The National Physics Curriculum May 2012 draft – Some comments from Keith Burrows

> *"We've arranged a global civilization in which most crucial elements – transportation, communications, and all other industries; agriculture, medicine, education, entertainment, protecting the environment – profoundly depend on science and technology. We have also arranged things so almost nobody understands science and technology. This is a prescription for disaster. We might get away with it for a while, but sooner or later this combustible mixture of ignorance and power is going to blow up in our faces"* -- Carl Sagan

On looking through this suggested physics curriculum a number of people have said "This just doesn't grab me - and it won't grab kids either". So where is the problem? Most (but certainly not all) of our favourite topics are there, but somehow there seems to be a lack of a coherent story that leaps out to inspire us.

The story that IS there is 'models'. We start with models of heat, the nucleus and electric circuits. Then we move on to modelling the motion of 'point masses', waves, sound and light. These models consist of various types of particles and the forces on them. In year 12 we get to add 'fields' to our models and expand them to include electromagnetism and the 'serious models' - relativity, quantum and the standard model.

As a philosophical construct this is probably all very fine. But hang on, we are trying to INSPIRE young people (including teachers) to LOVE and ENJOY the way physics, and science generally, looks at the world – the REAL world. The real world is full of fascinating PHENOMENA! There are rainbows, falling objects, lightning, planets, quasars, electric power plants, bridges, aeroplanes, induction motors (such elegance!) not to mention an expanding universe with dark energy ... the list is endless. These are REAL things not models.

Physics for EVERYONE!

Furthermore we are not (or should not be) providing simply a pre-university course for students who will go on to study science or engineering. We want to attract those who will go on to become journalists, lawyers, economists, hairdressers, and even politicians! We have to excite our students with the very **human** nature of the subject. It is not just about the latest gadgets, it is about **the most important way in which humans have come to understand and respect the world around them**. As Carl Sagan suggests in the quote above, we need to educate ALL students in this most crucial 'natural philosophy' if we are to avoid the sort of dangerous nonsense we are currently seeing, for example, around the issue of climate science denial. This is not an argument to include climate science as such, it is an argument to suggest that we need to educate ALL our students to see the importance and relevance of science – and particularly physics as it is the most fundamental of the sciences.

The amazing thing is that physics (yes, particularly physics) has, as the result of the inspired efforts of countless human beings, come up with a coherent picture of how this world of ours works. There are plenty of mysteries left, but on the basis of careful observation and reason we have built up a fascinating picture of matter, fundamental forces and the relationships between them. Physics is the story of a great human adventure. It is this HUMAN ADVENTURE that will inspire, not a set of models. The fact that it is not complete or perfect simply makes it all the more adventurous. But mostly, it is a human story that every modern citizen should be able to relate to. Imagine how different the political scene could be if more 'citizens', not to mention the politicians, could relate to science! At present we even seem to have a growing 'anti-science' movement. Or perhaps even worse, a 'make-up-your-own-science' movement.

Physics is not a set of separate unrelated topics connected by abstract concepts.

One problem a number of us see with the proposed curriculum is that it seems to be more a set of separate topics than a coherent story. Certainly there has been an attempt to connect them with some 'themes' – mostly the 'model' theme. There also seems to be a progression from 'force models' to 'field models' as we move from year 11 to year 12. But the progression **from** forces **to** fields seems very artificial. For example, when discussing gravity, it is the gravitational **field** that is most obvious to us – we live in a gravitational field, things fall! Universal gravitation, the **force** between any two masses, is a much more abstract concept (which is what was discovered by Newton).

On the other hand, we do not experience electrical **fields**. What we **experience** are electrical **forces** – the electrostatic force between a comb and bits of paper for example. So that while it is natural to progress from **gravitational fields** to gravitational **forces**, it is natural to progress from **electrical forces** to electrical **fields**.

It is artificial, therefore, to suggest that somehow the 'force model' should always come before the 'field model'. This results in such odd statements as *"A field model is used to explain the force applied by one mass on another mass"*. Surely it is the other way around? We experience the field, but as Newton showed, it is the field that is explained by the gravitational force between masses.

