Theatre as a means of supporting the teaching of science

Light Mystery

A script with added comments

TEACHING ENQUIRY
with MYSTERIES INCORPORATED

Theatre as a means of supporting the teaching of science
Light Mystery - A script with added comments

Authors: Marina Carpineti, Marco Giliberti and Nicola Ludwig
Translated and abridged for use in the UK by Nicholas Sarson, Dorothée Loziak and Peter McOwan

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Foreword

Dorothée Loziak and Peter McOwan, Queen Mary University of London (QMUL),
TEMI project coordinators

This play was developed by three academics from the University of Milan as part of the European Union (EU) funded TEMI project, to allow them to pilot engaging ways to learn about their favourite field of research: physics. Have you ever tried talking about physics without revealing any of its wonders, hoping people will develop a passion for it and for science? How do you engage with people to share your passion of physics? How do you help make young people develop a love for physics studies?

In 2004, Marina Carpineti, Marco Giliberti and Nicola Ludwig, physicists but also work colleagues with a common passion for acting and theatre, embarked on an unusual journey. They created a theatre play to extol the wonders of physics called "Let's throw light on matter" which officially launched their "Physics show initiative".

Since then, they have written seven plays, which they have performed 400 times, and have to date, end of 2015, reached an audience of 110,000 people.

One of the reasons behind their success is their ability to engage with the audience through showmanship, bringing to life the wonders of physics phenomenon such as light or electromagnetic waves and their playful invite to the audience to get involved, and to question phenomenon, a process of engagement that leaves the audience wanting to know.

In 2013, Marina Carpineti and Marco Giliberti started their collaboration with the TEMI project, an EU-funded project, Teaching Enquiry with Mysteries Incorporated. TEMI developed a pilot teacher training course which combines the use of a range of scientific mysteries which were then dissected following the 5E teaching model* (engage, explore, explain, extend and evaluate), the project also included the integration of showmanship or more generally presentation skills to keep the students engaged and finally a gradual release of responsibilities where students eventually lead both the questions and problem solving.

The TEMI course was tested across Europe with more than 600 teachers taking part between 2013 and 2016 and reporting more success in engaging with young people on science topics. Marina Carpineti, Marco Giliberti and Nicola Ludwig adapted the show Light Mystery and made it an integral part of their TEMI training courses delivered in Italy. In the script, they describe how the acts and scenes follow the TEMI methodology**. They worked directly with teachers on the use of science theatre as a novel and attractive means to engage and bring out curiosity, scientific reasoning and literacy in young people.

They have now made the script available to the public and annotated it with useful comments so that it can be used by teachers, theatre companies and school theatre clubs across Europe.

We hope you enjoy the script and that it, or selected parts of it, offer you an interesting tool to engage with students on some fascinating big scientific questions.

* Bybee et al., 2006
** Teaching the TEMI way: How using mysteries supports science learning, TEMI publication

Preface

Marina Carpineti, Marco Giliberti and Nicola Ludwig,
Physicists, actors and script writers

The "Light Mystery" play is a revisited version of the "Alice" shows written and played by Marina Carpineti, Marco Giliberti and Nicola Ludwig from the group "The physics show" of the Department of Physics of the University of Milan.

2015, the year of the show premier, was the international year of light. That explains the title "Light Mystery" in English because it is part of the international project TEMI, and because light in English means both light (and the main theme of the show is light itself) and "lightweight". It indicates the intention of the authors, that the show should be light to watch, entertaining for the audience.

In fact, it does not have any claim to be educational or explanatory but, on the contrary, its purpose is to engage, to trigger questions, to arouse curiosity; in other words to draw people to the world of physics through wonder and entertainment.

The theme of light was also chosen especially because, as mentioned in the show, "light is in front of everyone's eyes" and has many links with other science topics, like chemistry, biology, natural science in general and mathematics.

Contents

I. Introduction to the structure of the play

The Light Mystery play has three main acts, three characters, and three components. It also contains sixteen short scenes which can be used as short stand-alone performance pieces each with an approximate duration of 10 minutes.

The structure of the play allows for modifications depending on interest and topics needed and also provides a tested framework, theatrical staging and dramatic structure for similar plays on other topics such as biology, chemistry or mathematics.

The set up: a secondary school.

The acts:
- Initial test or "engage" step,
- Lecture or "explanation" step, and
- Final exam or "evaluation" step.

The characters:
- Marina: dedicated, smart and likable, but with an ingrained and traditional vision of what it is to be a school teacher
- Nick: the stereotype of a somewhat detached and eccentric university professor
- Mark: a free thinking proponent of creative approaches and enquiry-based discovery, and with a mysterious past.

The play elements:

The basic overall plot: an alleged alien (Mark), a university professor (Nick) and a teacher (Marina) find themselves by chance together with a secondary school class, in the midst of traditional teaching and an exam. Through a series of fun experimental adventures and engaging stories they explore ideas around the properties of light and the electromagnetic spectrum. Finally, at the end of the play, the true nature of the alien, Mark, is revealed.

The pedagogic themes: the play is a critical analysis of the strengths and weaknesses of traditional by-the-book teaching methods, a pedagogy where the teacher explains topics and gives answers to questions students have not even asked. This counterpoints the other approach that runs through the play, around enquiry-based learning, where the students undertake their own research to explore and understand the topics.

The scientific theme: the focus is on light, in the context of the wider electromagnetic spectrum.

II. List of the scientific material used

Note: the actual equipment required will depend on the scenes selected for performance. If specialist equipment is not available the scene may be omitted. Suggestions are given as to how to theatrically 'fake' prop equipment.

- Inclined plane with bells
- Large LED sign (the sign reads when illuminated: "Light")
- Vertical plexiglass mirror, size 100cm x 60cm mounted on wheels.
- Thermal camera and metal mirror
- Reuleaux triangles (see https://en.wikipedia.org/wiki/Reuleaux_triangle)
- Wave pendulums (see http://www.arborsci.com/cool/pendulum-wave-seems-like-magic-but-its-physics)
- Laser pointers
- Fog machine
- Diffraction grating
- LED or halogen lamp + power supply battery (12 V)
- Laser show (if available, otherwise a rapid sequence of dramatic stage lighting can be used)
- Two polarisers
- Three-LED ball (these are balls with RGB LED in them which can selectively be switched on and are available from scientific equipment sellers e.g. http://www.teachersource.com/product/mysterious-glowing-ball/light-color)
- Plexiglass bowl (approximate size: 40cm x 20cm, thickness 5cm)
- 3 irregular cylinders. (These are hollow cylinders of approx. 15cm radius and 50cm length, one empty, one containing sand and the third one containing a heavy object fixed to a point on its inside wall)
- Cellulose acetate disks and oil with equal refractive index.

ENTRANCE

[When the audience enters the theatre, the ushers hand out a test, attached here as an appendix. The test is to be completed before the show starts.]

Comment: The purpose of the test is for the audience to experience what it is to be a student taking exams.

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PROLOGUE

Scene 1: A visitor from space?

Comment: This first scene introduces the audience to the curious character of the "alien" (Mark). This character will only reveal his true self explicitly at the end and will until then, carry an air of mystery. Only the audience see him appearing. From the beginning they know that Mark is an alien, while the other characters will be blissfully unaware of this fact before they eventually uncover the surprising truth. The alien uses an accelerometer to measure local gravitational acceleration to help him ascertain which planet he has landed on. The scientific theme of gravitational acceleration will be revisited several times during the show. The gravitation theme is included as it draws on familiar knowledge of a phenomena studied in all high schools and allows us to find surprising connections with light later in the show.

[Lights off, green light and suitable laser or stage light show; Mark enters with his back to the audience, he turns with a leap. With a complex looking sci-fi looking laser instrument (this is simply a mocked up fake) he takes measurements, then frustrated he throws the instrument up high and times its fall, as if it were an accelerometer.]

Mark: What is this place? Where am I? *[He uses the laser to make measurements.]* Interesting! Gravitational acceleration here is 9.8 m/s^2… exactly the same as the planet Earth, but where on Earth is anyone's guess. There must be someone else around…

After all that travel, I'm starving... Should be some food round here somewhere. This planet seems to be Earth-like after all. *[Looking again at the instrument display]*

Gravity… *[He leaves stage singing]* ♬ ♬

♬ ♬ It's not only falling from a tree… Nor the transpose of a tensor field oh gravity, oh gravity!

Comment: The song should be a playful wink at the theories of gravitation in history, from the famous Newton apple to the gravitational tensor and warped space of Einstein's general relativity. The song is sung to the tune of "Yesterday" by the Beatles.

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ACT 1: A TESTING TIME FOR ALL

Scene 2: Enter our three characters

Approaching the audience

In this scene the three characters are introduced.

The alien Mark appears to put all people on the same level (calling everyone by their first names) and above all, seems not to know what a school is. He does not understand what a test is and all of his activities are defined by experimentation and direct measurement of data. He loves playing and introduces an interesting mathematical game that challenges and engages the audience. The game is called the four 2's, and it can also be used in the classroom as part of a student-focused mathematics lesson. It allows students to play with figures and can help introduce numerical properties in a more "natural way", for example exponentiation, factorial, summations, and even logarithms and their properties.

Professor Marina is tidy and abides by the rules. She wishes to draw her students to her subject. She wants to prepare a lecture on light, and is looking for a mystery to start from, to catch the attention of her students and give them a glimpse of the beauty of physics she knows to be there. But, as we will see later, she cannot help adopting a traditional approach, where the knowledge to be imparted to students is already written and is not discovered and learned by posing questions challenging the world.

University Professor Nick is a funny but egotistical scientist. From the very start he is excitable and very talkative and sadly not a good listener. He is not particularly interested in what happens socially around him, and rather annoyingly he has a ready explanation for every phenomenon he observes around him. For him, students are just a means for him to bask in his superiority. He does, however, love the media spotlight. He will remain distrustful of any scientific method challenging his chosen approach. For example, only at the end will he accept that it is good to play the mathematical 2's game, but this is mainly because of the fondness he feels for Professor Marina.

[Lights on, Marina is dressed as a teacher ready for lessons.]

Marina: Can someone turn the light on? *[She sees the fog.]* Ah, the janitor's bonfire, someone must have left the door open. Every year it's the same, the smelly cremation of his wet leaves… Oh well, time to get on….

Good morning students. On your chairs you will find your exam. When I say "begin", you will have 20 minutes to complete it. "Ok, begin. And no copying please!" *[We are at a secondary school and teacher Marina watches while the audience take the test. Marina tries to help the students a little by offering some explanation, but nothing she says makes any sense.]*

As you can see there is only one physics question. It is pretty straightforward. You can solve it two ways: either by using Maxwell's equations with the proper boundary conditions or, if you want to take the easy option, by using the Poynting vector. Remember, the school management has a target to be in the top decile of the national science league table, and we can't disappoint them.

Comment: Marina's comments about physics are correct, but are absolutely inadequate and far too advanced for secondary school students, who hardly know Maxwell's equations and certainly do not know about the Poynting vector. The objective here is to make the audience feel a little uncomfortable, and aware that the teacher is clearly not getting the level correct.

[Enter Professor Nick (holding an iPad-like tablet that he frequently looks at) to hold a conference. Upon his entrance Nick places the thermal camera pointing to the audience and approaches Marina.]

Nick: Marina, how are you? It's been a while! Thanks for inviting me along today! It's always such a pleasure to speak to your students about my research. It's good to get away from the university just for a while, and into our local schools…

Marina: Sorry Nick? I wasn't expecting you.

