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THE SCIENCE EDUCATION REVIEW

Ideas for enhancing primary and high school science education

Did you Know?

Functional Magnetic Resonance Imaging (MRI) may revolutionise research in education. MRI scans can monitor the activity of parts of the brain while experimental subjects are involved in thinking processes, because the part(s) of the brain being used experience an increase in blood flow and hence a decrease in the concentration of deoxyhemoglobin, which is paramagnetic.

In a study reported by Moore (2004), a particular kind of tutoring was shown to be superior to other interventions in developing, in 6- to 9-year-old children with reading disability, an area of the brain associated with skilled reading. This study, authored by 13 persons with expertise in areas that include psychology, child development, pediatrics, education, physics, radiology, imaging science, and industrial science, also illustrates the need to prepare students to participate in collaborative research that spans broadly diverse areas.

Imagine the questions that functional MRI may be able to help answer. For example, what regions of the brain are associated with thinking as a chemist? How do particular learning methods affect brain activity and development? Are such effects short- or long-term? Would examining brain activity provide a better way to evaluate learning than present methods?

Reference

Moore, J. W. (2004). Watching the brain think. *Journal of Chemical Education*, *81*, 919.

Science Story

The stories in this regular section of *SER* may be used to enrich lessons and make them more interesting.

Franklin's Kite Experiment: Fact or Hoax?

Ask a group of students what they know about electricity experiments and the name Benjamin Franklin will undoubtedly arise. In 1742, when he reportedly conducted his famous kite-flying experiment, static electricity was a very popular field of research. It was in fact Franklin who first proposed the terms *plus* and *minus* to represent the two kinds of electric charge.

The aim of the kite experiment was to determine whether lightning was the same phenomenon as the small sparks observed in laboratories. A silk kite, with a metal spike at the top, was supposedly attached to a very long length of twine which, for safety, was in turn attached to a few metres of silk thread (a non-conductor, but only if kept dry!). A metal key was attached at the join between the twine and the silk. The idea was that the spike would draw some of the "electric fire" from the sky, and it would travel down the wet twine and charge up the key. Franklin reportedly brought a knuckle close to the key and observed sparking similar to that produced in the laboratory.

The often-asked question, of course, is why Franklin was not killed, and the response depends on who one asks. For example, one school of thought is that he was lucky in that the key was charged by only stepped leaders, rather than by a full lightning bolt. However, there are many inconsistencies and irregularities in the account of the experiment, leading Tom Tucker (cited in Becker, 2004) to recently hypothesise that there is a better explanation--that the experiment never occurred. For example:

- Nobody has ever reproduced Franklin's results, although some have been killed trying similar experiments.
- Unlike Franklin's other experiments, there were no witnesses to the kite experiment.
- Franklin was a meticulous scientist, yet the report of this experiment lacks detail.
- Franklin never did publish a report. That task was completed by Joseph Priestley, a friend and fellow scientist, some 15 years after the experiment was said to have been conducted.

Benjamin Franklin was a habitual prankster, and a master of inventing stories, even publishing many using pseudonyms. But Tucker suggests that the report of the kite experiment was more than just a prank that got out of control. Rather, he believes it was a deliberate attempt to get back at William Watson, the British scientist and scoundrel who took the credit for Franklin's idea of plusses and minuses!

Reference

Becker, B. (2004). Question from the classroom. *ChemMatters*, *22*(2), 2-3.

Assessing Learning in a Student-Centred Classroom Environment

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Abstract

The author describes the manner in which student learning outcomes can be successfully measured, in a student-centred classroom environment, using both formative and summative approaches. He argues that by carefully planning units of work and/or individual activities in negotiation with students, it is possible to ascertain what they already know and understand about a subject and what skills and interests they may bring to the study of it. It is then possible to assess the growth of students' knowledge, understanding, and skill during, and at the end of, an activity or unit of study and report on this personal growth.

To read the full text of this article (14 pages), please **click here**.

Demonstration

While the activities in this section of *SER* have been designated demonstrations, they might easily be structured as hands-on student learning experiences. Although some sample lesson sequences may be included, the notes provided both here and in the following *Student Experiments* section are meant to act primarily as stimuli for classroom activities and to provide teachers with background information, so please modify any sample pedagogy as you see fit.

Pick the Sweet Liquid

Needed. Five vessels (labelled 1-5, each containing drinking water), and cut-off drinking straws.