And then, for the field model for electromagnetism, we find that "*The electromagnetic field model assumes that all charges are surrounded by an electric field and that moving charges are surrounded by an electric and a magnetic field"* and **then** *"Coulomb's Law states that ..etc."*. Somehow the force between charges (Coulomb's law) is supposed to **follow** from the 'assumption' that all charges are surrounded by a field. Surely the force is the fundamental thing (it is called a fundamental force after all). Surely the field is simply a convenient way of describing the force in more complex arrangements of charges.

Physics is not a set of 'models'

Reading through this curriculum one gets the feeling that physics is a set of models you pull out to explain a set of separate phenomena. Physics almost seems to be the **art** of making up models to explain things, rather than an investigation of the real world.

Professor John Rice (executive director of the Australian Council of Deans of Science) speaking about the curric on ABC radio: *"They make out that scientific knowledge arises as a consensus amongst scientists and in fact in some formulations of that, it goes so far as to make people think that it's possibly simply the fantasies of a bunch of scientists. And it's certainly not that."*

Prof Rice may be overstating the point a bit, but he is reacting to the same feeling that I have heard expressed a number of times: the curriculum seems to suggest that physics is not so much about investigating the real world as about making up models to 'explain' it. Perhaps this explains why some people (including a potential Prime Minister) seem to feel that science is some sort of 'belief system' and therefore you can accept or reject it depending on your political persuasion.

Here is an example: *Mechanical waves are transverse or longitudinal periodic oscillations of particles in a medium that transfer energy through the medium...* This is the start of *Mechanical models of waves*. After a number of dot points (which are equally exciting) we get to the next section *Wave model of light*:

The wave model can be used to explain phenomena related to reflection and refraction ... Light exhibits many wave properties; however, it cannot be modelled as a mechanical wave as it can travel through a vacuum A transverse wave model explains a wide range of light-related phenomena.

So physics is about making up a wave model and then using it to 'explain' light. I have quoted this at some length because I think most people will see that the reaction of the students will be *boring... boring!* Let's try a different approach:

Seeing the light

What is light? Simple question, but an endless answer! But another fascinating story in the great human adventure we call physics. There are so many ways of thinking about light. A good place to start is in trying to describe what we know about light – not a bad place for any physical phenomenon really. This leads to all sorts of questions. How fast does it travel? Or is is instantaneous? How can we measure its speed? What causes it to split up into colours? Why does it refract? Why does a rainbow form? Some of these questions we can answer in the lab with reflection and refraction experiments. (And, incidently we can find out how lenses and optical instruments work.) Others we can read about – Galileo's attempts to measure the speed and then later more successful ones. Sooner or later we get to wonder what light IS. We can't see it, so we have to use our imagination. NOW we can talk **models**! Is light some sort of particle? Or is it a wave? We can try out these ideas. THIS gives us a REASON to look at the properties of waves.

Having looked at wave and particle models (and finding that the wave model seems to work best) we are left with the question, well what is waving? Please don't START a study of light by saying "well light is an electromagnetic wave" (as in the Victorian unit 2 SD). What does that mean to a student who has little understanding of waves, much less electromagnetism? (This is NOT suggested in the draft fortunately, but the question then remains, what sort of wave is light? In the electromagnetism section em waves are mentioned, but without any reference to light.) Let's develop the questions first so that the answers have some meaning. A simple interference experiment to actually measure the wavelength of light waves is a great way for students to get a real feel for the wave nature of light. Physics is about HOW we know things, not just a list of what we know. Leave that to Wikipedia. The fact that the wave model, which seems so successful, breaks down later can perhaps be hinted at, but not discussed at this point. We have no basis for it yet. And let's leave the question, "what is waving?", with a few hints about the fact that it might have something to do with electricity and magnetism at this point. To just state that light IS an electromagnetic wave takes away the sense of curiosity. (The fact that some of them will 'know' that it is an EM wave doesn't make any difference. The question is HOW do we know?)

So where do we start?

The point that comes out of all of the above, I suggest, is that the curriculum draft appears to be more a philosophical statement about the structure of physics, than a document aimed at exciting young people about the world of physics. Of course I realise that in the SHE strand there is a lot about physics in the real world, but the essence of a curriculum is the content. Unless that will support 'science as a human endeavour' there is little point in all the fine sounding statements in the SHE strand.

So rather than starting with a series of 'models', let's start with the **real world**.