Nick: Really?! But I'm here for the conference on the applications of thermography to animal emotions!

Comment: The theme of thermography applied to the study of animal emotions is a real field of research, even if in this theatre setting it is treated as a joke. Defining the character in this case is done by presenting his very original field of research and thus making the scientist, albeit bizarre, fully authentic.

Marina: Well, I don't know what's going on. But today our students are sitting the exam for the year's new revised national curriculum in General Science, the replacement for last year's less new and revised national curriculum in General Science.

Nick: *[Not listening.]* Super… super…Ah, although it doesn't look like there are any animals here, the audience you have gathered are an excellent sample – perfect for illustrating my research on the thermo-imaging of animal emotion. *[He approaches a person in the audience.]* For example, I can tell that you are experiencing heightened emotions. You are radiating heat, which suggests that you are very excited, perhaps because you finally get to see me speak live!

Technical note: If it is not possible to borrow a thermal camera, a prop camera can be used, and thermal images sourced from the web can be projected on a side screen during this part of the show so students are aware of what thermal images look like.

Marina: Yes. Or maybe because they are in the middle of an exam and you're distracting them.

Nick: Vasodilation, which causes the heating up of skin, is a clear indication of the emotional state of an animal. I have studied this particular effect on rabbits and pigs – both highly emotional creatures. I tell you what, the easiest way for you to understand my work, is to watch this real-time film I did for the Discovery channel documenting the life of a pig on road transport over a 24-hour journey…the first film of its kind.

Marina: *[A little upset.]* Excuse me Nick, that's all very well, but WE'RE IN THE MIDDLE OF AN EXAM!

Nick: I'll just get it started. *[In the meantime he fumbles about and a film on pigs starts.]* AND THAT'S THE PIG! Do you see how her ears warm up as she gets onto the lorry? It's an index of their emotional state.

Marina: *[She gets in front of Nick and shows him the paper with the questions.]* WE'RE IN THE MIDDLE OF AN EXAM!

Nick: *[Suddenly he changes his attitude and acts as an examiner.]* An EXAM! Why didn't you say something? You know I love a good exam! BUT HOLD ON: THEY'RE ALL COPYING EACH OTHER! No wonder they haven't got a first clue by the time they get to university.

[He makes people in the audience swap seats.] YOU MOVE! SIT HERE!

[Improvisation….]

[Later Mark also arrives.]

Mark: Erm hello! I just wondered if you know if you have any food around here? Excuse me, do you have any food? A bar of Plintomag would be ok. Yumm, anything?

Marina: *[Exasperated by the constant interruptions.]* Excuse me? Firstly, what are you doing in my exam hall? Secondly, what are you talking about? And thirdly, and perhaps most importantly *[beat]* … who on Earth are you?

Mark: *[Turning as if to find a 'you' and then turning again to Marina.]* Me? Who am I?

Nick: Yes, you!

Mark: Me? I'm Mark.

Nick: A professor, no doubt?

Mark: Not at all! My name is not Mark Professor, you may have heard of me?

Marina: Well, you must be a doctor of something.

Mark: No, I am not a doctor. I am a physicist explorer!

Marina: *[Whispering to Nick.]* I bet he's an Ofsted inspector… *[More loudly.]* Ah, so you are here to invigilate the exam!

Mark: I don't know. What is an exam? Do you mean a kind of experiment?

Marina: *[Quietly.]* That's probably some kind of Department of Education joke… or it may be a rather frightening policy statement! *[More loudly]* My name is Marina, this is Nick. Thanks for offering to help. Please make sure they don't copy each other.

[Marina and Mark approach the audience fussing and cajoling, making sure they do not copy.]

Mark: Copy what?

Marina: Each other's answers. You, please, move.

Mark: *[mimicking her voice and manner]* Right, you, please, move.

Nick: *[wanting in on the act]* You two, swap seats, you look as if you're both up to something.

Mark: *[mimicking his voice and manner]* You two swap seats you look as if… *[returning them to their previous seats.]* hummm … do you have a slice of Pirot cake?

[After rearranging and quieting the students, Marina and Nick wearily sit down at the table and quietly start to exchange pleasantries to break the ice. They notice Mark is still lurking looking awkward]

Marina: Mark, come sit with us. So, tell us about yourself. Where are you from? How did you get here?

Mark: *[Approaching the table.]* Well, to be honest, I'm still a bit confused. I'm trying to understand this strange place. I'm taking a few measurements. *[Showing the sci-fi looking unearthly instrument prop used in the prologue.]*

Marina: Ah sure, we know how you feel. The world of education, and especially this secondary school, is like a parallel universe, isn't it Nick?

Nick: Absolutely. I mean I teach at a university, and even I feel like someone from another planet here!

Mark: Exactly what I am! I don't even understand what you are saying: school? Secondary school? University?

Marina: Ah, very funny! *[Aside.]* Another one of those Ofsted jokes.

Nick: He must be from the private sector or …. even perhaps … *[beat]* industry.

Marina: Brilliant! Perhaps I can draw on his real-world experience, his industry-standard transferable soft skills, and his no doubt extensive professional networks to help me prepare my next set of lessons.

Mark: What do you mean by lessons?

Marina: This term, I want to tackle the concept of light and I want to introduce it starting with a mystery... a mystery, to excite and intrigue.

Mark: What mystery?! Light is here – in front of our very eyes. Why don't we talk about gravity instead? Much more interesting. By the way, I've just checked, and gravity here is $9.8\ m/s^2$.

Marina: Well, we are on Earth…

Mark: Ah! I knew it!

Nick: *[Rushing and standing among the audience.]* Stop it, don't use this distraction as a chance to copy your neighbour, I saw that!

Marina: Gravity is all good and well, but we're not studying gravity. Now light, light is a wonderful physical phenomenon… and what's more, the EU has financed a research project on it.

Nick: Interestingly in my conference, and guest appearance on Blue Peter I was going to use my thermal camera to talk about light, invisible light, but light.

Marina: Please, be serious, I really have to prepare my lessons. *[She moves away.]*

Getting to know you: the four 2's craze

Mark: Please, don't go, you both interest me. Let's play a game to get to know each other better! What about four twos?

Marina: Is that a card game? ...An app? I don't know it. And I've got lessons to prepare *[complaining]*.

Mark: You don't know it? But it was invented on Earth. Everybody plays it at home, don't they? *[To the audience]* The homes of planet Earth must be full of the joys of solving mathematical puzzles? No? Strange… well the game, was invented in the German town of Gottingen by a small group of excitable theoretical physicists. What you have to do is to make every integer out of exactly four 2's using simple mathematical functions.

[He takes a piece of chalk and writes on the ground, because it gives him unrestricted space to write long equations]:

$$0 = \frac{2}{2} - \frac{2}{2}$$

Marina: Mark! Please use the blackboard.

Mark: But there is less room! … OK. Your turn Nick!

Nick: This is easy! So: 2 … *[Writing on the blackboard]:*

$$2 = \frac{2}{2} + \frac{2}{2}$$

But that's five 2's. Is that wrong?

Mark: Not at all! Only numbers to the right matter.

Nick: OK, I'll try 3… 3 = 2x2 - 2/2

[Marina suddenly lights up.] Wait a minute! We are already at number 3 and we have skipped number one! There... it could be *[writing on the blackboard]:*

$$1 = \frac{2x2}{2x2}$$

Mark: You, you in the seat there, come and do 4! *[Calling a person from the audience to the blackboard and, if unsuccessful, calling another. They go onto other numbers]:*

4 = 2x2x2/2

5 = 2x2+2/2

6 =2x2x2-2

7=… *[Mark coughs and shuffles his feet and moves on to 8 hoping no one notices]*

8= 2+2+2+2

9= (2+2/2)2

Comment: The four 2's game is a mathematical game to show that the feeling of solving a mystery isn't only possible through performing striking and strange experiments. Children, and most people in general, engage intellectually with things that at first sight appear to be "useless", before the wider applications can be explored.

Number 7 is, in fact, a little more challenging to write than the others using the four 2's. This is an interesting fact that will be reflected on during the show, but will not be solved. Only at the end of the show, and only if people in the audience ask, should the answer be given … You have to arouse curiosity and questions before giving answers.

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Scene 3: Risky business

Marina: Maths games are all good and well, but I still haven't prepared my lesson on light! *[She goes off into a corner while the audience play four 2's with Mark and Nick. After a while Nick joins Marina at the table.]*

Nick: *[Nick offers a cup of hot tea to Marina, in readiness for him to impart his wisdom to her.]* Oh come on, just say the usual stuff. Light travels in a straight line. Reflection and refraction. Total reflection. Then move on to wave motions, diffraction, interference, and end with polarization. Easy.

Comment: What Nick has just proposed is a "usual" lesson on light. Correct, but maybe also a little dull for those who are not already motivated. Marina is looking for something more engaging.

Mark: *[Wandering over and joining the conversation.]* Well, light is an area of science with practical applications like high-speed optical communications and pop band stage shows. And these days, that's all earthlings… *[correcting himself]* ah …people care about. For research to be valued it seems it has to be 'useful', with a practical application that it solves, what you call 'a real-world problem'. I wonder about the pure research on this planet, – science for science's sake? I tell you what, that nice Mr Newton wouldn't get funding for apple trees today.

Nick: *[Offbeat look, then ignores the last comment]* You're right, Mr Physicist Mark. Applied science! My latest and currently greatest invention was only possible thanks to the great discoveries of Marie Curie… if she hadn't discovered radioactivity in the early 1900's my invention would never have come into being.

Marina: And what have you invented?

Nick: Radioactive tea. *[Pointing to the cup.]*

Marina: *[Spitting the tea into the cup.]* What?!!!

Nick: *[Standing up and going near the Geiger with a can.]* Didn't your mother teach you not to spit?! Yes, radioactive tea. Say you wake up, really wanting a cup of tea, but you don't know if you have any left and you can't be bothered to unscrew the tea jar. What do you do? Well normally you'll have no choice, but with radioactive tea you can go into the kitchen with a Geiger counter like this and check if the tea is used up … without even opening the jar! A brilliant invention.

[Bringing the can close to the instrument that suddenly goes off.] See here, there's still some left.

Comment: This is a mockery of the stereotype of the ivory towers university professor inventing useless stuff and not being in touch with reality.

Technical note: The Geiger counter is faked, and simple sound effects can be played when the can approaches the fake device.

Marina: *[Marina approaches in order to take the tea caddy.]* Give it to me a second.

Nick: Why? I told you there's still some left. No need to open the jar. Plus, it's radioactive.

Marina: *[Opening the can to remove what looks like rod of radio isotope (a prop cardboard tube faked with appropriate stickers).]* This is a radioactive stone. Are you crazy?! This is dangerous.

Nick: *[Throwing the tube into the audience]* Well, I admit... the invention needs to be perfected.

Marina: If you're finished irradiating my pupils, I've got to prepare this lesson on light. Stop distracting me!

Mark: How's he distracting you? All the light coming from the universe, whether from the Sun or the stars, comes from a nuclear birth, like radioactivity. My data feed shows that at the centre of the Earth there is a huge nuclear reactor.

Nick: See, Marina, we are surrounded by nuclear reactors, we're standing on a nuclear reactor. Maybe this gentleman works in a nuclear reactor, there is an odd glow about him, and you are worried about my tea? How risky can it be?