Tell students that our tongues are amazingly sensitive to sweet things, capable of detecting just a few thousandths of a gram. Invite volunteer students to use a cut-off straw to test the five liquids and pick the one to which a little sweetener has been added. Although all vessels contain the same drinking water, the first two students you choose should be students with whom you have previously consulted (secretly) and arranged to respond in the same way--for example, "I think it's Number 3" (or any other agreed number). Choose further volunteers (even the whole class, perhaps), record their responses, and check for how readily they follow the stooges.

I (the Editor) have found this activity to work a treat with younger students in Australia. Nine-year-olds (Year 4), for example, have strongly resisted being the "odd one out," while older children tend to be more independent in their thinking. The activity is based on a famous psychology experiment, and may be used to highlight the value of having one's own ideas and sticking with them, until you become convinced of the need to change, and the potential problems associated with "following the crowd."

The discussion may be extended to a consideration of the relative merits of subjective and objective testing, and the importance of measurement in science. When experimenting with human subjects, researchers often use double-blind testing. In a double-blind experiment, neither the subjects nor the persons administering the experiment know the critical aspects of the experiment. This lessens the influence of prejudices on the results, such as experimenter bias and placebo effects.

Source: Dunkerton, J. (2004). Solutions. *Journal of Biological Education*, *38*(3), 136.

Student Experiment

Reminder: Appropriate risk assessment, supervision, and guidance are necessary.

The Burning Candle Question

This experiment is not only interesting, but one that many books and other resources explain incorrectly.

Needed. Ceramic or metal plate (plastic ones may not work as well), measuring vessel, water, plasticine, two candles, matches or other lighter, clear glass jar.

Invitation. Measure 125 mL of water and pour the water into the plate. Use plasticine to stand one candle near the middle of the plate, and light it. Predict what might happen when the glass jar is turned upside down and used to cover the candles, with the rim of the jar resting under the water on the plate.

Teacher's Note: The Think:Pair:Share (Volume 1, p. 17) and/or Your Turn (Volume 2, p. 133) techniques are useful here, and at other places where students' ideas are being sought.

Try it, and observe any changes, noting the extent of a change, where applicable.

Students may make various observations but, for the purpose of this lesson, ask them to focus attention on the rising water level inside the jar. They should note how high it rises.

Exploration. A hypothesis is a possible explanation. Suggest a hypothesis for your observation (i.e., suggest an explanation for why it occurs).

Various hypotheses may be offered, but make sure that this one is included: The water rises because oxygen in the jar is used up (with the water taking the place of the original oxygen).

Devise a way to test your hypothesis.

We can test a hypothesis by checking the accuracy of predictions that follow from it. Guide the discussion by asking what the hypothesis predicts should happen, and why, if two candles were to be used. Ensure that both the following are raised.

Prediction 1: The water should rise higher, because more oxygen is consumed.
Prediction 2: The water should rise to the same level as with one candle, because the same amount of oxygen (all of it) is used up in both cases.

Invite student discussion about each prediction, and the associated reasoning, but leave the correctness, or otherwise, of their reasoning open.

Test you hypothesis. What do you observe? Was your prediction correct? What do you conclude?

The water will rise higher than before, in accord with Prediction 1. However, the reasoning for this prediction is not valid, for the correct reason given in Prediction 2. So, with both Prediction 2 and the reasoning behind Prediction 1 wrong, one is lead to conclude that a better hypothesis is needed (i.e., that the observations are not explained in terms of the consumption of oxygen).

Can you propose another (and hopefully better) hypothesis? If so, how might you test it?

Concept introduction. The burning of the candle needs oxygen and is, therefore, taking away all the oxygen under the jar. The flame extinguishes as soon as all the oxygen is used up.

It is also tempting to think that the water level rises because the oxygen is used up (less gas in the jar means lower pressure, and the air outside the jar pushes water up into the jar). In fact, many books make this mistake. True, oxygen is used up, but as a candle burns, other gases such as carbon dioxide are also produced and fill the jar.

The reason the pressure inside the jar eventually decreases is that the heat of the flame expands the air under the jar just before it hits the water. At that moment, air escapes from under the jar. After the flame goes out, the remaining air cools off and contracts (i.e., it fills a smaller space).