Teaching physics in a historical context might not seem very 'fashionable', but in fact it does relate to the way in which teenagers develop their own picture of the physical world. It simply makes sense to them to follow the way humanity has come to understand the way works.

So where does this human adventure start? Not, I'm afraid with "the kinetic particle model describes matter as consisting of particles in constant motion". Perhaps it does start with Aristotle puzzling over the confusing pattern of the speed of falling objects? Or Ptolemy describing the orbits of the heavenly bodies around the Earth? Certainly it soon arrives at Galileo's 'argument' with Aristotle about objects all tending to fall at the same rate. Kids will relate to that because they have exactly the same difficulty with Galileo as Aristotle did! Working through all that helps them to UNDERSTAND – as distinct from simply parroting answers to questions from text books and then going on thinking just like Aristotle in everyday life (as has been shown over and over in various surveys).

Newton may or may not have been hit on the head by an apple, but it makes the story of the discovery of universal gravitation something more human, something that kids can relate to (more than 'objects modelled as point masses and acted upon by forces'). What did Newton think after that experience? What connection did it all have to the Moon? Furthermore it introduces the students to the first of our fundamental forces – and indeed to the whole concept of a fundamental force.

Teaching physics in a 'historical context' certainly does NOT mean putting in a few dates and a some pictures of 'old men'! It means trying to get inside of the heads of some of the world's greatest thinkers and puzzling WITH them about the big questions they were trying to answer.

A simple example: Galileo wrote a 'dialogue' between three speakers, Simplicio (representing Aristotle), Salviati (Galileo himself) and Sagredo (the open mind, ready to learn). In this dialogue, Galileo, through Salviati, puts the case that Aristotle's theory of the motion of falling objects is self contradictory. It is a GREAT example of the way in which science works and one which our students can easily relate to. The fact that Aristotle lived 2000 years before Galileo is irrelevant, the important point is the clash of ideas and the development of a new way of thinking about the world.

It might be argued that students already 'know' Newton's laws after having done them at year 10. But being able to plug some numbers in a formula does not mean that they UNDERSTAND the laws. How many of us find that students coming into year 11 actually understand the concept of inertia or inertial frames of reference for example? It would be great to think that all students coming into year 11 have a good background in physics and have been taught by inspired physics teachers. Unfortunately we all know the reality.

Mechanics, fundamental physics

Mechanics has traditionally been taught first in a physics course for two simple reasons. First, historically it is where natural philosophy all started, and second, it is **more concrete and simpler to understand** than, say electricity. It is where we can develop a proper understanding of the **concept of energy** which is so vital in every other area of physics. It is also, as suggested above, an area where the human context can be used very effectively.

The concept of energy is fundamental to physics. Certainly students will have developed some qualitative ideas about it by the time they enter year 11, but they have not developed a clear idea of the fundamental notion that some form of **work** has to be done in order to **transfer energy**. As we all know, students easily mix up concepts such as energy and power until they have a basic grasp of the **fundamentals** of work and energy.

Gravitational potential energy is easy to picture, electrical potential energy is much more abstract. If the student has a good understanding of GPE then it is much easier to develop the idea of electrical potential energy. If, for example, we wanted to teach electric circuits before a sound understanding of potential energy is developed then the concept of electrical potential energy per unit charge (voltage) – which is basic to any real understanding of electric circuits – simply becomes a concept defined by its definition with no real meaning to the student. Sure, we can plug numbers into formulae and follow the rules, but does it lead to any real understanding of electrical circuits? The fact that students so often mix up even the basic concepts of voltage and current illustrates the fact that they have not developed a real feel for what is going on in a circuit.

Starting with basic mechanics gives the students a sound understanding of the fundamental concepts, in particular, force, work, potential and kinetic energy which they will use in virtually all other areas of their study.

We could also add that after studying energy in mechanics we have a good opportunity to introduce basic thermodynamics – the law of conservation of energy (first law) as well as the idea that some types of energy are of 'higher quality' than others (second law).

So why not 'Models in Thermal, Nuclear and Electrical Physics'?

As outlined above, mechanics is the one area in which the real nature of force, fields, work and energy can be developed in a concrete way which the students can relate to easily. They can literally FEEL the forces, work and energy involved. To teach thermal, nuclear or electrical physics without that basic understanding of those fundamental concepts will simply involve more of the 'hand-waving' approach that the students will have experienced at lower levels (where it is more appropriate).