Mark: Well, the risk obviously depends on the length of exposure, and on the rate of absorption. There are a lot of factors involved, and your history shows radioactivity can help cure humans as well as hurt them. *[He approaches a person in the audience.]* Excuse me, do you have some slumdring? I'm very hungry … *[He keeps bothering the audience looking for unknown type of food.]*

Comment: Mark's behaviour, keeping asking for food while talking to the audience, in addition to creating interaction, comedy potential and making the show livelier, has an additional psychological reason to be included. It is possible that someone in the audience might feel that they cannot follow all the scientific arguments and feel out of place. Being given a safe space by Mark with his absurd requests for unknown type of food can give this person an excuse to say they "missed" some parts of the conversation without fear of feeling unable to follow the explanations in their entirety. This aspect of the play highlights how the use of interactive theatre and comedy can help diffuse tension in learning for some.

Marina: OK, let's make things clearer for the students or they'll get confused: so the extent of a risk is assessed as the product of P by D. *[Writing on the blackboard]* R=PxD. With D being the damage from an event and P its probability. There is a product: R may be small if either one of the quantities is big, and the other small. But there may also be few cases of infinitesimally low probability, but huge risk. Think about the Large Hadron Collider, the CERN laboratory accelerator built under Switzerland where the Higgs boson was discovered. They used it to recreate the conditions of the Big Bang, but some people were worried that they might unintentionally create a black hole!

Mark: Yes records show that many people weren't even interested that you discovered the Higgs boson! Some news outlets said the particle could one day be responsible for the destruction of the known universe, where a vacuum bubble expands through space at light speed and … puff! The universe is wiped out! But any physicist knows that the likelihood of this happening is pretty much nill!

Marina: Yes… it's all about probability. But what about the potential damage? In the very remote possibility that the universe did disappear into a black hole … well, I'd say that kind of damage would be considered quite bad...

Mark: Arguably every time we do an experiment, however trivial, we could discover anything! *[Addressing Nick.]* Take, for example, a bean plant. Cross breed it with another bean plant. What would you expect?

Nick: Ahhhh… A new kind of bean plant? ... *[Starting to take notes in the notebook.]*

Mark: But what if, due to some odd statistical fluctuations, a vacuum bubble grew? Or a black hole?

Marina: Impossible!

Mark: Well the probability is very low, but it may never be zero until you do the first experiment. And even if a small black hole did grow in a particle accelerator, we wouldn't even notice! It would be so light-weight and move so quickly that it would distance itself from the Earth in a fraction of a second. Even if a few thousand atoms were swallowed into that black hole, no one would notice. Because the usual sized objects you are dealing with day to day contain huge numbers of atoms: there are over one-thousand billion atoms in just one sip of water. So what's a few thousand atoms between friends?

Nick: *[Writing]*… Sip…

Marina: Perhaps, but the perception of risk is very different, people worry. It's the same with nuclear power plants. They can provide the energy we need but the extent of the damage in the case of an accident is practically incalculable.

Nick: … Incalculable…

Marina: Radioactive contamination lasts for hundreds of thousands of years... There is a low probability of a catastrophic event... but, if it does happen, enormous damage...

Nick: … Enormous…

Marina: And that is why an insurance company will never insure a nuclear power plant.

Mark: An insurance company … what's that?

Marina: Ah … indeed… *[Nick's telephone rings, he is being interviewed about nuclear energy.]*

Nick: *[On the phone.]* Good morning, good morning… Excuse me Marina, it's the BBC, they want to do a telephone interview with me.

Mark: *[While Nick is talking, and addressing Marina.]* Could someone explain to me what the BBC is?

Marina: *[Grumbling exasperated.]* Eh?

Nick: Yes, of course, the interview on the new frontiers of physics: we are talking about accidents at nuclear power plants. And of course, the calculation of risk. *[He talks into phone to a reporter on the end of the line]* Yes, well the risk is calculated as the product of PxT... Yes… Damage is incalculable, … yes…. Contamination damage lasts for millions of years...you can quote me on that… fantastic!

Marina: if you are quite finished playing the media star, perhaps we can get back to our discussion!

Mark: *[Thinking she is referring to him.]* Is a media star some kind of giant out of control stellar phenomena?

Nick: Well, see, European physics reportedly has always excelled in this field until the Large Hadron Collider, certainly well known by our radio listeners. In the Big Bang experiment at the Geneva CERN laboratory when a small and delicate vacuum bubble will be born, we will not even notice, it is vacuum… and even if the Universe disappeared, it would be … like drinking a sip of water! Like a bean, a black hole!

Marina: What are you saying? You did not understand anything.

Nick: *[Ending his phone call with gusto and ensuring the others hear him]* …. Of course! … The appeal of these subjects to the public … pardon? … whales? Ah yes, I'm sure I could provide informative comment, thank you … yes, I do have a fine speaking voice … yes fine then, talk to you on Sunday for the interview on the white whales of Kamchatka? Yes, I am sure I could cook up my favourite dish live too… strictly… well I have been a medal winning ballroom dancer in my time … Ok speak later, goodbye.

Mark: Are you a cosmologist?

Marina: He is a complete fraud!

Nick: Not at all! *[Addressing Mark.]* If I talk about the white whales of Kamchatka, am I a marine biologist? I am a sought-after polymath and natural scientific communicator! *[To himself]* Must remember this time to check, they report it is whales not snails that are migrating South in the ocean.

Comment: The radio interview is a reference to the willingness of many scientists to communicate their work, but also being expected to be able to communicate the work of others to the general public and the press. It also reflects the media's quest for sensation and their frequent lack of scientific background that sometimes leads to spectacular misreporting that hits the headlines. It also satirises the current trend of media friendly 'star' scientists who often appear as guests on shows where it is about personality, and any science is often dumbed down or takes a back seat.

Marina: STOP NOW! Put your pens down. It is time to hand in your answers! *[Addressing the audience.]*

Nick: Come on… *[Marina and Nick collect the tests.]*

Mark: *[Aside to self]* I must resume my game of four 2's, if I find the solution to 7, I will be popular.

[He cannot solve 7 and goes to help Marina and Nick collect the tests.]

Scene 4: Storytelling in the dark

Comment: during the returning of the copies of the tests, the light in the room goes off. Ultra violet lights turn on and by doing so pick up some florescent elements on set. The darkness and suitable music will indicate to the audience that a fairy tale is about unfold.

"Who turned out the lights? Where I come from, we tell stories when it's dark", the alien prompts Marina, and Marina feels she needs to oblige.

The narration is accompanied by the actions of Mark and Nick who are drawn into act as two characters living in a world from which the sun has disappeared many years ago.

Mark and Nick's hand gestures help to show the various properties of light that are displayed.

As each optical phenomenon is demonstrated, ghostly voices echo the name of the phenomena.

At the beginning, a small dot appears on the wall. It is the reflection diffusing on the coarse surface of the wall of the light emitted by a green laser, which stays invisible until small droplets of water and then some fog are sprayed along its route. That is the phenomenon of diffusion, which makes a bottle full of milky liquid light up like a bulb shortly thereafter.

Next there is refraction (the laser is expanded using a lens), specular reflection and diffraction grating which multiplies the light beam. These are simple experiments, performed with small common objects, but that is the reason why the approach is effective. The audience listen attentively and are in awe of the magic created by the small hand motions, sensing science behind them.

Comment: This story is an example of showmanship through storytelling. It may be taken out of the show and used in class as a self-contained activity to engage with the topic, for example having it played by students who may then be intrigued by the story and the experiments and decide to learn more about the topics covered, and talked through again in detail when reflection, refraction, diffraction and interference are explained. An additional opportunity is to give students the story as an example and ask them to invent a new one on a different science topic.

[The lights go off with clatter. General shock. A few seconds of silence, then a mini crisis.]

Marina: What's happening?

Nick: Who turned out the lights, why is it dark?!

Mark: Why?

Marina: Mm, mysterious.

Nick: Is there an electrician in the room?

Mark: *[He moves to carefully stand in front of the table.]* Be careful Marina, I can't see you, where are you?

Marina: I'm here; coming. What should we do?

[Marina, Mark, and Nick go back on stage.]

Nick: Marina, this is an opportunity. Darkness must help you shed some light on your light? You must have that lesson ready by now?!

Marina: You didn't let me prepare anything! White whales, four 2's, the Large Hadron Collider, black holes and your career with the BBC. You keep distracting me!

Nick: Come on, it's just a lesson! Say the first thing that comes into your head.

Marina: That is not how lessons are delivered!

Mark: It's dark here… Where I come from, when it's dark, we tell stories.

Nick: A story! Great idea! Will help me practice for any CBBC shows!

Marina: A story? Are you joking?

Nick: No! Marina, tell us a short story, you are great at telling stories. I'll be taking notes!

Marina: *[Baffled]* Okay… *[starting in a low voice and gradually getting carried away by the story, in the room the light is dim.]*

Marina: Once upon a time….

Nick: *[Interrupting]* In a galaxy far, far away?

Marina: *[Starting again, after giving him a dismissive look]* Once upon a time there was a sun-less town. It hadn't always been like that. The old folk talked about a long-ago time when a very bright star used to shine in the sky, when the world was full of colours, warmth and fragrances.

But one day something came between the star and the land and the sky slowly darkened. Now the sky was filled with many small remote stars which only spread enough scattered light to let people walk along the roads. People's houses were lit by small bulbs, but their light couldn't be too bright, for fear of hurting their eyes.

Life had changed a lot from the golden age the old folk used to talk about, but people get used to anything and those who had been born in this new world lived without worry and without knowledge of what they were missing. One day, on his way to school, a boy saw a small dot on a wall which he hadn't been there before.

[Mark starts moving like a school boy, pointing at the small dot on the wall. A green laser turns on off stage, hitting a vertical wall on stage.] It was different from anything else he had ever seen in his entire life. It looked like a star, but it was on the wall. And it was green, but he had never experienced such a green. He moved closer, full of curiosity and… the small dot disappeared.

[Mark moves closer to the wall and his body intercepts the laser that the audience now see on his bum.] He looked for it up above. And down below. But the small dot had gone. He walked away filled with sadness. But then the small dot was back. He saw a friend come and called to him:

Mark: "Come here! There's a small bright green dot on the wall; it looks like a star and when I move close it disappears." *[Mark gestures to Nick and repeats the previous scene.]*

Nick: "But I can see it there on your back; or rather, on your bottom!"

Marina: … They tried to grab it *[Mark and Nick try to grab it and slowly move away from the wall]* until they decide to look where the beam is coming from. STOP! That small dot is a beam of light that has come to rest on our wall. It may look delicate and shiny, but if you look straight at it, it can burn your eyes. We need to understand where it comes from without looking straight at it! *[Marina uses a spray to make the light beam visible. The fog machine starts.]*

They soon understood that the light beam came from a far-away place, just above the line of the horizon. Soon a small crowd of onlookers gathered around them. They all said the same thing: we have to make this spot of light bigger so that it lights up amore of our wall. *[Nick places a lens on the ray that is expanded.]* The light had spread over more of the wall as they wanted, but it had become less bright. *[Nick removes the lens and the small dot is back on the wall.]* They said: "We have to move it to where we need it, where we can each look at it". *[Mark, using a compact mirror, reflects the laser light so that it shines above the heads of the audience.]*

But everyone wanted it in a different place. *[Marina uses a C-shaped, curved plexiglass mirror, to cause the ray to make multiple reflections.]* Someone tried to put the green light in a bottle. *[Mark intercepts the laser using a glass bottle full of water in which some milk is dissolved, and it completely lights up like a green bulb; then he removes the bottle as if taking the light away inside the bottle.]* But he could not take it away. *[Mark repeats the action.]* "We have to split it, so that there is one each." *[Marina uses a diffraction grating to divide the beam into many other light beams.]* Little by little, the small dots started multiplying and after a while the entire wall lit up. *[Marina and Nick point two lasers, with an in-built grating that multiplies the beam, on the sides and above the heads of the audience; the fog is also used to view the rays.]*

The people looked in wonder, each in their heart hoping that this new light was an omen that meant that the sun would slowly return to warm the earth. *[A moment of poetic silence …]*

Let us hope that it will.