When two candles are used, there is more heat energy to expand the air under the jar just before it hits the water. This pushes more air out of the jar, so that less air is trapped inside the jar. When this trapped air cools, the water therefore rises higher than when only one candle is used.

Some students think that the two candles will burn more oxygen, but this is not the case. The amount of oxygen in the jar is the same in both cases. In any case, it is not the burning of oxygen that causes the water to rise.

Peter Eastwell

Critical Incident

An Invitation

Readers are invited to send, to the Editor at editor@ScienceEducationReview.com , a summary of a critical incident in which you have been involved. A critical incident is an event or situation that marks a significant turning point or change for a teacher. The majority of critical incidents are not dramatic or obvious, but are rendered critical through the analysis of the teacher (see Volume 3, p. 13 for further detail). You might describe the educational context and the incident (please use pseudonyms), analyse the incident (e.g., provide reasons to explain your observations), and reflect on the impact the incident made on your views about the learning and teaching process. Upon request, authors may remain anonymous.

We have undoubtedly all done things about which we were very pleased, and perhaps done other things about which we did not feel so pleased, and we all need to remain reflexive of our practice. While teachers will view an incident through the lenses of their own professional experiences, and may therefore explain it differently, this does not detract from the potential benefits to be gained from our willingness to share our experiences and thus better inform the practice of other teachers.

Setting the Boundaries

Contributed by: Gary Simpson, Woodleigh School, Victoria, Australia, on behalf of Lisa Cookman simpg@woodleigh.vic.edu.au

On this teaching practicum, I was placed in a co-educational, Victorian (Australia), government school in a middle socioeconomic area. The school has a poor reputation, and many of the students who attend are from the lower end of the middle socioeconomic scale and/or troubled homes, or have been expelled from other schools. The majority of staff have been teaching for well over 12 years, and many are dejected.

One of my classes was a Year 7 Science class, to which I was to teach a unit on forces. Having never taught at the Year 7 level before, I was a little nervous about this class. I was also unable to observe them properly with their teacher before I was to take over, so I had no idea how they might behave.

I was thrown in at the deep end. My first class teaching 7B was Period 6 on my second day. Their teacher (my supervisor) takes them for Maths and Science and treats it as a block, using the time as she needs. That is, one week they may have six periods of Science and three of Maths, the next it might be vice-versa. So on this Tuesday I was to take 7B after a Science test in Period 5. It started off in a reasonable way. However, things got progressively worse. In fact, I would say that it was a pretty bad class overall. Many of the students were off-task, and I doubt any except the bright few actually heard or understood anything I was talking about.

The teacher introduced me to the class and said I would be taking them for Science over the next few weeks. I then greeted everyone, and told them that I was going to be teaching them about forces. Mistake No. 1--I didn’t go in firm! I was friendly and just jumped straight into my lesson plan. I didn’t go over my rules or what I expected of them. I thought that seeing as though they already had rules from their teacher, they would go by them. I was wrong. Throughout the class, they pushed to see how far they could go with me and how I would react. They talked and yelled out and were very noisy. I hadn’t gone into the class with any idea of what I expected from them, how I would manage their behaviour, or what the consequences would be. I had only been thinking about what I was going to teach and what activities I would do with them. I didn’t spend the time to clearly set out in my mind the behaviour I would expect from the class, or how I would tackle misbehaviour, let alone clarify this with the students.

So, on I continued, oblivious to my mistake, asking a few questions about what they thought a force might be. I gave them a few scenarios, and asked them if there were any forces working and whether they knew the names of any. This part went okay. Fortunately, the students liked to talk and share their ideas, so a brainstorm/discussion was a good way to start the new topic. It helped me to see what level they were at, and how much some of the students knew. I had no idea of even the kind of language they would use, so this discussion was very helpful to me. However, I did notice that it was the same few answering the questions. Not knowing their names, or their comfort in answering questions in front of the whole class, it was difficult to call upon others. I think that once I got to know the students a little better, I found it easier to involve some of the quieter students. I also used the discussion to make the noisy, off-task students get back on track.

After this, I had some notes for them to put into their books. I told them what we were doing before I started writing the notes, but didn’t put a heading on the board.

Mistake No. 2--unclear topic material. I didn't think about having a heading and telling them to start on a new page. I was not used to having to tell the class every little thing that they had to do and writing it down for them. The Year 7's seem not to be able to think for themselves at times. As I learnt from this class, and the many more to come, I needed to be super clear on every instruction and set it out for them. I hope that when I have my own class, I will teach them from the start to think a little more for themselves.

