Discovering black holes: A report on the workshops

- Roshan J. Dattatri

Introduction:

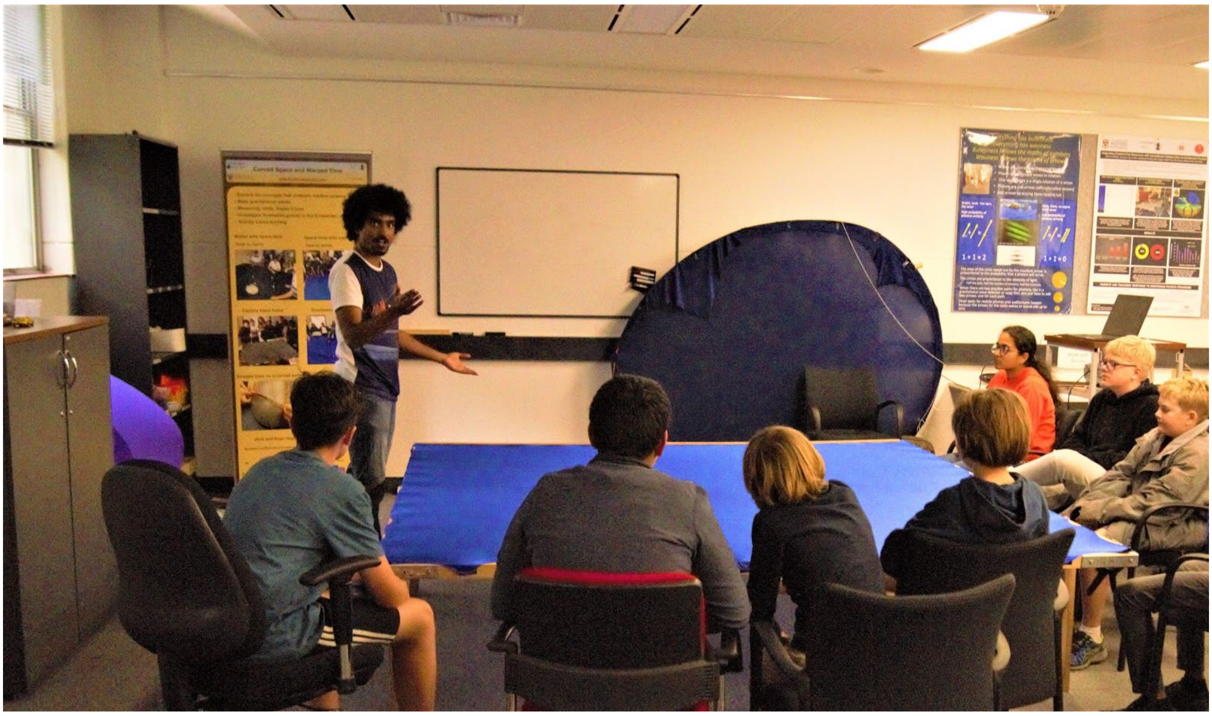
In this report, we will reflect on the program comprising two four-day long workshops, 'Discovering black holes' for school students, conducted from the 29th of September to the 2nd of October, from 3pm to 5pm every day, and from the 6th to the 9th of October from 10am to noon every day. 24 students in total enrolled for this program. This program was conducted in the Einstein-First room in the physics building at UWA. This program was created to teach young students the concepts of modern physics and publicise the Einstein-First Project among students across many schools in Perth and their parents. Using this project, we aim to demonstrate that our pedagogical methods are excellent in teaching school students concepts of modern physics that are conventionally believed to be too complicated for their level. We will look at how the lessons were structured and the feedback given by the students. We have also taken into account the feedback from the workshop conducted in February and we will investigate whether the feedback this year reflects the slight modifications to the workshop. We will also use the feedback to improve the workshop should there be another rerun in the future.

The lesson structure:

In the Einstein-First Project, we employ a hands--on approach in teaching Einsteinian physics. Hence, all the lessons were planned to ensure short periods of active listening and discussion, with hands-on activities at regular intervals stimulating the students so that they do not lose focus by sitting and watching slides for too long. The students were told at the beginning of the lesson what they would learn that day. The lesson starts off by recollecting some points learned in the previous lesson (except for the first lesson) and building on that in a sequential manner to reach a point where we introduce an important concept towards the end of the lesson. Rather than explore the last concept mentioned that day, we withheld its exploration until the start of the next lesson, so that students remain curious and think about it overnight. While there were slides, these lessons were not lectures. The slides were largely images, with a few slides to introduce a topic for discussion. Everything that the students learned, they learned from activities, videos and discussions amongst themselves and with the instructor. During the previous workshop, we had a 5-15 minute break in each lesson, however the feedback reflected that the students were bored during the break, so we did not have a break this time.