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Scene 5: Lighting the colourful way to renewable energy

Comment: This section covers, in a playful manner, current science issues, such as energy problems, and cultural issues such as colour theory, looking at them from unusual perspectives and related to the development of new technologies. The main highlight is that, in strictly energy-related terms, the conversion of potential energy derived from the normal motion of a person into visible light energy is enough to light up an entire theatre! And, implicitly, most energy problems affecting contemporary society are caused by the waste of resources rather than their absence. The subsequent praise of the LED, a visible light source that converts most electricity into visible energy, results in an appealing experiment on additive colour mixing. Three colour LEDs (RGB) – flashing at a higher frequency that the human eye can resolve (persistence of vision) – are placed inside a little ball to make it look white when it is stationary, but radiates different colours at different points in space when it is moving.

Nick: Well done. *[Clapping with difficulty.]*

Mark: That was a really beautiful story: it raises a lot of questions! For example, what are those small dots of light? Are they maybe a diffraction phenomenon?

Comment: Mark's previous line underlines how a "mystery" (the grating multiplying the beams) is helpful to generate questions.

Nick: A shame that your fairy tale hasn't been enlightening. Hopefully your lessons are more effective.

Marina: Come on! You asked me to say something!

Nick: Clearly there are some science questions to investigate, but unfortunately the light isn't back on yet. I'll deal with it. I have brought you a piece of flooring. *[He carries a wooden panel from which wires come out and puts it on the ground.]*

Marina: Oh… thank you! What a lovely gift.

Nick: This isn't any old kitchen lino. It's a piezoelectric energy harvesting floor; it converts a person's footsteps into electricity. When I take a step, I generate energy as it happens in the London or Tokyo underground. *[Nick takes a step and turns on the halogen light which goes off as soon as he takes a step off.]*

Technical note: such devices can be obtained on http://pavegen.com/home, however if not available a fake prop version, with a stage hand turning the light on and off from offstage can be substituted.

Marina: It is a nice idea, but you don't give off a lot of light.

Nick: Of course not! That is an incandescent lamp emitting most of its energy in the infrared, as heat, which is invisible! We should use LED lights instead – they are able to emit up to ten times more light than an incandescent light bulb for the same energy consumption. Only producing visible light, not infrared. Anyway, I'm not an expert. Now I am connecting the LEDs and we have light!

The wording LIGHT appears

Mark: *[Commenting on the wording LIGHT.]* Beautiful! And cool too.

Marina: Guys, I bet you know that the 2014 Nobel Prize for physics was awarded to the inventors of blue LEDs. It may not seem to be a big deal, but it's only thanks to this discovery that today we have the white LED lights that we are using. I have something else intriguing to show you that involves LED lights. Do you see this small ball? Excuse me, stop passing that LED round for a minute because I need the room to be dark again. If I turn it on, it shines a white light, but look what happens if I rotate it! Red, green and blue appear.

Mark: That's great! *[They play a while, Marina rotates it, Mark rotates it on its side and Nick rotates it on a small radius, so that also yellow and magenta are visible.]*

Keep it still and bring it over here please so I can carry on now playing four 2's. Don't drain the battery!

Nick: Moving on a piezoelectric step, where the bending of the strip causes an electrical charge to be generated, can charge a battery, Its conversion into electricity of potential energy = mgh. Its mass m remains unaltered, but if you do some big jumps the h contribution clearly increases.

Marina: *[Addressing the audience]* Transforming the mechanical energy of jumps into light. We could also use this invention with fleas, each of their jumps generating energy.

Nick: *[Lost in thought while checking the tests]* Yeah, but we'd need quite a lot of flees because their mass is tiny. But maybe in the future? Did you know that in one of their jumps they can reach 100 times g in acceleration? We could install turbines and start a flee-powered power station …or a hamster-powered station with hamsters running with fleas. *[Nick spots on the tests in Marina's hands.]* On that note, look at what's written here!

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Scene 6: Getting the right reflection on mirrors

Comment: This section is optional, and is perhaps more suited to higher ability classes. The segment concerns a famous misunderstanding in geometrical optics[1 2] that is part of the test. In fact many people believe that the virtual image reflected on a plane mirror lies upon the mirror itself; while in reality the virtual image exists at a point symmetrically opposite to the source image from the mirror and does not depend on the position of the observer. The following experiment proves this. It could be replaced (both the test question and the experiment) with another common misunderstanding from another subject if appropriate.

Marina: You're right, look… everybody got this question wrong. The question was: Imagine you have a fluorescent tube placed vertically in front of a vertical mirror.

Mark: Funnily enough I think I saw the perfect objects to illustrate this in the room next door.

Marina: Yes, I prepared them earlier to illustrate the question. It's called lesson planning. *[Mark goes to fetch a mirror, vertically mounted with a fluorescent tube on the front that is taller than the mirror itself so that the mirror only reflects a part of it, and another fluorescent tube identical to the previous one. He places the mirror in front of the audience.]*

So the question was….

The image of the tube made by the mirror is formed:

a) on the mirror

b) in-between the tube and the mirror

c) behind the mirror, symmetrically opposite to the position of the tube

d) it is different for everyone because it depends on the position of the observer

e) *[Looking at her watch.]* But now I have little time left … I have to go to lesson.

Nick: Wait, I'll come with you. *[The two of them go towards the exit. Mark addresses them.]*

[1] F. M. Goldberg, L.C. McDermott; (1986) . "Student difficulties in understanding image formation by a plane mirror" The Physics Teacher; 24 (8); 472 -480 .
[2] I. Galili, F. Goldberg, S. Bendall; (1991). "Some reflections on plane mirrors and images"; 29 (7), 471-477

Comment: The following exchange of lines, apparently surreal, focuses on one of the problems of traditional teaching, i.e. dealing with topics which do not come from the primary interest of the student. An IBSE-based approach really helps solve this problem.

Mark: Hey excuse me? Do you know which is the right answer?

Marina and Nick: *[Exiting]* Of course we do!

Mark: *[Now alone on stage]* But, if you know the answer, why did you ask the question? *[Addressing the audience]* Well, I will show you.

Look at the tube and its reflection. Now I will switch on this tube here. Tell me when you see it superimposed on the reflected image of the first tube. *[Mark switches on the fixed fluorescent tube in front of the mirror, he then switches on the other tube and puts it in front of the mirror.]* Matching?

Audience: No!

Mark: *[Moves it behind the mirror.]* Matching?

Audience: No!

Mark: *[Eventually positions it symmetrically to the first tube.]* Now they are matching! *[He then rotates the device and shows the position of the two tubes.]* There, see. The two tubes are arranged symmetrically to the mirror, the right answer was c. I'm off now. I still haven't found anything to eat, and I'm starving.

[Darkness]

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ACT 2 - THE LESSON

Comment: In this act, the TEMI-related teaching innovations are clearly signposted for teachers to understand the TEMI pedagogic process. By way of worked examples, the science topics are presented following the TEMI methodology (mysteries to Engage, experiments to Explore etc.) and are intertwined with a lightweight debate on the current situation of education.

Scene 7: How to be hot and polarised

Infrared radiation

Comment: The term infrared is, scientifically, an ambiguous term since it includes radiation which corresponds to a very wide range of the electromagnetic spectrum and refers to very different physical phenomena. These extracts of the "conference" held by Nick, even if they are introduced as a play, with frequent interruptions and asides, constitute a more focused informative part of the show, introducing important notions on thermography.

[Act 2 starts with Marina, Nick and Mark arriving in dribs and drabs at the classroom where the lecture is held.]

Nick: *[Entering, and looking furtive.]* I'm alone at last. I can start. Welcome to my conference on the application of thermography to animal emotions.

The temperature distribution of a body may be measured using such devices as these heat-sensitive plastic strips. Different parts respond to different temperatures so it can be used as a thermometer. The strips contain something called a thermochroic liquid crystal, which contains atoms in different layers. As the temperature changes so the spaces between the layers change and this changes the colour of the light reflected back. You can even use this in clothes so they change colour depending on the weather or your body heat! … *[has a thought]* hum….

However, temperature can also be measured remotely, without contact. It is a matter of measuring the non-visible light emitted by all bodies – infrared light.

In this image you can see the radiation you are emitting. This mysterious radiation that the camera allows us to view behaves like the light our eyes see and being subject to reflection refraction and interference just like visible light.

To really get to grips we need to consider the Maxwell's equations or the … *[his voice trails away and we fade to black as presumably the lecture continues]*.

Technical note: In this section a number of devices can be sourced that demonstrate the detection of thermal emissions. Thermochroic strips for example are available for use as thermometers from local pharmacists, colour changing clothing e.g. http://www.fazetshirts.co.uk/ and thermal imaging cameras (these are available on Amazon for example. If no thermal imaging camera is available again images on a screen can substitute.)

Now you see me, now you don't: Polarization

Comment: Polarization provides an intriguing mystery. It is totally counter-intuitive that by putting two clear films on top of each other it is possible to completely block the light from passing through and that this crucially depends on the orientation of the two films, one to the other.

The mystery of blocked light helps to engage the audience on the topic of light. Additionally with polarizers it is possible to create an entire 5E cycle to characterize the discovery of the strange properties of the polarization of light. Polarization is a property of electromagnetic waves. It's full understanding requires some knowledge of mathematics and physics. However it is possible to have a similar experimental approach to that of Etienne Louis Malus – who discovered the polarization of light – who managed to describe the phenomenon from a phenomenological and quantitative perspective, despite not having yet understood the oscillatory electromagnetic nature of light.

This segment of the show provided a humorous introduction to the polarisation phenomena.

[Marina enters with two polarizers: (opposite Nick).]

Marina: There you are! At MY school, in MY classroom, during MY lesson. Good morning kids, today I'll start my lesson on light. I would like to start with a mystery. Can you see me? *[Putting the polarizers in front of her eyes. She rotates them and disappears from sight.]* Now I am gone and now *[replacing the polarizers as earlier]* I am back.

Nick: *[Hiding Marina again with the polarizers.]* No look, you are wrong. I have just started my conference address to your students, it was just getting fascinatingly mathematical, and you have interrupted me. You invited me for this! And the one talking about light, infrared light, will be me.

Marina: What are you talking about? *[Turning around the polarizers again and reappearing.]*

I have the timetable from the admin office.

Nick: *[Nick hides her again.]* And I have the invitation from the head of year, as you can see. *[Showing a poster to Marina who turns around the polarizers, reappears and looks at the poster.]*

Marina: How can such a CARELESS mistake have happened!

Nick: Perhaps we could take half the audience each, that side look as if they love doing maths! And I'm sure if I ask them they will all be able to write down all the Maxwell equations correctly and solve that strange man Mark's missing 7 with the twos puzzle, *[to half of audience]* don't you agree?

