**Hands-On Fields Eureka 2018 Roberta Tevlin**

All of the materials for this workshop can be found at roberta.tevlin.ca. If you have any questions or suggestions, feel free to contact me at roberta.tevlin@tdsb.on.ca

This worksheet follows the PowerPoint slides but could be used without them. The slides mainly provide more illustrations. There is also an article on the OAPT website.

1. The field description of gravity, Fg = m**g** = m (**GM/r2**) is only slightly different from the force description Fg = GMm/r2? Does it satisfy you? Does it get rid of spooky action at a distance? Isn’t it just some mathematical sleight of hand?

It says that each mass produces a field that affects all of space. What is this field made of? How can it exist in empty space? This explanation seems to create more quetions than it answers. It reminds me of the Pilot Wave interpretation of quantum physics. Why are fields considered to be a key concept of physics while the pilot waves are just an interesting idea? The rest of this workshop is an attempt to answer this question.

1. **Visualizing magnetic fields:**

First we will try to ‘see’ the different fields by providing many small test objects. Seeing is believing. Magnetic fields are easiest, lots of fun and already familiar.

1. Draw a simplified diagram of the pattern that iron filings make around a bar magnet.
2. **Predict** what the field in between two poles will look like. **Observe**.

Similar Opposite

1. **Visualizing gravitational fields:**

Which pair of magnetic poles will provide a field that is similar to the gravitational field between two stars?

1. two north B) two south C) one north, one south

Explain: B: This question confuses students because they think about whether the forces attract or repel each other, when they are being asked what their combined fields will be. The two poles need to be the same, because there is only one kind of mass. The two poles must be the same so that in between the two, there will be a zero field. At that point at test object will feel no force because of the equal and opposite forces on it. Finally, the two poles have to be south poltes because magnetic field line directions point toward the south pole and grvitaional fields always point towardt he mass.

1. **Visualizing electric fields.**
2. How can you make the electric field visible using balloons and hair?

To make any field visible, you need really small light test objects. Hair is good for this. Rubbing a balloon on hair is one of the best ways to get charged objects. It even works on a hot humid day.

1. What is the field like between oppositely charged plates?

The photo has small threads suspended in a fluid. You create this field with a charged Plexiglas plate supported a few cm above the table. Place paper bits from a hole punch between it and the table. Rub the Plexiglas with wool or fur and the paper bits will line up vertically and hop up and down.

1. **Visualizing magnetic fields:**

Where can you find a similar, uniform magnetic field?

This is the field inside a solenoid. This field is very simple, like the gravitational field near the Earth’s surface and the electric field of a parallel plate capacitor. They are simple enough that students can do calculations with them. The simple magnetic fields have important applications in particle physics. (It was also very important for cathode ray tubes but they aren’t so important any more.) It is also the field inside a bar magnet. This field rarely gets shown, but it is important to include this because magnetic fields lines are different from electrical and gravitational lines because they always form loops. This is because there are no magnetic monopoles.

1. **Visualizing gravitational fields:**

What is the gravitational field in this classroom like? How can you make it visible?

Dangling objects at the end of strings will show this easily.

Students have already used the concept of gravitational fields in grade 11 physics, but this was probably not examined very deeply. The gravitational field strength, g, is usually just called gravity, which does not distinguish between the field and the force. Also, there is confusion because g = 9.8 N/m gets confused with g = 9.8 m/s2. These two are the same because gravity gives all masses the same acceleration. This is very suspicious, because that’s what fictitious forces do. Maybe gravity is not really a fundamental force, but is due to an accelerated frame of reference. This thought led Einstein to General Relativity.

1. **Simulating electric fields**: <https://phet.colorado.edu/en/simulation/charges-and-fields>

Simulations allow students to explore more arrangements of fields and to display the field more clearly. This can help make the fields more conceptually tangible. It is also an opportunity to continue to reinforce the similarities of the three fields.