Lesson 1:

The first lesson started off with an acknowledgement of country, overview of the workshop and an overview of the first lesson. Then there was an icebreaker activity where the students formed pairs, introduced themselves to each other and then introduced their partners to the class and the instructor. Following this, the instructor led the discussion by asking the students to best try and explain the concepts of space, dimensions, time and mass. They learned how four dimensional spacetime can have all dimensions represented using units of distance, using the relation “distance = speed*time”. This was followed by the introduction of the spacetime simulator (STS). We demonstrated how light travels in straight lines in empty spacetime using pullback cars. Then, by adding balls onto the lycra sheet, we demonstrated John Wheeler’s quote that “Matter tells spacetime how to curve, and spacetime tells matter how to move”. We then asked the students to aim cars at dots on the other side of the STS, with masses placed on the STS. They quickly realised that gravity makes light bend and that the farther you go from the mass, the less the STS is warped and the less the paths of the cars deviate. We also saw how larger masses cause greater curvature and make smaller masses orbit them. We could also see that objects orbiting closer to the larger mass moved faster than objects orbiting at a distance.



Lesson 2:

The second lesson started off by recollecting how distance and time can be expressed in terms of each other if a constant speed is known, this being the speed of light. We defined a lightyear as a unit of distance equal to the distance travelled by light in one year. We found this to be a rather large distance in kilometres, writing which would be a cumbersome and error prone process as one can easily delete or add a zero to the end of the number. Therefore, we established the need for a better way to express large numbers, and hence introduced the scientific notation to express large numbers. Following this, we watched a video to see the size and scale of the universe in powers of 10, and came to understand that the scientific notation is very useful in describing very large and very small numbers. After this, we watched a video showing the sizes of various celestial objects in our solar system, then some stars, supergiants, nebulae, galaxies, clusters, etc. After this, the students were shown a Hertzsprung-Russell (HR) diagram. After some discussion about this, we went back to the STS and did an activity where students place small balls on the STS to simulate particles of gas and dust, which eventually come together under the influence of gravity to form a star with a few planets in orbit around it. Given a clue about how stars form, the students were then split into groups of 3-4 and given a set of 10 flashcards showing different stages in the lifecycle of a star. They were then asked to order them and weave a story about the formation of a star and its lifecycle, which we then use to explain the HR diagram on the Powerpoint and the formation of neutron stars and stellar black holes. Finally, the students at the end of the lesson got to use virtual reality to watch SciVR's bigger than big program and the Starlab program.

Lesson 3:

This lesson was all about black holes. First, we recollected how stellar black holes were formed. Then there was a bit of discussion on the GW190521 event and why there is a forbidden mass range for stellar black holes, which means one of the black holes in the system would have had to be formed by the merger of two smaller black holes in the first place. Then we saw a video explaining the immense mass and miniscule size of black holes. Then we went over to the STS once again and this time, we used the tungsten ball, which was very popular amongst the students because of its weight. This caused a lot of curvature on the STS. We had an activity to demonstrate spaghettification on the STS and repeated the pullback cars activity to explain bending of light to show how gravitational lensing around black holes works. After this, we used the laser pointer and a lens to show what gravity does to point sources of light. Later, we had some pictures of gravitational lensing for the students to look at. It was during this time that Sir Roger Penrose was announced as the winner of this year's physics Nobel Prize, and this was told to the students, and the Penrose diagrams for flat spacetime and around a Schwarzschild black hole were illustrated and discussed using the STS. Finally, we looked at the Starlab program (VR) again, and noted that the black hole is invisible and we would know of its presence only by firing the neutrino cannon and watching the projectile under the influence of gravity. Similarly, we had another activity where we had a wooden board with a number of neodymium magnets taped to the underside. The objective was to roll magnetic marbles across the board and observe any deflections caused by the magnets underneath and then estimate the number of magnets on the board. This is analogous to observing black holes by looking at the deflection of stars when they pass near them. At the end of the lesson, the students were introduced to the concept of gravitational waves.