Marina: *[detecting the lack of enthusiasm from the audience]* Or, perhaps not … we may have to consult …the headmaster! *[They freeze in place, there is a dramatic chord and we fade to black]*

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Scene 8: School, teaching and a bit of theatricals

Mark: *[Entering and shaking them from their terror.]* There you are, I couldn't find you! I couldn't find a snack machine either, just a janitor who smelt of burnt leaves and grumbled something about 'that Jamie Oliver'.

Marina: *[Whispering in a low voice to Nick.]* The inspector…

Nick: At least it is not… the headmaster *[the dramatic chord plays again they look round to try and find its source]*

Comment: Some bureaucratic procedures, roles and red tape that are often bothersome are now gently ridiculed …

Mark: My data feed tells me this is a laboratory, isn't it? I would like to conduct some experiments …

Marina: No! This is a classroom, my classroom. To do experiments you need the authorization of…. the headmaster *[the dramatic chord plays again they all now look round to try and find its source]. [Regaining her composure]* Do you have it?

Mark: The authorization of the headmaster? … what is a headmaster? Is it worse than a Jamie Oliver?

Marina: Come on don't mess around! We both know that *[quoting the regulations to impress the 'inspector']* standard operational procedure for permission to do experiments means you have to fill in the risk forms and complete all the health and safety documents… in triplicate, and you need to go the admin office.

Mark: *[Answering as if insulted.]* I need to go… I need to go? Are your sending me to the admin office!? How dare you? You go to the admin office!

Marina: No! You've misunderstood, inspector, wait …

Nick: Good, you take care of him and I'll take it from here. *[Marina and Mark move backwards and keep quarrelling about who needs to go where.]*

Nick: We were talking about the infrared radiation emitted by bodies, the power of which depends on their temperature raised to the power of four; the infrared radiation emitted by all living bodies… But also *[pointing at the people in the audience]* inanimate objects, the chair, a glass, or a sweaty student after a one-hour gym lesson … as you may have noticed.

Mark: *[Addressing Marina]* Shush! The admin office can wait. Let me listen to him.

Comment: Here one of the central "themes" to TEMI is introduced now: students asking themselves questions before finding out the answers; often in traditional science education rote learning the answers to unmotivated problems forms the core of the teaching.

Nick: However, before we continue I would like you to understand that I don't like being interrupted while I am speaking. Not by anyone, including colleagues, especially as I'm not interested in your questions. So, please, no questions!

Mark: Excuse me? Why are we not allowed to ask questions? You don't answer the questions they ask, but you give answers to questions that they haven't asked? How strange… *[Mark chases after Nick in the audience questioning him about why he has a problem with students' asking questions.]*

Marina: *[To get rid of Nick.]* I hear there is a film crew outside, doing a report on… *[she makes it up]* the health effects of pollution smouldering sticks, Nick.

[Nick rapidly leaves the stage in search of media fame, Marina addressing the audience]
Let's start the lecture.

As our inspector can see, I will stick rigidly to the curriculum on light. One of the first subjects I will cover is the law of the reflection of light. *[Playing with a compact mirror she reflects a strong stage light in the faces of people in the audience]*

Marina: *[As Nick re-enters]* Film crew vanished? This is another mystery! Missing the spotlight, then let me help! *[She is now reflecting the light on Nick's face to annoy him.]*

Nick: Reflecting light, I thought you said you were using a mystery, What kind of mystery is just reflecting light off your mirror? You are beginning to annoy me!

Mark: No, she is right. Science means seeing mysteries where others see nothing. And there is more than meets the eye here I suspect.

Marina: Indeed, and fortunately I don't need a laboratory to explore my mirror mystery, *[she takes a sly glimpse at Mark]*… so no trip to the admin office needed!

Instead I will show you, let's call them 'daring demonstrations from my desk', yes that sounds intriguing.

Please take notes, it helps you focus, even though it's already written up in detail in your text book. When I have finished we can certainly accept questions. We can also have, say, a one-minute Q&A every fifteenth minutes.

Mark: Well, I'm sure we will have questions.

Nick: NO! No questions! I have to continue my conference.

Marina: To be honest this is exactly the fifteenth minute. Technically, it's the question-time minute.

Mark: But what is going on here? You have to have questions to ask, because it is the only way for us to know which answers we need to find. We also need to know the questions that will check how well we understand what we learned; doing science is all about asking questions all the time, not just at teachers' question time, and exploring with experiments to find the answers.

Let me show you…

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Scene 9: The Length and the pendulum

Comment: Mystery in physics often concern questions which sound nonsensical for … "common sense". This scene shows how traditional, albeit correct, school answers often lack deeper motivations. As Mark said in the previous scene, "Science also means seeing mysteries where others see nothing."

How long is a metre?

Comment: Starting from a very trivial and apparently silly question, what starts as looking like a tedious physics problem for students takes a surprising turn. This section uses the relatively little known historical-scientific truth: "one metre is the length of the pendulum striking one second". In the XVII century, in the search for a universal unit of length to replace the numerous anthropometric units of length used in Europe, such arm's length and so on, an Italian mathematician, knowing the consistency of swing of the pendulum[3], proposed the length of a pendulum whose half period was exactly 1 second as a universal unit of measurement.

In the following century, more and more accurate measurements of earth gravitational acceleration showed that it is not constant at all, but varies depending on the latitude (due to earth rotation) and the variation of the earth radius. It also is locally dependant on the geology of the subsoil.

[3] The fact is that in a pendulum the period of swing does not depend on the width of the swing if the angles are small enough. The principle is the basis of pendulum clocks and balance wheels which started being developed in that the same historical period.

The metre as a unit of measurement was adopted by the scientific community and initially referred to the pendulum swinging in a set geographical location (London or Paris). Over the following years, in order to make the length of the reference metre more stable and accurate, other measures were adopted; but our current method refers to a fixed distance travelled by a laser in a vacuum.

Mark: *[Joining the audience he asks one-to-one questions.]*

Do you have any questions? ...What about you? Any questions?

I have one! "How long is a metre?"

Nick: What kind of question is that? One metre is one metre long!

Marina: Or more precisely, *[she checks her book]* it is the distance travelled by light in a vacuum in a time interval of 1/299,792,458 seconds.

Mark: Then allow me to rephrase my question: why is a metre exactly one metre long?

Marina: Because it is one ten-millionth of the distance from the North Pole to the Equator calculated along the meridian that passes through Paris.

Mark: That can't be true. Because otherwise one metre on Mars would be approximately 53cm long, which would equal one ten-millionth of the Martian meridian from the Pole to the Equator. But we all know that one metre on Mars is only 10cm long.

Marina: Erm… *[nervously leafing through her lecture notes]* … well, it would be necessary to read the Martian lecture notes …

Nick: That was just a way to attach a universal value to it, but actually one metre, or more accurately its measurement, comes from this object here that I picked up when I guested on antiques roadshow. *[Taking a pocket watch attached to a metre-long chain out of his waistcoat.]*

Marina: A watch?

Nick: No, a pendulum. Look. Let's say that I wish to make a pendulum whose half period, that is a swing from here to there *[swinging the pocket watch, whose chain is one metre long, from one extreme to the opposite]*, is one second. *[Swinging the pocket watch again, then moving to the blackboard.]* Well! How long is this pendulum? One metre! *[Marina goes near him and takes the pocket watch.]* A crazy coincidence, isn't it? No! The fact is that the basic definition of a metre derives from swinging a pendulum … Because in fact … *[writing on the blackboard]*

$$T = 2\pi\sqrt{\frac{l}{g}}$$

Marina: Instead of going off on a tangent, the professor should at least have emphasized that the period of a pendulum only depends on the length of its chain *[sliding two fingers along the swinging chain thus clearly changing its length and the period of swing accordingly.]* Look what happens if I change the length. When I shorten it, T becomes shorter.

Nick: To conclude, a metre is one metre because a second equals one second. On Mars, where the gravitational acceleration is different, one Martian metre is in fact 10 Earth centimetres. Not a lot of people now that.

Wave pendulums

Mark: *[Entering with wave pendulums.]* Your history shows you use pendulums to make watches. I've got my granny's watch here and where I come from it is used to understand which planet you are on. *[Starting the pendulums and quietly observing them until they misalign. Then, pointing at each pendulum …]*

Nick: What is he talking about?

Mark: *[He points to the differing lengths of the pendulums]* This is a metre on the surface of the Earth. At about 90 earth centimetres long this is the Venus metre and at around 70 cm long this could be the metre on Beta Pic, a planet that is 63.4 light years from the solar system. Now look at the motion of the pendulums as a whole … They start all together, in phase… Then, when they start to become different, to go out of phase, their motions look less even … Then, when there are two rows of pendulums in opposing phase strange new motions appear … The time taken for them all to get back in phase is our unit of time: we call it the "massif". It's like your "minute", but a little bulkier.

Comment: The previous experiment concerns the motion of pendulums of different lengths, they have been built so that once the swings are started, initially all swinging together they completely misalign in opposing phases but eventually fall back in sync. This phenomenon only happens if there are set ratios between the lengths of the pendulums. The experiment clearly highlights the dependence of the period on the length of a pendulum and can provide a surprising demonstration.

Nick *[Still thoughtful…]* Really! Listen, this is great. I had never thought about it before. It is a clever idea and it even works!

Mark: Of course it works! We all still use it.

Nick: Who do you mean by 'we'?

Mark: 'We' from Epsilon Eridani b.

Nick: What's that? An office in the Department of Education?

Mark: Of course not! It's a planet.

Nick: What do you mean?

Mark: Well, it is an exoplanet colonized by the human species in the future to escape the menace of the red tape… a terrible thing.

Comment: Epsilon Eridani b is an existing planet outside the solar system, with a presumably Earth-like gravity.

Nick: And when did this colonization that you talk of supposedly take place?

Mark: In our year zero, of course. That if I am not mistaken was the year 2130 on Earth, give or take a massif or three.

Marina: Ignore him. He's pulling our leg!

Nick: So how did you get here?

Mark: Good question! And like many good questions, I do not have an answer. I was doing an experiment on space time, you know that twisty turny timey winy stuff and …

Marina: *[Bewitched.]* So you are a real alien!! Why didn't you tell us earlier?

Mark: Because you didn't ask.

Marina: An alien and a physicist! Truly a higher intelligence. You must have some amazing knowledge. Maybe you could help me deliver my lesson on light … Can I show you another mystery?

Mark: Of course!

Nick: Marina, watch out, he is crazy! Ignore him!

Refractive index

Comment: The experiment is made by using two cellulose acetate disks (these are membrane filters used in the chemistry lab) that are applied on the lenses of a pair of lab goggles.

[4] Cipelletti L, Carpineti M, Giglio M. (1997) Microporous membrane filters: a static light scattering study. PHYSICA. A, vol. 235, p. 248-256, ISSN: 0378-4371

[5] Cipelletti L, Carpineti M, Giglio M (1996). Fractal morphology, spatial order and pore structure in microporous membrane filters. LANGMUIR, vol. 12, p. 6446-6451, ISSN: 0743-7463

[6] Cipelletti L, Carpineti M, Giglio M (1996). Fractal morphology, spatial order and pore structure in microporous membrane filters. LANGMUIR, vol. 12, p. 6446-6451, ISSN: 0743-7463

Marina daubs them with a liquid with the same refractive index as cellulose acetate[4] [5] [6]. The change of fibre refractive index in the filter now makes them transparent in air. The light can pass through the filter now without suffering the multiple diffusions which caused the disks to be opaque. The effect is surprising, making the experiment a great way to introduce the topic of refractive index.