They copied down the notes, and were fairly quiet while doing so. There were only three sentences, yet judging by the time it took some of them to finish, you would have thought they were writing an essay. This was yet another eye opener--seeing the different writing abilities. Some students would keep up with my writing pace on the board, while it would take others three times as long to do.

The students were starting to talk, so I ran the activity. I wanted them to discover for themselves what forces can do. It was a simple activity from their textbook, so I told them what the activity was, asked them to open their books to page 68, copy the table into their workbook, and write down their observations. Another mistake--No. 3, I believe. My instructions were unclear, and some of the students were mucking around. The activity was written clearly in their textbook, but I should have read it out loud with them. I expected that they would all read through individually, as I had asked them to do, but no one really did. Most of the students just started playing with the equipment, rather than actually testing and writing down observations as the activity asked them to do.

After this class, I was very upset. They had been noisy and I don't think anyone really did any meaningful work. Looking back, I now realise that I missed the key to starting with a new class. I should have set out my rules and expectations and outlined the consequences of breaking them. It would have set the class on the right track from the very second I met them. I realise that I am never going to have a chance to observe my class before I teach them, and that any new start to any new class requires the regulations to be set out clearly right from the second I meet them out the front of the room. I now have a strategy up my sleeve for approaching new classes. It was recommended that I put on the "bitch persona" for the first few weeks and, although I think it is necessary to go in firm, I don't want to have to put on an act to get my students in line.

I have also learnt the importance of being very clear in my instructions, otherwise the students will have no idea where to begin. To do so, I need to make sure everyone is listening (pens down, face me, nothing else but listening) and to involve the students in the instructions to make sure they understand and are taking it in (ask students to repeat steps, answer questions, explain to the class). There is then no reason for what is expected to be unclear.

I believe that if the rules are outlined, negotiated, and enforced consistently and fairly, I shouldn't have a similar situation again. I did try to clarify my expectations at the start of the second class with this group, and it worked to some extent, but I felt like I was playing catch-up. It is something that needs to be done initially, as most of the students will make their minds up about you in the first few classes, if not the very second you open your mouth and speak a few words!

I also learnt some strategies for getting the class quiet and on task, such as counting to a particular number, names on the board with a tick means detention, and writing minutes of detention for the whole class. I did keep students in on a few occasions, and the threat of this seemed to work better for some than others.

I had a few other incidents with this class, and although they weren't the most pleasant group to teach, they were mostly pretty good kids and I learnt more during that 5 weeks than I have over the past 4 years of my education degree. Experiencing a difficulty first hand, and having to deal with it for myself with the advice of my supervisors, taught me how to cope with tricky situations. The main things I learnt from this experience were that behavioural management requires strength, clarity, and consistency, and that when teaching a class--whatever age they may be--the instructions need to be clear to not only you, but the students as well.

Science Poetry

Reading and/or listening to poems that have been composed by other children their own age can inspire and reassure students as to their ability to understand and write poetry, and the science poems in this regular section of *SER* may be used for this purpose. Please find information about the *International Science Poetry Competition* at http://www.ScienceEducationReview.com/poetcomp.html .

Earth's Poem

The atmosphere has layers four
And I do not think it a chore
To tell you a little about them all
Even though it may be small.

When you go up to the sky
It is really way too high
For then you reach the Troposphere
And then it comes to my worst fear
For up there it is very cold

-55 degrees I'm told
It's 11 km above the ground
And forms a layer that goes round and round.
The Troposphere causes all the conditions
From which we form our premonitions
Of what the weather is, in days to come
And sometimes it looks very glum
Because we're to get so little Sun.

The second layer is the Stratosphere
Which is very high up I fear,
For that is where planes like to fly
But I think I would not like to try
To jump on out of an aeroplane
And land back on Earth again.
For conditions up there are very cold
It's 50 ks from the Earth I'm told.
To go up there you'd have to be brave
Or perhaps you'd just have to crave
Some adventure in your life,
Maybe once or twice
For to some people that would be quite nice.

Next up is the Mesosphere
And it gives me a little tear
Because I don't want to go up there
It would give me quite a scare
Its altitude now is 80 ks
And -100C I say.
It's not as big as the Stratosphere
It's just a fragment smaller I fear.

