lighter powder heaps stay along the centre line. This means that the powder is guided by the air currents along the surface which on tilting slightly might be making the antinodes take up an upward motion.

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[20] John Miles and Diane Henderson, Annu. Rev. Fluid Mech. **22**, 143 (1990). (*Parametrically Forced Surface Waves*)

[21] Thanks to Mr Srimurugan V from the Physics Section of IISc UG Programme for assistance in taking data.

[22] H. J. Pain, *The Physics of Vibrations and Waves*, 6th Ed., (John Wiley & Sons Ltd, England, 2005), pp. 169. (Using standard values of surface tension, density of water and acceleration due to gravity)

[23] Thomas D. Rossing *et al.*, Am. J. Phys. **60**, 620 (1992). *(On the Acoustic of Tuning Forks)*

[24] N. Riley, Annu. Rev. Fluid Mech. **33**, 43 (2001). *(Steady Streaming)*