Marina: Here I have a pair of goggles covered with paper disks. Please, put them on. *[Mark wears the goggles with the paper disks on.]*

Marina: See? No light can pass through! Now I will daub them with this oil, which has exactly the same refractive index as that of the cellulose fibres in the paper discs. Et voilà! They become clear.

Mark: How strange! I can see through them.

Marina: All thanks to the oil with the same refractive index.

Mark: The refractive index! But why the index and not the thumb? *[looking at his index finger].*

Marina: Oh, please, Mr Alien! Could you help me prepare my lesson on light?

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Scene 10: Playing with the audience and move your bodies

This scene provides a great opportunity for interaction with the audience. The topic of uniform linear movement can be used in a stand-alone format.

Mark: For me, light is the simplest thing in the universe. It always travels at the same speed, the speed of light, and it moves in straight lines most of the time, it's a lovely, tidy uniform linear movement. Light moves too fast to see this, but I can illustrate uniform linear movement with people! Come on, Marina, help me!

Nick: Marina, what are you doing? He's mad!

Marina: Not at all! He's an alien, with superior skills and knowledge…

Nick: He's not an alien, he's just alienated! He is completely crazy.

Mark: *[Calling the audience and asking.]* Do you have a small carpens for me to eat?

[He lines up some people (at least 4) at equal distances one from the other explaining to them that, when a runner - another person taken from audience who shall move in uniform linear movement – passes by, they will have to clap their hands.] Now each of you must

clap your hands when our runner passes by *[pointing at the chosen person]*. Come on, now try to move in a uniform linear movement! *[Nick, at the blackboard, looks on, puzzled.]*

Marina: Ah I see dear Mr Alien, we know that the distances between our clappers are the same so we will be able to recognise the uniformity of the movement when we hear hands clapping at regular intervals, like ticks on a clock.

[IMPROVISATION doing tests at a different speed.]

Mark: *[Clapping.]* There, see how good our runner is? Give yourselves a round of applause and back to your seats!

Nick: *[Addressing the runner.]* Where do you think you're going? Back here please. Can you just write on the blackboard the sets of equations that illustrate the principle that you have just demonstrated.

[…Awkward silence…]

Nick: Our apologies! It is not your fault. Please go back to your seat. *[The person returns to his/her seat.]* There, Marina, do you see that these methods are not educational? A lot of clapping but no equations on the board!

Mark: Well, as much as formulas are nice, dealing with a problem in physics does not just mean learning to write down equations.

Marina: Exactly! Did you hear that, Nick?

Nick: You are just having fun, I'm being formal

Comment: The following sentence hints at the very famous Einstein's equivalence principle and may generate further discussions on gravity.

Mark: That's all well and good, you go your way and I'll go mine, but let's all get back to the light show now.

Those lovely straight lines that light travels in aren't always straight, in the presence of a gravitational field the light bends. In short, it falls, a bit like a stone when subject to gravity. We are talking about uniformly accelerated movement, which we all know very well because we are used to the free-falling motion of bodies attracted to the Earth.

Comment: The following example describes the use of the history of physics in a full 5E cycle (even if the explanation phase is not part of this script) concerning the fundamental notion of equal gravitational acceleration of all bodies.

[Mark drops a small ball.]

Marina: Well… this doesn't have much to do with light, but it's interesting I suppose, in an alien sort of way …

Nick: I know where this is going… *[Nick writes formulas on the blackboard.]*

Comment: This refers to the TEMI Explore phase.

[Mark drops another small ball. Marina looks at him …]

Mark: Acceleration is constant even when the motion is not in a straight line *[removing them from his pockets, he throws crumpled paper balls in high curved arcs into the audience]*. In fact, do you realize what constant acceleration means? It means that in equal time intervals speed always increases by the same amount.

Marina: Galileo had already hypothesised that without even knowing about gravity. Listen to what he said … it is in my lecture notes, page 72: "When, therefore, I observe a stone..."

Comment: This refers to the TEMI Explain phase

Mark: Hey, I have a stone right here! *[Fetching a polystyrene boulder and throwing it from the terraces to the stage, above the heads of the audience.]*

Technical note: for this stunt a trick polystyrene brick, available in most joke shops or online, can be substituted; the actor simply needs to mime weight in the brick before harmlessly throwing it.

Marina: "...initially at rest falling from an elevated position and continually acquiring new increments of speed, why should I not believe that such increases take place in a manner which is exceedingly simple and rather obvious to everybody?"

Mark: And we can also try it with liquids *[taking two water pistols and giving one to Marina. They start playing shooting around and soaking the audience.]*

Comment: This refers to the TEMI Extend phase

Marina: We only tend to see short trajectories, therefore everything occurs very fast and we don't realise how revolutionary the idea of uniform accelerated movement was. In fact, Galileo had the bright idea of reducing acceleration. How did he do that? With a very simple but brilliant object: an inclined plane! Think about it, with this simple object Galileo managed to slow down an objects fall and found the same law for all inclinations. As he could incline the board more and more, so deduced that this law also had to apply to a vertical fall too! So Galileo managed to describe the movement of falling objects by experimenting on his kitchen table.

Mark: Yes, Galileo measured the distances travelled in equal time intervals, if in the first interval the small ball travelled distance 1, he found in the second interval the distance travelled was 3, in the third it was 5 and so on for all odd numbers.

[Going to the blackboard.] The sum of consecutive odd numbers starting from 1 always gives a square number: *[drawing on the blackboard only one small dot…]* 1 is the square

of 1, *[adding 3 small dots to make a larger square]* 1+3 is the square of 2 *[adding 5 small dots to make a larger square "3x3" with three overlapping rows of 3 small dots each]* 1+3+5 is the square of 3 and so on …

clever old Galileo discovered that the distance travelled is proportional to the square of the time.

Comment: What follows is the use of an inclined plane with bells attached at distances scaled according to a squared law. It is similar to the object used by Galileo. In class, you can ask the students to build their own or following on from the demonstration of linear uniform motion with runner and clappers, you can line up a number of students at increasing distance scaled to the odd numbers. To get the students to clap their hands at regular intervals a passing runner must be able to run the increasing distance between one clapper and the next in the same time period.

Marina: Rather than use student clapping and running, too much fun for Nick, we can hear this equation here on the track when the bells ring as the small ball rolls by. The bells are positioned at distance intervals fixed by the odd numbers, just as our friendly alien explained to us. Let's listen for the bells *[rolling a small ball on the inclined plane which makes the bells ring.]* that's the sweet music of science.

Mark: In Galileo's times there were no stopwatches and, in order to position the bells so that they could ring at regular intervals, Galileo, son of a talented musician, would sing a song under his breath to time the experiment.

Comment: What follows is an example of showmanship.

Let's try it with Frère Jacques.

Marina: *[rolls a small ball]*.

Frère Jacques, frère Jacques,

Dormez-vous? Dormez-vous?

Sonnez les matines! Sonnez les matines!

Ding, dang, dong. Ding, dang, dong.

[Mark and Marina repeat the operation a few times singing under their breath, then Mark asks the audience to join in.]

Mark: Come on, all together now! You remember "Frère Jacques"? Come on, let's start following the bells.

[Marina drops some small balls in a sequence and Marina, Mark and the audience sing together] "Frère Jacques".

Marina: And now we can try a round! Look Nick, we could win X Factor with the appliance of science!

Nick: That's a NO from me! What a shame!

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Scene 11: Reuleaux triangles

Comment: This scene presents a geometry based lab, an opportunity to explore some properties of plane shapes. For this experiment, we use Reuleaux triangles[7], geometrical shapes that are not circles, but act as circles when rolling in between two flat surfaces. This especially strange result goes against the common idea that wheels need to be circular in order to work properly, i.e. to allow a smooth and even motion while rolling on a flat plane.

In fact the Reuleaux rollers used here could not be used as wheels because their rotational axis doesn't remain at the same distance from the ground when in motion, making for a bumpy ride. All this is true if the ground is flat. If the terrain to be covered was rough and hilly, the axis of the circular wheels would not move horizontally, but would follow the profile of the ground. Is it possible to match bumps and "wheels" shape so that the axis doesn't jerk? This could be an interesting way to extend[8] the discussion and exploration.

Nick: *[Addressing Mark]* Since you are so good with Galileo… Wouldn't you like to follow the journey that the human race has made to get to such wonderfully intellectual constructions which have changed the way we see the world? I am talking about the Principia by Newton… the famous book by the father of mechanics.

Mark: What a good question! I will refer to a presentation that I should have somewhere here, if I can connect with your slide projector. *[Messing about with a small device placed on his watch.]*

Hum, that's just a load of Newton's selfies. Ahh, it should be this one, yes. *[Two slides appear, Mark reads the title. "The science of mechanics: a historical, critical, epistemological, sociological, mythical, etiological, cosmological, phenomenological, gnosiological, allegoric, anthropic account of its development."]*

Comment: The title is a playful take on fundamental work on Einstein's thought as

7. See, for example: https://it.wikipedia.org/wiki/Triangolo_di_Reuleaux; http://mathworld.wolfram.com/ReuleauxTriangle.html.
8. See, for example http://mathtourist.blogspot.it/2011/05/riding-on-square-wheels.html

"The science of mechanics: a critical and historical account of its development" by Ernst Mach. The following short explanation, on the other hand, is inspired by the initial part of the conference on mechanics titled "Űber die Prinzipien der Mechanik" that physicist Ludwig Boltzmann held in Vienna in 1902. The science of mechanics: a historical, critical, epistemological, sociological, mythical, etiological, cosmological, phenomenological, gnosiological, allegoric, anthropic account of its development.

[While Mark is speaking and without him noticing, an interference pattern appears, as if from an out-of-tune TV set and the presentation moves to an overview of personal pictures of Mark.]

The first human tool, the simplest we can imagine, was probably the club. The orangutan. There it is... *[Slide showing Mark dressed and ready for skiing]* … also uses the club for the same purposes for today …The club *[pointing at the screen without turning; a slide appears showing Mark wearing a sweater and cropped trousers]* led to the invention of the lever *[slide showing a bare-chested Mark]* the first real mechanical tool; and the need to carry bulky weights led to the invention first of cylindrical rollers *[slide showing Mark wearing beach trunks]*.

[Nick, alarmed, tries to catch Marina's attention; she's looking ecstatically at Mark's pictures as in each he appears in somewhat less clothing.]

Mark: And then world's simplest machine, the wheel *[motioning to change slide]*.

Nick: *[Catching Mark's watch preventing him from changing slide.]* I think we have seen enough thank you!

Marina: Yes, you are really getting to the naked truth there *[she catches herself and stops day dreaming]*.

Cough, we know the first wheels ever used by humans were tree trunks, and everybody knows they have a circular cross-section so a load that is carried on these cylinders naturally runs along quite smoothly. But, I seem to remember, wheels with much more irregular cross-sections still work well.

Mark: Maybe, but can I continue my presentation now?

Nick: Not a good idea!

Marina: Come and help me! Quick, give me those strange wheels *[Nick and Mark take some coffee tables having base and top shaped as Reuleaux triangles, two are triangular, one is quadrangular, one more pentagonal etc. they arrange them on the floor.]* This looks like a triangle and look … *[He rolls the triangle]* it does not roll very well. And this and this as well *[he tries to roll the pentagonal ones.]*, smooth rollers they are not.