The last layer is the Ionosphere
But in this layer Auroras appear,
Sun rays come down with a little power
Then give us a little shower
Of green, purple, and blue lights
In the middle of our nights.

The Ionosphere is the largest part
You can see it you don't need a chart
Small space rocks sometimes come very near
But deteriorate because of the atmosphere

The Ionosphere takes one percent of our air
But there is still lots and lots to spare
This atmosphere has no end
It just keeps going again and again
Until it becomes thinner and thinner
Then it’s outer space that you enter.

And now we enter into space
And now it has become a race
To find out what it does behold
But we cannot see what the future will hold.

The Sun lets out lots of rays
That gives us all of our days
Now let me tell you of it all
Of how the sunlight rays do fall.

The Earth is tilted on an axis
But not because we pay our taxes
The Earth, you see, was made that way
And that’s how I think it’ll always stay
Where we are it’s nice and warm,
We hardly see a single storm
But for others it’s another story
And it is a little worry
For I would not like to take a stroll
Across the North and Southern pole
Cause down there it is just way too cold.
One space will have 6 months of light
Not a single sign of night
The other, 6 months of darkness
Not a single sign of brightness.

Another thing that is out of sight
Is how we get our day and night.
Our small Earth rotates which equals 1 day
24 hours as you might say
But while performing this little rotation
The Earth begins a Sun revolution.
Now this equals 1 whole year
365 days I can say without any fear.

We also have two main seasons

Winter and Summer but they’re not our reasons
Of feeling so cold and feeling so hot
It’s more the Sun’s rays that thicken the plot.
For when one side of Earth is facing the Sun
They are having Summer and lots of fun
But the other is having a very white Winter
Feeling very cold like a frozen splinter.
But the other two times when the Earth faces the Sun
We are experiencing Spring and Autumn.
Autumn is the time for trees that are bare,
While Spring is the time for flowers that are fair.

The Earth is a very curious place
Along with the many new things we can discover about space.
All you need is the thirst for knowledge
And you can find most of the answers
At the McDonald College.

Chantale Dorrington, 13 years
Australia

Students’ Alternative Conceptions

Students’ alternative conceptions have been variously called misconceptions, prior conceptions, preconceptions, preinstructional beliefs, alternative frameworks, naive theories, intuitive ideas, untutored beliefs, and children’s science. The tasks in this regular section of *SER* are based on the literature and may be used at the beginning of a constructivist learning segment to arouse the curiosity of students and to motivate them, while simultaneously eliciting their ideas or beliefs. They are designed to address areas about which students are likely to have an opinion, based on personal experiences and/or social interactions, prior to a specialist learning sequence, or areas that might be considered important for the development of scientific literacy.

1. In each of the following cases, which material is better for keeping things hot?

    (a) Aluminium (Al) foil or wool.
    (b) Glass or foam rubber.
    (c) Wood or pottery.

2. Repeat, this time choosing the better material for keeping things cold.

Comment: For both questions, the correct responses are wool, foam rubber, and wood, respectively--the poorer conductor of heat energy. Many students will likely incorrectly think that Al foil, for example, is good for keeping things like drinks, apples, and yoghurt cold, when in fact it is a good thermal conductor. Reasons for such a misconception might include the following:

- Metals are cool to touch, so they are therefore also good at "holding the cold." (The Al would actually be at the same temperature as the wool, and feel cold simply because it readily conducts heat energy away from the skin.) Extending this erroneous thinking, things neutral to the touch (e.g., wool, rubber, and wood) must therefore keep things warm. Some students may even take another (incorrect) leap in reasoning. Having learned earlier that metals are thermal conductors, and knowing that they feel cool, a conductor must therefore be something that keeps things cool--so an insulator must be something that keeps things hot!
- Family, or other, history. Try arguing with a mother who wraps her child's lunches in Al foil to keep them cold, whose mother had done the same for her, and who asks what more one could possibly need than these many years of experience to prove that it works!

Some advertising may also facilitate misunderstandings. Try these, for example:

- "Buy your BBQ chicken here. We wrap it in foil to keep it hot." There is more to such a wrapping than just the foil.
- "Improved thermos flasks, made of metal, inside and out." First, the metal is stainless steel, an alloy which is a poor thermal conductor. Second, it is the vacuum between the layers that provides most of the insulating ability.