Reading through the dot points under 'Kinetic particle model – heating processes' one sees terms such as the following:

average kinetic energy, changes in internal energy, capacity to do mechanical work, work done by the internal energy of the system, change in internal energy of a system is equal to the energy added or removed by heating plus the work done on or by the system. These are all complex applications of the basic concepts of work and energy developed in mechanics. If they are introduced right at the beginning of the course before students have had a chance to develop their understanding of them in more concrete situations they will be confused – and quite likely put off physics for life!

What about nuclear?

We have taught the atomic model early in our VCE physics course for quite a while now. Does it work? On one level it does seem to. Kids are interested in radioactivity and nuclear energy. However, how much of what the students are learning is simply rote learning? Do they really understand HOW Rutherford discovered the nuclear atom? Can they really discuss the relative magnitudes of the electric and nuclear forces without any idea of Coulomb's law and inverse square rules? Do the relative masses of atomic particles make any sense unless we can give them some evidence of how we know they have the masses they do? What does nuclear energy mean when they have not yet developed the idea of the relationship between work and energy or between kinetic and potential energy? And of course the idea of the equivalence between mass and energy is pure hand-waving at this stage.

So isn't the logical place for the nuclear model after mechanics and electromagnetism? Maybe we should look at replacing 'The Standard Model' in unit 4 with a more basic section on HOW we know what we know about the atom? The students have done the basics of atomic theory at lower levels, and so they know enough to cope with the simple atomic ideas in electricity and magnetism. Nuclear energy certainly is an important topic in a physics course, but at the beginning of the course it really is nothing more than a 'hand-waving' exercise. Later, we can talk about the **meaning** of energy measured as MeV's and the hugely greater nuclear forces compared to electrical ones (because we will have done Coulomb's law and inverse square laws). And if we have done Einstein's Relativity it is a great example of $E = mc^2$!

... or electricity?

The draft curriculum has electric circuits in the first unit, followed by mechanics in the second and Coulomb's law and electric fields in the third. I want to argue that circuits should **follow** the development of the concepts of energy in mechanics, and of the fundamental electrical force and fields.

It might be argued that sound concepts of potential energy and Coulomb's law are unnecessary provided we have suitable 'pedagogical scaffolding' in place to support the students' development of an understanding of electrical circuit models. An example would be a water analogy for electrical circuits. I would argue, however, that at this stage the students need a much more accurate picture of what is happening in an electrical circuit. Clearly the water analogy breaks down in many ways once we start asking questions about the flow of positive and negative charges and what really constitutes an electrical current. The water analogy also leads to misleading notions such that the battery 'pushes' the charges around the circuit like a pump pushes water around a pipe. The water analogy may be ok in junior science (I would question that actually) but surely it is not appropriate in senior science.

In order to establish the idea that a battery sets up an electric field around a circuit we need to develop the concept of a field. It is not sufficient to simply say that a field is a 'region where a charge experiences a force'. The obvious question is 'why is the charge experiencing a force?' In order to answer that we need to establish that the Coulomb force exists between all charges – rather like the gravitational force that exists between all masses.

As pointed out earlier, while we tend to talk about the gravitational **field** before we talk of universal gravitation (force) the situation in electricity is somewhat reversed. We **experience** the gravitational field of the Earth while the concept of universal gravitation is somewhat more abstract. On the other hand, what we **experience** in electrostatics is the **force** between two charged objects. From this it is easy enough to move to the force between two 'point' charges – Coulomb's law. The concept of the electric **field** then **follows** from the idea of the **force** around a charged object. The battery then establishes the electric field around a circuit by creating a varying 'concentration' of charges around the circuit. This happens 'at the speed of light' (almost), but the current is the movement of charges in response to this field. And of course positive charges move in the direction of the field and negative ones in the opposite direction. We have established this idea of positive and negative 'charge flow' quite simply, and without having to resort to strange ideas about 'negative water' to try to explain why electrons don't move in the direction of the current. Or worse, that 'conventional current' is opposite to the 'real' current, the flow of electrons!