Now look what happens if we put a flat surface on top. Quick, put a flat surface on top! *[Nick and Mark take the piezoelectric floor and put it on the rollers.]*

Nick: What about these? They are sort of triangular and sort of not!

Mark: Only one way to find out, experiment with them!

[They find a board to place on top of the Reuleaux wheels, and find that as they push it the board moves smoothly forwards. Marina is invited to lie on the board]

Marina: *[Lying comfortably and giving directions.]* See, despite the strange irregular shape of these "wheels" you can see that the table moves forwards without jerking. *[Nick pushes her off stage where Marina noisily falls. Broken glass noise.]*

Nick: Well, I think we can finish my lecture here, I'll get my coat. We didn't really manage to talk about light … I only said a couple of things on infrared but… I'll get paid. Which way to the admin office?

Mark: But she may be hurt!

Marina: *[Comedy staggering back on stage]* Aaah, what happened, I don't remember anything,

Mark: Marina, are you all right?

Marina: Ohi ohi ohi… shortly the exam will start! Who will help me? *[Addressing Nick:]* Oh Nick, Nick … what happened to me? I don't remember anything!

Nick: Don't worry. You gave an enlightening lesson, Marina.

Marina: But now it's time for the exam. Can you help me please?

Mark: What is this exam thing you keep mentioning?

Marina: Oh poor Mr Alien, of course you can't know it all! There is a thick book over there with all the rules. *[Pointing at a very bulky book.]* Read it carefully and then you'll be able to help us. *[Mark goes to fetch the book.]*

Nick: *[In a condescending tone]* Fine, let's do the exam … Let's go and prepare, come on then.

ACT 3 - THE FINAL EXAM

Scene 12: Playing with enquiry

Comment: In this act, the eccentric attitude of Professor Marina turns the exam into a crazy situation where the examiners show the exam-takers physical phenomena or objects, expecting the exam takers to ask the questions. The questions must come from the students and it is up to the teacher to arouse their curiosity so that the questions come spontaneously.

The topics covered are varied and of differing levels of difficulty.

- A number of identical cylinders are rolled across the floor, each one has a different behaviour but behaving completely differently. If the distribution of mass inside a body is not homogeneous a cylinder may even run up an inclined plane without breaking any physical law.

- When discussing the law of reflection and refraction (Snell's law) and the resulting functioning of lenses, we also hear about the extraordinary ability of the archerfish which hits it out of the water prey by spitting a jet of water. How can the fish target the prey if its eyes are under water? The refraction in fact shows the prey in a very different position from where it actually is.

In this exam setting, there is also the story of the famous Hafele-Keating experiment, a time travelling test of the theory of relativity.

To conclude, it is again light with its surprising behaviour that leaves the audience amazed. After all the talk of light moving in straight lines, a bent light beam is presented, an appropriate finishing mystery[9] to bring the show to its conclusion.

Technical note: To create the bent light beam we need to understand that light changes direction when it goes from a medium to another

Question: what happens in the presence of a continuous variation of the refractive index? This is a potential question to initially pose (but also a possible "Extend phase", to be use during a TEMI lecture on refraction).

Answer: the answer is that light gradually changes direction and its trajectory is no longer a complete straight line, but rather each of the straight line element differs in direction and combines to produce a curve.

[The three enter together in a line one after the other. Marina still mildly concussed, has gone a little crazy and fiddles with a laser and a compact mirror, playing with the laser light as if it were a ball passing from one foot to the other… Mark has finished the big book to please Marina, he enters holding the book up high occasionally, checking pages to ensure he has remembered all the regulations. Marina, Mark and Nick stand in front of the table where the exam will be held.]

9. See the section "mysteries" of http://www.teachingmysteries.eu/

Nick: As I'm the most important person here, I'll chair.

Mark: *[Using an official tone and with great pride.]* I have read the rules carefully. I don't understand what their purpose is, but I will try to enforce them properly. The book of regulations says the chair is the most senior person. As I'm the oldest here, I'll chair.

Nick: No, no, no. You're not the oldest – your age is negative; you come from the future! You've yet to be even born according to earth public records.

Mark: Well, when you put it like that. I come from 2262. My age is the result of 2016 – 2262. That makes me -246 years old. But the rules don't mention the mathematical sign before the number of years, the correct interpretation of the rules is that only the absolute value matters. So I'll chair.

Marina: Talking of age: what time is it?

Nick: *[Looking at the watch]* it is... *[Telling the actual time.]*

Mark: *[Looking at the pendulums.]* Your watch is one minute behind.

Marina: *[Talking to herself.]* You know, Nick, it's much better to have a stopped watch than one that runs one minute late every day.

Nick: And why is that?

Marina: Because a stopped watch reads the right time twice a day, while a lagging watch only reads it once every two years!

Mark: You'd better replace the battery then.

[Mark and Nick sit at the table.]

Mark: *[Reading from a sheet and looking at the audience.]* Today we have 576 candidates sitting the exam.

Marina: *[Running to the blackboard.]* That, if you play four 2's, is: (2x2)!x(2x2)!

Mark: Let's call the first one. Nick, you call.

Nick: *[Aside, addressing only the audience.]* One thinks they are an alien; the other hasn't been the same since that unfortunate wheely bad fall. *[Now addressing everyone.]* Anyway, let's start in alphabetical order. A.

Marina: Come along! *[Fetching a member of the audience and taking him/her in front of the desk.]* What's your name?

Audience 1: *[Saying his/her name.]*

[Marina and Mark sit, Nick stands away from the desk.]

Mark: Please, sit down. *[There are no chairs for the audience member to sit on; he/she has to stand.]* All right, stand then, we can start. *[Marina, Mark, Nick stare.]*

Mark: *[Marina nervously removing and replacing the pen cap.]* You look very nervous. Just relax. I'll tell you a joke that will help. Two aerials meet on a roof, fall in love and get married. The reception was brilliant *[Marina and Mark laugh uproariously, Nick remains petrified.]*

Nick: *[Ironically to Audience 1.]* Don't worry, my colleague has had a tough day today. Be patient.

Marina: *[Nervously removing and replacing the pen cap.]* I will give you another hint. Look at this image *[a slide is shown with a reflection and refraction chart without symbols or signs.]*

[Marina and Mark remain quiet as if waiting for an answer.]

Nick: *[Dumbfounded, he looks at Marina.]* Marina, but what is the question?

Marina: Exactly. As our alien chair said – the student has to ask it. Who's next? Do we have any willing takers?

Nick: *[Looking dismayed.]* All right, let's start again in alphabetical order … A.

Marina: Right then come along! What is your name?

Audience 2: *[Saying his/her name.]*

Mark: Very well, take a seat [there is no chair for him/her to sit on either]. Humm, still no chairs, OK, let's start…

[Marina, Mark and Nick stay silent waiting for a question.]

Mark: Come on, ask me your question.

Marina: *[Staring at and addressing audience member 2 she starts removing and replacing the pen cap, repeating the following sentences nervously and causing anxiety, restless.]* If you cannot ask questions, you surely can't know the answers. *[Marina standing up and going to the opposite side of the table.]* Do you think you know the question?… Yes? Fine, then tell us what you're thinking … and think of what you're saying… after all it is the same thing.

Nick: Not at all! They are not the same thing at all, Marina! It would be like saying that "I ask what I know" is "I know what I ask". Or that "I understand what I measure" is like "I measure what I understand"! In your opinion, when I do an experiment do I get what I expect or do I expect what I get?! *[Then, more reassuringly, but addressing the audience member.]* If you do that, you end up inverting question and answer.

Marina: *[Appearing anxious, restless:]* He/she doesn't know what to ask, doesn't know what to ask, see, what can we do? He/she doesn't know what to ask, doesn't know what to ask …!

Nick: Ask them to do one of your little experiments … come on, yes! The stuff you were doing during your lesson.

Marina: Right, ok!! Let's roll the cylinder on an inclined plane. *[Taking a cylinder]* Quick Alien, help me. *[Marina positions the first cylinder (homogeneous) and places it on top of a slightly inclined plane. The cylinder rolls along the plane and continues until Mark stops it.]*

Mark: Come on, you can do it! Ask me a good question.

Nick: *[Adapting]* Look, I understand the situation. I'll help. First check the movement of the cylinder, analyse this perfectly reproducible mechanical phenomenon. No, listen, you try it, take this cylinder and roll it.

[Marina points audience member 2 to the non-homogeneous cylinder (on the outside it is identical as the first, but inside it has sand which prevents it from rolling). Audience member 2 positions it on the inclined plane; the cylinder stands still. Marina and Mark laugh.]

Marina: impossible? Or perhaps you now have a question? Come on, we'll give you a final mystery to solve.

[Mark takes a third cylinder and puts it on the edge of the inclined plane (this time the cylinder is exactly the same as the other two, but with a metal bar fixed on the inside, so that, due to its weight, if the cylinder is correctly placed on the inclined plane, it will climb up the slope a short distance, this can be fixed so the cylinder falls off the slide and swings.]

Marina: *[Forlorn, looking at audience member 2.]* The cylinders must have some secrets inside … have a think, while I go back to the first person who took the test. I think they need a little light helping! *[Clicking on the PC, numbers 1 and 2 appear on the slide again with the diagram showing a light ray passing through two different refractive index media and possible routes taken.]*

Nick: *[Showing the slide to the first person examined (softly)]* Say… Snell's law…

[If the candidate says "Snell's law" Mark says "But that is not a question!"]

Marina: The same law on which the operation of lenses is based. See? *[Taking a very big lens she looks through it distorting her face]* The light is redirected and, since the lens surface is convex, the parallel light rays converge to one point, called the focus. *[Experiment with green laser pointer sliding along the flat surface of the lens and talcum to show that the beam is redirected and refracted light converges to one point and the images appear enlarged.] [Nick looking forlorn at Marina's large face.]*

But maybe we should return to the cylinder.

Scene 13: Time travel and the Hafele-Keating experiment

Comment: Here we discuss the Hafele-Keating experiment, with two identical synchronised atomic clocks placed on two identical commercial airliners – departing from the same airport and flying in opposite directions around the earth – the two clocks measuring different times when they are then re compared. This is a well-known relativistic effect.

Mark: No, that's not it! We are still talking about refraction that is linked to the different speeds of light in the two materials. It reminds me of that famous experiment, I think is called the Hafele-Keating experiment, using two airliners both with super accurate atomic clocks inside. Both the airline experiment and the refraction experiment need two means of transport. But one experiment costs a lot more!

Nick: But what is the question?

Mark: He/she has to ask me.

Nick: At least explain the experiment to him/her.

Mark: Sure. It is the famous experiment in which two atomic clocks are put aboard two planes flying around the world, the first eastward, the second westward.

[Marina and Nick are respectively on the left and the right side of the table. Marina throws a paper plane to Nick and Nick throws one to Marina.]

Now the speed of light c is the same for all observers. So, if c is constant, moving clocks should run slower. As the clocks were in flight the measurements of space and time should be different to a clock left on the ground. The theory showed that the clock travelling eastward, in the direction of the earth's rotation, should have slowed and missed 40 nanoseconds while the one travelling westward, against the earth's rotation, should have gained 275 nanoseconds compared to a clock positioned on the ground.