Source: Lewis, E. L., & Linn, M. C. (2003). Heat energy and temperature concepts of adolescents, adults, and experts: Implications for curricular improvements. *Journal of Research in Science Teaching*, *40*, S155-S175.

Please send to *SER* any suggestions you may have, based on your own experience or the literature, for adding to or otherwise modifying the items in this task.

Teaching Techniques

This regular section of *SER* describes thinking, cooperative learning, and other teaching techniques.

Jigsaw

Contributed by: Patrick Croner, Venado Middle School, California, USA
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Several different jigsaw structures are possible, all aimed at making students more active and responsible learners and promoting communication skills. A jigsaw also allows a group of students to address several aspects of a topic in a shorter time than might otherwise be the case.

Simple Jigsaw. Divide your class into groups of four, say, with each member of the group being responsible for a particular section of the chapter. He/she then plans and prepares a presentation to other members of the group. I strongly encourage the students to design visual organizers to aid their presentations. This process enhances understanding, because teaching a topic requires greater comprehension than just learning it for one's own sake.

Rather than a section of a chapter, each member of the group might be assigned a sub-task of the task being undertaken, or a sub-topic of the topic being considered. They would then be required to undertake appropriate preparation to allow them to teach that topic to other members of the group, or to share their findings with the group so a report can be completed.

Expert Jigsaw. Alternatively, with sub-tasks assigned to members of each Home Group, each member meets with members from other groups assigned the same sub-task (i.e., they meet in Expert Groups) and plan a presentation to their partners. The number of Expert Groups is the same as the number of sub-tasks (which in turn is the same as the number of students in each Home Group), so students will need to take a chair with them.

Having researched and/or discussed their sub-task, and with a set of notes, the “experts” return to their home groups and report back to other members. Ideas can be modified, and the collective knowledge used to prepare a whole-class presentation by the Home Group or individual reports for the teacher.

When I teach classes of students who have not had success in a traditional lecture setting, I use one variation of the Expert Jigsaw quite extensively--each sub-task being the teaching of a section of the chapter to other members of the Home Group. The peer-to-peer interactions can be extremely effective, as students communicate with each other using jargon and phrases from their “own” language and culture. Finally, extra students can be accommodated in a jigsaw (e.g., 5 students in a Home Group, when most have 4), by assigning a pair of students to operate as a single identity.

More Mnemonics

This helps students remember the order of classification: ***K***eep ***P***onds ***C***lean ***O***r ***F***ish ***G***et ***S***ick. I think this is neat and the students ALWAYS remember it.

Jade Gopie, USA

A mnemonic I use to help students remember the five classes of vertebrates is: ***FARM*** Birds (***F*** - Fish, ***A*** - Amphibians, ***R*** - Reptiles, and ***M*** - Mammals).

Paul Beier, USA

In remembering the order of classification, my Year 11 Biology students came up with the following suggestion: ***K***en ***P***lease ***C***ome ***O***ver ***F***or ***G***reat ***S***ex. In the interests of school sensitivity, I suggested they change "***S***ex" to "***S***paghetti," and this is what we now work with. I have heard of other examples for this same task, but have found that having students create their own mnemonic is very powerful.

Grant Eyles, Victoria, Australia

This mnemonic is for the first 20 elements of the periodic table: H, He, ***Li***ttle ***Be***tty ***B***oron ***C***auses ***N***othing ***O***n ***F***reds ***Ne***ck, Na, Mg, ***Al***l ***Si***lly ***P***eople ***S***ip ***C***h***l***orins ***Ar***ound ***K***ym and ***Ca***llie. It not only helps students remember them, but also gives the symbols for each element. Year 9 and 10 students enjoy using it.

Bruno Testa, Beaconhills College, Victoria, Australia

Turning Around Newton's Second Law

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Abstract

Conceptual and quantitative difficulties surrounding Newton's second law often arise among introductory physics students. Simply turning around how one expresses Newton's second law may assist students in their understanding of a deceptively simple-looking equation.