Lesson 4:

The last lesson was all about gravitational waves and their detection. First, we established that GWs are ripples in spacetime caused by binary systems revolving around each other, with only GWs from binary compact objects being strong enough to be detected. Then we discussed possible ways to detect GWs. We then heard the GW profiles of the 150914 and 170817 events and listened to Rana Adhikari's interview by Veritasium about LIGO and GW detection. We then discussed challenges faced by LIGO by getting the students to try to align a laser beam with the two mirrors of the interferometer, and discussing the rest of the challenges faced by detectors. Later, we demonstrated through soap bubble interference how changes at the nanometre scale can be observed directly. We then saw BBH and BNS mergers on SciVR and observed how these detections are made. After this, we discussed a bit about time travel and warp drive in SciFi using the STS to show compressing of space in front of the spacecraft and reexpansion after crossing the area to appear faster than light. After this, students were encouraged to ask any questions they had. Some topics covered in this section were Hawking radiation and why the planet with the mountain sized waves in Interstellar was unphysical. One student asked about teleportation, but there wasn't sufficient time to explain that. In the last 10 minutes of the class, the feedback was collected.

Feedback:

At the end of the workshop, all the students were given a feedback form each to fill up, so that we know what we did right and what we need to improve for the next time. The questions on the feedback forms are shown below.

1. What is your name? Which school are you from?
2. What topic did you find most interesting during this workshop?
3. Were the lessons fun? Why were/weren't they? Which was your favourite lesson?
4. Were the activities fun? Why were/weren't they? Which was your favourite activity?
5. Was there any topic that you feel we didn't explain well enough? Which topic would you have liked us to explain better?
6. What was the most boring part of the workshop? (You cannot say it was this sheet)
7. Would you recommend this workshop to your friends?

The responses:

2. What topic did you find most interesting during this workshop?

13 out of the 24 participants said that their favourite topic was black holes, which is quite understandable because that is what the workshop was called and hence, what brought them to attend. It is also notable that in the workshop conducted in the second week, the formation of stars was also a favourite topic for 6 out of 10 students.

3. Were the lessons fun? Why were/weren't they? Which was your favourite lesson?

The answer to whether the lessons were fun was a unanimous yes. As for the favourite lesson, there were varied responses. Some said the second lesson was their favourite because of stellar evolution and the first use of VR in the workshop. Others said the third lesson was their favourite because it focussed mainly on the eponymous topic of black holes and involved Penrose diagrams. A lot of students said that the fourth lesson was their favourite as it involved time travel, warp drive and other SciFi. Only one said the first lesson was her favourite because it is where she discovered that gravity and acceleration are indistinguishable for small, closed spaces.

4. Were the activities fun? Why were/weren't they? Which was your favourite activity?

Everyone agreed that the activities were fun because they engaged the students and made them get up and learn actively as opposed to sitting and watching slides. The most popular response for favourite activity was the spacetime simulator, but these were all for different activities on the STS. VR was also a very popular response. There was one response each for soap film interference and for the stellar evolution card arrangement activity.

5. Was there any topic that you feel we didn't explain well enough? Which topic would you have liked us to explain better?

Most people felt everything was explained well. There were two responses about how the topic of warping of time around a massive body was not adequately explained. There were responses that teleportation, virtual particles and quantum mechanics were not well explained, but that was not a part of the workshop anyway and these topics arose due to questions and the instructor did not have the time to answer these questions adequately.

6. What was the most boring part of the workshop? (You cannot say it was this sheet)

Last time this workshop was conducted, most people said the feedback form was the most boring part of the workshop, so this time it was explicitly forbidden, however a few students still wrote that. Most students found trivial parts boring, such as setting up the VR and waiting for the lesson to start. However there were a few responses about the introduction and the slides at the beginning of the first lesson being boring. There was one response each about the long videos and the explanation of the scientific notation (numbers in powers of 10) as the most boring part.

7. Would you recommend this workshop to your friends?

This was a unanimous yes.

Conclusion:

On the whole, I would describe the workshops as a success from which the students learnt about modern physics and were able to visualise and understand the concepts quite well.

Scope for improvement:

In the first week, a nerf gun was within the eyesight of the students. This caused them to be distracted from the class as they wanted to play with it.. This was removed in subsequent lessons. Furthermore, there were very few participants in primary school, which meant those that attended were with older peers. It would be better to have a batch comprising only primary school students so that they don’t feel left behind in a class of older peers which I felt was the case this time.