1. How do you simulate an electric field that is similar to a bar magnet? 2 opposite charges
2. How do you simulate an electric field that is similar to a binary star system? 2 similar charges
3. How do you simulate the electric field of a parallel plate capacitor? Lines of opposite charges.
4. **Modelling fields with fabric**:

A physical model has the students using senses other than sight and lets them see the effect on moving test objects. The fabric can be held by a circle of students or it can be held by a large hoop like the rim of a bicycle. The first method has more people directly involved and the second shows clearer results because the field is more uniform.

1. How do you model an electron orbiting the nucleus?

Make a deep well and launch a small dense ball tangentially at the right speed. This model is usually used for gravitational orbits – but it can be extended here.

However, there is a big problem with this model of the atom. An orbiting charge is an accelerating charge and so it should be radiating energy and spiral in. Well, our model does this, so maybe it is a good model of the atom. We need quantum physics to fix this.

1. How do you model an asteroid spiralling into the Earth?

This is modelled just the same as the atomic model. The asteroids spiral in when they meet up with the atmosphere. Outside of the atmosphere, asteroids and planet keep on orbiting – or do they? Einstein predicted that this motion should cause gravitational waves to take energy away from the system and cause the orbits to spiral in. This effect is impossible to detect for planets but was detected for two neutron stars several years ago (Nobel Prize work) and more recently the gravitational waves have been detected directly (more Nobel Prize material.)

Note: This model does not explain gravity because it uses gravity to make it work. The model will not work if you hold it sideways or upside down. There are other models that get around this. See workshops on Hands-On General Relativity. <http://www.tevlin.ca/roberta/Workshops.htm>

1. How do you model alpha particles deflected by a gold nucleus?

For this situation, you need to pull the center up so it makes a repulsive force.

1. Simulating motion in electric fields:
2. Electric Field Hockey <https://phet.colorado.edu/en/simulation/legacy/electric-hockey>

How would you use this with your class?

I do this as an optional assignment for my students. They need to send me a screen shot showing that they have achieved level two – without charges leaving the screen. This qualifies them for a lunchtime contest for who can get to the goal with the fewest number of charges in level three.

1. Rutherford Scattering <https://phet.colorado.edu/en/simulation/rutherford-scattering>

What will you use to calculate the upper limit of the size of the gold nucleus?

1. ½ malpha v2 = KQq/r2 B) ½ mgold v2 = KQq/r

C) ½ malpha v2 = KQq/r2 D) ½ malpha v2 = KQq/r

This simulation let’s you see the effect of the field on moving charges. In grade 12 they can only handle the math for the simplest situation – a head-on approach. This is an important application of conservation of energy and how we know what we know. So much of what students learn in grade 9 science is finally explained by grade 12 physics.

1. **Applying electric and magnetic fields**:

**Physics in Action: Electromagnetism and Circular Motion in a Cyclotron**

<http://www.triumf.ca/home/for-media/publicationsgallery/videos/e-m-and-circular-motion>

This is a great resource. I spend a whole lesson exploring how fields are used in this Canadian cyclotron. The details can be found in unit four. <http://www.tevlin.ca/roberta/12U%20Course/12U%20Course%20Main.htm>

1. What type of field is used to accelerate the ions?
2. gravitational B) electrical C) magnetic

Explain:

The ions can only be sped up by electrical fields. Gravity is way too weak and magnetic forces are always perpendicular to the velocity, so they can only turn the ion. The electrical fields are used to turn the ions when they are moving slowly, but when they are moving really fast, magnetic fields are used because a greater force is needed to turn fast particles and the magnetic force increases with the speed.

1. Why does the electric field switch directions every half a period?

It needs to switch because every half circle the ions change direction and a constant field would speed them up and then slow them down. This is similar to why a commutator is needed for a motor.

1. **Maxwell’s equations and fields**:

Faraday developed the experiments and field concepts for these equations, but he did not have the mathematics to take it further. Maxwell’s genius was to recognize Faraday’s genius and to apply a mathematical language to Faraday’s work. Our students’ mathematics is at about the same level as Faraday’s. An introduction to Maxwell’s Laws can help unify what they have already learnt and strengthen the importance of the field model

See the PowerPoint slides for the equations and illustrations.