Think of the equations in physics that have made their way into the popular culture. Physics educators at all levels relish the idea that even a small part of our scientific culture pervades the society at large. One of the pitfalls of this widespread knowledge is that students entering the study of physics may have deeply ingrained misconceptions that can take years to correct. An example of this is Einstein's famous $E = mc^2$ equation from special relativity. Einstein's equation rolls off the tongue of most nonscientists, even if they have no idea what the equation means. Introductory physics students can enter a first physics course in high school or university with that equation in their heads. When an instructor tries to include a little modern physics at the end of an introductory course, students may have a tough time understanding that while an object's energy can change, its mass is an invariant. The equation $E = mc^2$ that students know so well is better written as $E_0 = mc^2$, though that will likely never make it to the popular culture. With the understanding that E_0 is the *rest* energy, the equation makes more sense (Okun, 1989). Had students never heard of $E = mc^2$, they may not have the erroneous belief that an object's mass increases with increasing speed. What I propose in this paper is that there may exist similar problems with Newton's second law.

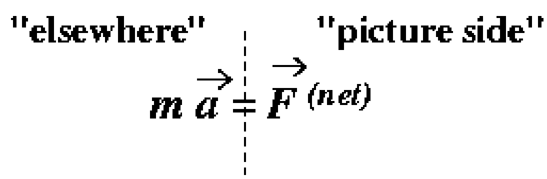
Before many students ever encounter a physics class in high school, they are taught something about Newton's laws. Most people have heard the phrase "action - reaction," even if they have no basic understanding of Newton's third law. The second law is often taught in physical science courses in the lower grade levels. The equation $F = ma$ rolls off the tongue for many people in the same way as Einstein's famous equation. However, simply saying "$F = ma$" hides much of the subtlety of that deceptively simple looking equation. For one thing, one does not "speak" the vector character of the equation when saying it. Also, one does not usually say *net* force when verbalizing the equation. Lower levels of science usually make use of Newton's second law in extremely simple cases where there is only one force acting and only one direction in which an object can move. Unfortunately, as a result of the effort to introduce physics concepts early in a student's career, students can sometimes develop the impression that using Newton's second law is as easy as "plug and chug." I have noticed over the years I have taught at the university level that I have more initial success teaching Newton's laws to students who have not had high school physics compared to those who have. Most physics educators that I have spoken with over the years have had similar experiences. Even at the high school level, most physics problems tackled by students are quite simple and can be handled using a plug-and-chug approach; the statement of a problem typically gives two of the variables and asks the students to find the missing one.

Of course, when one teaches Newton's second law at the university level, one must discuss vectors, addition of vectors, coordinate systems, and other such niceties. A student who once thought dealing with Newton's second law was merely plugging two givens into a simple equation and solving for the single unknown is forced to think in a different, and more sophisticated, manner. A typical student comment I have encountered sounds something like: "Physics was easy in high school and very hard in university." The reality, of course, is that the high school approach is often too simplistic and the university approach is not really that "hard." My own perception is that a student gets "$F = ma$" so ingrained in his or her head that trying to solve university-level problems using Newton's second law really is quite hard. Compared to a student who was never introduced to physics before coming to university, the veteran of high school physics must go through an added process of putting aside an already established notion of a "plug and chug" approach to problem solving.

My approach to solving this problem of having "$F = ma$" so easily fall off the tongue is to simply turn around the equation. When I introduce Newton's second law in my introductory university physics course, I write it as

$$m\vec{a} = \vec{F}^{(net)}.$$

Now, this may seem silly. However, I noticed several years ago that if I avoided saying "$F = ma$" with students who were struggling with Newtonian physics problems, they were quicker to achieve success than if I kept saying it. I began to wonder if the ones who kept hearing me say "$F = ma$" were not recalling how they did things in high school. To further aid students, I write Newton's second law a second time in the following way:



The idea is to convince students that there are two distinct sides to Newton's second law. Once the students have selected a coordinate system (and remain faithful to that choice!), they write equations like $ma_x = F_x^{(net)}$ and $ma_y = F_y^{(net)}$, if the problem involves two dimensions. They learn that the single vector equation really contains more than one equation. In component form, I still use the dotted line to delineate the separate sides of Newton's second law. The right side of the second law equation is obtained from a "picture" or a "free-body diagram." Once the students have made a free-body diagram and broken all forces not lying completely on one of the coordinate axes into components, they simply list the forces on the right side of Newton's second law as if they were doing "bookkeeping."