Having established the idea of a force between charges, it is easy to paint a reasonable picture of **potential difference** (voltage). Clearly, in pushing charges closer together we are storing energy (just like lifting a weight or compressing a spring). The amount of energy stored up by pushing a whole lot of charges together is the voltage (for each unit charge). This is a much more satisfactory picture than trying to draw analogies with water pressure (which is NOT a measure of energy per anything). But in order to achieve this understanding of p.d. we need to have a sound idea of what potential energy in general is. And that is best established by thinking about the much more concrete example of gravitational potential energy. That is, electricity must follow mechanics.

Students notoriously mix up concepts in electricity. They will often say, for example, that voltage 'flows' around a circuit, or that a light bulb will glow if connected to the + side of battery even if there is a break in a circuit. In other words, they don't really know the difference between voltage and current. If they **do** understand that a potential difference establishes an electric field in a conductor, and it is this that drives the current, these misconceptions are avoided. But this requires a sound understanding of electric forces and fields, and of electrical potential energy.

Most students will have had some introduction to electric circuits previously, but in many cases bad analogies and a formulaic approach to it all will get in the way of a sound understanding of circuit theory. We are all familiar with having to help students 'unlearn' some of the misleading ideas about electricity they have picked up either at school or from the internet! A physics course is (hopefully) not about learning techniques to solve electrical problems, but about developing a sound UNDERSTANDING of electricity – from which the ability to solve problems will flow easily. Furthermore, we will have developed a good basis for exploring more complex electrical situations.

One of the most significant 'applications' of physics in the modern world is surely the **information revolution**. One might hope that this deserves at least a passing mention in a 21st C physics course! The idea of a simple voltage divider circuit with a light or heat sensor (LDR, PD, thermistor) as a detector/controller is a simple application of basic circuit ideas and should surely be included. One might also hope that the transistor (and its descendants) might rate a mention as the basis for ALL the modern electronic gadgetry we are so obsessed with! The fact that we don't seem to have any mention of photonics, the interaction between electronics and optics also seems to be an unfortunate oversight.

So where should electricity come in our curriculum? Certainly not at the start of year 11 I would argue. And definitely AFTER mechanics.

Could we start with light? And more on models.

As outlined above (Seeing the light) if we treat the study of light as a series of questions about the properties and nature of light it is not particularly dependent on more advanced concepts of forces and energy or electromagnetism. It could therefore be an appropriate 'introduction' to physics in year 11. Furthermore, it is an inherently interesting topic to most students and provides many opportunities of experiments and investigations. If we are looking for an alternative to starting with Mechanics perhaps it could be light.

It also introduces the concept of 'models' in physics in an appropriate context – ie. how can we understand the properties of light? As distinct from the 'top-down' approach suggested in the draft. There, the properties of waves are studied before light and then used to 'explain' the properties of light: *"A transverse wave model explains a wide range of light-related phenomena"*.

There is a subtle but important difference here. It is important that the idea of the models (particle or wave) is introduced not as a way of 'explaining' the properties of light, but as an answer to the question, "what do these properties of light that we have discovered suggest about the nature of light?" It might sound similar, but the first approach leads to the sort of criticism that we have from Prof John Rice (*Physics is not a set of 'models'* above) while the second more appropriately reflects the place of models in science – a useful way of approaching what we see as the reality of the phenomena. Physics doesn't use models to 'explain', it uses them as a path toward 'understanding'.

This is not the end of light!

In fact it is just the start. Understanding the nature of light is a recurring and very important theme right throughout physics. Clearly the question we are left with at this stage (the beginning of our study) is; If light is a wave, what is waving? And if we know the wavelengths of visible light, what if we increase of decrease it? When we discover that electromagnetic fields can propagate, are they the same as light? How do these EM waves travel through a vacuum? Is there some medium in space that carries them? An aether? Does the relative velocity of light behave in the same way as sound? How can we measure the relative velocity of light? And what does it mean that we find it has a constant velocity whatever our relative motion? Later, of course, we find that the wave model breaks down and it looks more like a particle!

The point, of course, is that light can be used to tie together a lot of very important physics. The central ideas in physics weave and wind through all of the content. The connection between light and electromagnetism is one of the triumphs of physics. But just stating that "light is an electromagnetic wave" is not SHOWING the connection – or giving kids that great feeling of wonder and achievement that can happen when we finally bring them together. (As we used to many years ago incidentally!)