[Marina and Nick keep throwing paper planes back and forth and throwing them to the audience. Mark, excited, goes to the blackboard to write the equations. His scribbles become unintelligible and Marina and Nick hit him with paper planes.]

Hum *[mumbles]* -time trajectories of the two airliners…. Minkowski distance measures … time elapsed for each airliner. And finally as you can see, it becomes clear that the time elapsed for this airliner *[pointing at a longer line]* is shorter than the time elapsed for the other one.

Scene 14: Facing up to Fermi problems

Comment: Fermi estimates are problems where you can get to a good estimate of the numerical solution from the little data easily available. They are named after Enrico Fermi, a 20th century physicist, who used to enjoy solving surprising problems, like estimating the number of pianoforte tuners in the city of Chicago. These problems usually consist of making credible guesses on quantities that seem to be impossible to calculate. Another well-documented example is his estimate of the power of the Trinity nuclear bomb that Fermi made just using measurements of the distance travelled by scraps of paper dropped from his hand during the explosion.

Nick: *[Quite annoyed, throwing one last paper plane.]* Of course, if we keep not asking questions…

Marina: *[Embarrassed.]* Well… let's at least ask relevant questions. *[Moving through the people examined.]* For example: How many lights will be switched on tonight in London? How many table-tennis balls are needed to fill this classroom? Or, how many lifts are there in Rome?…

These are the sorts of questions I want, to be asking free flowing questions, questioning everything now…

Nick: *[Moving close to Marina.]* These sound like Fermi estimates, problems whose solution can be approximated using the scarce data available and some basic scientific questioning.

Mark: *[Going towards the audience.]* Well, let's call another person on stage to ask Marina some questions!

Nick: Why don't you ask yourself a question?

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Scene 15: Spit it out with the archerfish

Comment: The Archerfish species is known for its ability to catch prey by spitting a very powerful water jet. Many problems in physics can be explained by the analysis of the Archerfish's behaviours and ability. One such problem is refraction, as it's in the water the fish sees the prey in a different position from the real one, the other is the energy that the jet releases in the impact that cannot be simply explained on the basis of the animal's musculature[10].

The example is used to show students a glimpse of the applications of physics outside purely technological fields, in which are usually presented.

Mark: Oh yes, wonderful, I love questions! Me, how does the archerfish hit its prey?

Marina: *[Jumping in and almost spitting on Nick.]* By spitting.

Nick: How disgusting! You are talking about fish, not physics here!

Marina: No, no, not at all! It has to do with light and refraction. How can the fish aim if it is under water? When passing from water to air, light changes direction so the fish sees the prey in a different place from the one it is actually in.

Mark: It's strange. The archerfish can do it without even knowing the formulas; we wouldn't be able to do it, but we can understand how it is done.

Nick: I get it, I have an idea. You come on stage *[calling a person from the audience. Mark takes a person from the audience.]* You can play at being the Archerfish. Marina, take this insect *[giving Marina an insect-shaped target mounted on a pole that she grabs and holds over her head]* and you move behind the fish tank. Here, take my colleague's water gun. *[Handing a water gun to the person from the audience.]*Try to hit the insect while looking through the water. Ready?

Marina: No! If you want to play at being the Archerfish you have to put your head inside the tank … *[Mimes placing her head inside a tank.]*

Mark: But there is no need to! I have these special goggles here which give you an idea of how archerfish see. *[Taking the prismatic lenses and handing them to Nick.]*

Nick: There, perfect, please wear them. And you, Marina, hold the insect-shaped target up above your head. Are you taking aim? Three, two, one: fire!

Marina: *[Getting hit.]* Ouch!

Nick: See! You have experienced pure awesome fishiness, and seen how difficult it

10. Vailati A, Zinnato L, Cerbino R (2012) How Archer Fish Achieve a Powerful Impact: Hydrodynamic Instability of a Pulsed Jet in Toxotes jaculatrix. PLoS ONE 7(10): e47867. doi:10.1371/journal.pone.0047867

is to aim by looking through one medium to the other? Is there someone else who would like to try and squirt my colleague?

Marina: No, please, I've haddock enough, have you no sole?

Nick: I think she cod do batter!

Mark: We should dolphinitely scale back on the fish puns.

Marina Nick and Mark: (all together) Agreed!

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Scene 16: The bright finale

Comment: The script ends with a short explanation of the meaning of the show (Marina is back in her right mind), and a final mystery where notary to all we have been told a bent light beam is presented live on stage.

Marina: *[Looking around herself dumbfounded and speaks to audience 1 and 2.]*

What's happening? This is not a laboratory it's a classroom. What are you doing standing here? Have you taken the chairs? Go back to your seats.

[To the class] You will find everything in my lecture notes!

Nick: I'm glad that you are back to your usual self because this exam makes no sense at all! We haven't even asked a question.

Mark: That's not just it, Nick, in order to ask the important questions you need to be inspired, and this is very rarely going to happen during an exam.

[Nick looks at Mark and exits.]

Comment: Marina's following talk is another example of showmanship.

Marina: In order to bring questions to life, you have to feel intrigued by a mystery. And I have found the mystery I was looking for my lesson on light! Our world is a natural stage of fantastic light phenomena, take mirages for example …

Under particular conditions the light beams passing through the atmosphere don't move in a straight line *[pointing a laser to the fish tank]*, but they bend.

Now I wonder what would happen to a beam of light in the presence of a continuous variation of refractive index? *[Rapt silence as the final demonstration is revealed, showing the laser bean bending in the liquid as promised.]*

This phenomenon happens, for example, on the sea, when the higher air is less dense than the lower, it is called "Fata Morgana"… and in this mirage we seem to be able to see ships floating above the horizon.

That is how a physicist understands the mystery, from a different perspective!

The human race has made spectacular scientific progress through trying to solve mysteries, yet arguably we have more questions today than we did a century ago. This, despite the fact that we know more now than we ever did in the past. Our hunger for knowledge will never be satisfied.

Mark: Talking about hunger, I have been asking you for food for the last hour and a half. Can you give me a bite to eat?

Comment: So here we discover that Mark's hunger is a metaphor for his hunger for knowledge. It is important to look beyond appearances …

Nick: *[Rushing in.]* MARINA, MARINA! Maybe he's not an alien! He comes from Epsilon Eri – it is not only an inhabitable exoplanet, but also a mysterious international education research project.

Marina: No! Aren't you an alien?

Mark: The fact is that I came here under cover just so that I wouldn't be recognized while I was researching your methods.

[A laser show starts among the audience, including fog from the fog machine.]

All: In this laser show I just saw light, now the sky's the limit!

- END -

Comment: We see one thing or other, depending on how we look at them. It is important to learn to look and ask questions, but also being aware that, as the great physicist Niels Bohr used to say "The opposite of a profound truth may well be another profound truth".

APPENDIX – USER NOTES FOR NON SPECIALISTS

Where to find more about these mysteries?

The four 2's game and the solution to the 7 mystery

Here are some possible solutions to the 7 mystery, it is quite complicated:

$$7 = (2*2)!! - \frac{2}{2}$$

where "!!" is the mathematical symbol for double factorial: the product of all the integers from 1 up to some non-negative integer n that have the same parity as n is called the double factorial or semifactorial of n and is denoted by n!!. In this case 4!!= 2*4=8

$$7 = \sum_{i=2-2}^{2} 2^i$$

$$\sum_{n=2}^{2*2} n = 2+3+4$$

$\sum$ is the mathematical symbol to represent summation of similar terms that are described by an integer index of summation varying from a lower bound to an upper bound of summation.

The first summation is: $\sum_{i=2-2}^{2} 2^i = 2^{2-2} + 2^{2-1} + 2^2 = 1+2+4$

The second one is: $\sum_{n=2}^{2*2} n = 2+3+4$

The clever use of the symbol $\sum$ allows us to avoid using numbers that are not 2s.

The archerfish

The archerfish and its peculiar way of shooting down its prey have been the subject of many scientific papers. Here you can find text and videos describing archerfish behaviour, and why it is of interest scientists.

http://www.nature.com/news/fish-shoots-down-prey-with-super-powered-jet-1.11668

http://www.nature.com/news/how-archer-fish-gun-down-prey-from-a-distance-1.15845

The bent light

The bent light beam, while strange to observe, is a quite simple experiment that can be easily reproduced. The description of this experiment and its use in a typical TEMI lesson can be found in the book of mystery of the TEMI project and is named "the curved light". It works by using layered liquid with a varying refractive index, which causes the light to bend as it passes through.

Things to be careful about

When calling people from the audience onto the stage, it is recommended to ask for volunteers or to call adults or teachers only. Young people may feel uncomfortable, or may have faced issues such as bullying at school and therefore find being the centre of attention uncomfortable. It is important to be mindful of such sensitivities. You should be aware of any local child safeguarding issues you need to adhere to while working with underage children.

Stage directors should always check the local health and safety requirements and ensure they are strictly complied with. The authors of the script cannot be held responsible for any accident or damage that could occur during representations by theatre companies and school drama clubs.

The test handed out at the beginning of the play:

The example test given here contains nine questions. The first three are used to understand the audiences view on plays and theatre. (Are they regular theatre goers for example?) The next five questions are used to understand the audience views on the discipline (physics in our case). Only the final quiz question is focused specifically on a domain related problem, and this is used during the show at the end of the first scene.

Depending on individual needs, the number and topic of the questions may vary, as may the difficultly of the final quiz question.

Please answer the questions to this test carefully by crossing the right answer. A completed test is required prior to watching the show.

Sex_____ Age _____ Education qualification_________________________________

1) How many times have you gone to the theatre in the last twelve months? ______

2) Do you have a theatre season ticket? YES NO

3) If you have seen any play, what theatre genre was it?
(a) Classic (Shakespeare, Goldoni, Pirandello etc.)
(b) Scientific
(c) Entertainment (musical etc.)
(d) Other (specify) ____

4) Physics is INTERESTING because …
(a) It stimulates thought and reflection on the laws governing natural phenomena
(b) It deals with unusual and surprising phenomena which arouse curiosity
(c) It deals with day-to-day phenomena, observed from an unexpected perspective
(d) I am not interested in physics

5) Physics is COMPLICATED because …
(a) It is full of mathematical formulas which make me feel ill at ease
(b) It is necessary to have an above-average IQ to be able to follow the steps which bring to the solution of a problem
(c) It is not intuitive, I cannot ask myself the right questions to investigate its secrets
(d) Physics is not complicated

6) Physics is FASCINATING because …
(a) It researches regularity in natural phenomena to establish the general properties of the universe
(b) It deals with what is infinitely small and infinitely big and with what is unimaginable for ordinary people
(c) It overturns the frames of mind that are deemed obvious by common sense
(d) I am not fascinated with physics

7) Physics is USEFUL because …
(a) Pure research opens real possibilities for human kind which would have not been seized otherwise
(b) It is necessary to develop technology
(c) It creates jobs
(d) Physics is not useful

8) Physics is MYSTERIOUS because …
(a) You can see incredible experiments and phenomena
(b) You need to think out of the box to be able to grasp it
(c) It deals with disturbing and far-away phenomena
(d) Physics is not mysterious

9) Imagine you have a fluorescent tube positioned vertically in front of a vertical mirror. The image of the tube reflected by the mirror is formed:
(a) On the mirror
(b) In-between the tube and the mirror
(c) Behind the mirror, symmetrically to the position of the tube
(d) It is different for everyone because it depends on the position of the observer
(e) Other (specify) ____

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