1. The first two equations and their diagrams tell you about a fundamental difference between electric and magnetic fields. What is it?

There are no magnetic monopoles. That’s what the zero tells us.

1. The third equation tells how an electric field can be formed by a changing electric field. What devices use this? generators, transformers
2. The fourth equation tells how a magnetic field can be formed by a changing electric field (current). What devices use this?

Electromagnets, motors, speakers.

1. Maxwell added an extra term to the fourth equation. What does this predict? How fast does this move?

Maxwell’s most important contribution was adding this term for reasons of symmetry between electricity and magnetism. It led to the prediction of an electromagnetic disturbance that would move at a speed of 3 x 108 m/s. This was first confirmed by Hertz for radio waves.

We started with a concern that fields was just a hand-wavy idea and we have ended up with the realization that light – which is very real – is made of EM fields.

Light’s behaviour at very low intensities requires a particle – not field – model. That leads to Quantum Physics.

1. **Summarizing fields** **(up to 1905)**

Minute Physics: **Real World Telekinesis** <https://www.youtube.com/watch?v=NMgcX8UNIGY>

Would you show this video before or after the activities and discussions done today? Why?

Perhaps both? A first viewing can give you the sense that you understood something. After going through these investigations, you will realize that you understand so much more. Real understanding takes time and effort.

1. **Fields and special relativity (1905**):
Electromagnetic radiation is made of changing electric and magnetic fields. Its velocity was calculated from two universal constants which are the same in all reference frames. This suggests that the speed of light is the same in all reference frames.
2. Suppose a space ship is travelling towards you at ½ c. The light from its headlights approaches you at \_\_\_\_\_
3. ½ c B) c C) 1 ½ c

Explain:

Maxwell’s equations give the speed of light using universal constants, which suggests that the speed is always the same regardless of your frame of reference. This realization led to Special Relativity. The answer must be B.

1. Einstein used the invariant speed of the electromagnetic fields to predict that time and space would change with one’s frame of reference. Special relativity is at work in
2. nuclear power B) GPS C) PET scans D) all three

D: Nuclear power converts small amounts of mass to large amount of energy using E = mc2

The GPS uses SR to deal with the slower time on the satellites.

PET scans use positrons, one form of anti-matter. Antimatter was predicted by Dirac using Einstein’s full equation E2 = (m c2) + pc)2 and considering what the negative root might mean.

1. **Fields and general relativity (1915):**

GR says that gravity is a fictitious force – a result of the curvature of space time. Masses curve spacetime and this curved spacetime tells masses how to move. Its predictions have been confirmed for gravitational

A) red shift B) lensing C) waves D) all three

D: The red-shift is not the cosmological red-shift of the Big Bang. It is the slowing of time in a gravitational field. It has been measured on Earth and for white dwarfs. It is essential for the GPS.

Gravitational lensing was predicted by Einstein but he didn’t think we would ever be able to detect it. It has not only been detected but it is now used to help astrophysicists see more. It is used to locate black holes and dark matter. This year, for the first time, we should see its effects on the supermassive black hole at the center of our galaxy.

1. **Fields and the standard model (1970”s):**
2. How is the repulsion of like charges explained?

Conservation of momentum by the exchange of virtual particles. Virtual particles vilate conservation of energy, but they do it so fast that this cannot be detected because of the Heisenberg Uncertainty Principle.

1. How is the attraction of unlike charges explained?

Reverse conservation of momentum by the exchange of virtual particles.

1. What holds the nucleus together?

The strong magnetic force which is the results of the exchange of gluon particles.

1. How is the weak nuclear force different from other forces?

It does not push or pull. It determines which decays can occur and what their probabilities are.

1. Why were they looking for the Higgs boson for 25 years?

Finding the exchange particle, confirms the presence of the Higgs field.