Everything is connected

As suggested above, the continuing study of light leads us to both Einstein's Relativity and to Quantum physics. Rather than having these topics presented as separate 'add-ons' in unit 4, they could be introduced as part of the developing story of our understanding of the nature of light. Just as Einstein's theory was developed out of earlier ideas of motion and electromagnetism, we should be preparing the students for twentieth century physics by giving them the appropriate grounding. After all, we DO have the benefit of hindsight!

There is no time at present to map this development out in detail, but hopefully it can be seen that because of the strong connections with light and electromagnetic theory, Relativity does not need to be something separate and isolated, but part of the evolving 'story of physics'. In fact, Relativity starts right back with Galileo and Newton.

Inherent in Galileo's law of inertia, is the 'Principle of Relativity' (that all velocity is relative). Here we have a starting point for **Einstein's 'Theory of Relativity'.** We can discuss **Galileo's** idea of relativity AND set the scene for the later development of Einstein's relativity. Newton realised that he was making an **assumption** about the nature of space and time – that they were 'straight' and independent. (Did Newton make an assumption about an absolute rest frame as suggested in the draft? Not sure that's true?) We can also include this with our discussion of his laws of motion. It just raises ideas in the students' minds that later can be built upon. Don't forget that they HAVE heard of Einstein and they will be curious about the reasons for his fame. To start setting the scene at this stage helps to raise the students' curiosity and interest. It gives them something they can look forward to in the 'physics adventure'!

Just as Einstein's Relativity emerged from problems in classical physics, so too it should not just come 'out of the blue' for our students. We should be setting the ground work as we go through the course.

The same applies to quantum physics. Right back when we wonder whether light is a wave or a particle we are setting the scene for the quantum picture of the world. Rather than *"Quantum theory, which postulates the quantisation of light, is used to explain..."* we should be starting with the **experiments** (the photoelectric effect) which led scientists to question whether the wave model was an adequate picture of the nature of light. Again, we seem to have an approach that we start with models that 'explain' things rather than starting with the real world (experiments and observations) which lead us to develop models which help us to **understand** the world. Our object is understanding, not model making.

There is no time here to examine the merits of the 'nuclear model' (unit 1) and the 'standard model' (unit 4) but they are of course related. Rather than a hand-waving nuclear model in unit 1 and a rather abstract standard model in unit 4, would it not be better to develop the picture of the atom and the nucleus as one of the intertwined themes throughout the course as we develop more sophisticated ideas about forces, energy, light and matter?

The big picture

Perhaps the best way to tie the whole course together at the end is with a look at the 'big picture' – Astrophysics. Here we have one of the most important areas of physics and yet it doesn't rate a mention in the national curriculum! Surely it is one of the main 'interest areas' that attracts students to the subject. It is an area which has the potential to excite students about the power of physics to understand our world. It also ties together ideas about light, electromagnetism, relativity and nuclear physics (including Higgs bosons and the like!).

Finally, there has been a lot of talk about getting kids interested in physics at the start of year 11 by doing 'sexy' topics – no let's just say topics that grab their attention! But what will actually build the numbers in physics are not the 'gimicky' topics at the start of year 11, but the students who leave year 12 saying 'wow, that was a great subject to do!' The message will eventually get around (with a bit of luck even to careers advisors!) It's not bits and pieces of 'interesting' topics that will do this, it is a coherent, human, story of discovery and understanding that runs through the whole course.

There is much more that needs to be said and argued over with the suggested draft and this paper is simply one attempt to get this discussion started.

Just one more comment on models. Those of us trying to convince the public of the importance of climate science often come across the objection that "oh it is just computer models that predict warming – and we all know how reliable they are don't we - ha ha!!". I feel that we must reinforce the impression that physics is about the real world in which our students live, work and affect the future, not make it into some abstract modelling game played by 'geeks'.

As Carl Sagan suggested, unless we can convince many more people that an understanding of the "most crucial elements of our global civilization" is worthwhile then "this combustible mixture of ignorance and power is going to blow up in our faces". We don't have to look very far in this world to see that this prediction just could come true.

Let's not underestimate our potential to make a real difference to the way modern people see our world!