Having completed the right side, they need to look "elsewhere" for the left side. For example, is the mass given in the statement of the problem? Are we told the object is moving in a circle? Does the object move through a gravitational field? Does the problem tell us that the object's velocity is constant, thus meaning the acceleration is zero? Perhaps the acceleration is the unknown and the problem wants us to determine what the object's acceleration is if it is subjected to a given number of forces.

While I do not continue writing the “elsewhere” and “picture side” labels, and making the vertical dashed line, as the course progresses, I do maintain writing Newton’s second law with the net force on the right. I even continue this practice in my classical mechanics course.

After 10 years of teaching physics to beginning students at the university level, I have found turning around Newton’s second law to be an effective way of communicating the complexities behind such a simple looking equation. I see fewer cases of students believing that there is a force “*ma*” acting on an object. This was especially a problem when centripetal motion was introduced. I used to see free-body diagrams of, say, a car going over a rounded hill and leaving the road with two downward forces on the car, one the car’s weight (fine!) and the other labeled as mv^2/r (wrong!). Students would see something like “$F_c = mv^2/r$ is the centripetal force on an object moving in a circle” in a textbook and think that some external force “mv^2/r” was acting on the object. By turning around Newton’s second law and labeling the two sides, my students know that v^2/r (the acceleration, *a*) has to be obtained “elsewhere” (knowledge that the object is moving in a circle).

Allow me to now make this discussion more concrete by considering the following problem from a textbook popularly used in the United States. Here is the problem: “A 1000-kg sports car moving at 20 m/s crosses the rounded top of a hill (radius = 100 m). Determine (*a*) the normal force on the car, (*b*) the normal force on the 70-kg driver, and (*c*) the car speed at which the normal force equals zero” (Giancoli, 1998, p. 140).

Consider the two free-body diagrams in Figure 1.

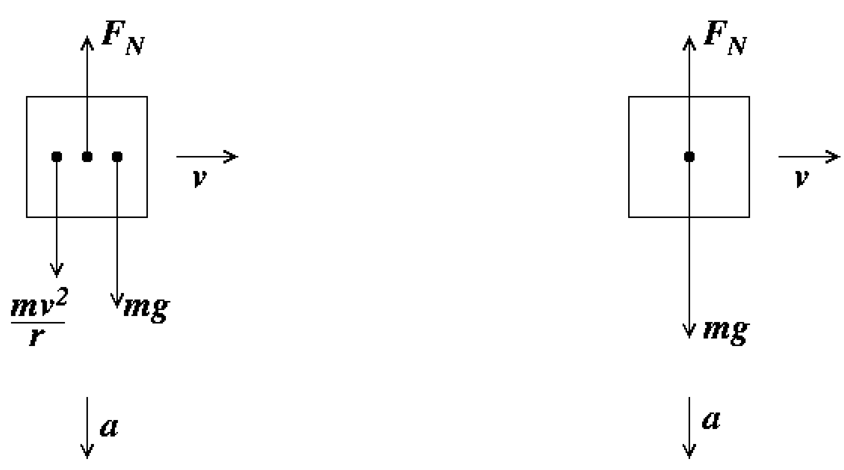


Figure 1. Two free-body diagrams for a car crossing the rounded top of a hill (*left*, incorrect; *right*, correct).

The diagram on the left is one I have seen too often from students. The one on the right is, of course, the correct free-body diagram. I teach my students to draw force vectors emanating *out* of a very simple drawing for an object (a square, in this case). They then draw the velocity and acceleration vectors, but not *on* the object. The error I have already mentioned is that many students will take a book's definition of "centripetal force" as mv^2/r to mean that such a force acts *on* the object, as seen in the incorrect free-body diagram in Figure 1. Students then get confused when writing the second law down because they do not know what to put in for a on the ma side. Some will put zero, thinking that there is no acceleration since the speed is constant (i.e., they confuse speed with velocity). In this case, students get to the "right" number, though they often have to fudge a sign to get there (try it to see what I mean!). Other students will correctly take $a = v^2/r$. However, if they use the incorrect diagram shown above, they get stuck with $F_N = mg$ and do no know what to do with part (*c*) of the problem! I usually ask students who make the incorrect free-body diagram to identify the entity responsible for the mv^2/r force. We know the Earth's gravity is responsible for mg and the road (in the case of the car) or the car's seat (in the case of the driver) is responsible for F_N. Usually, students see their error when they cannot think of any other objects responsible for forces.

Once I have students drawing the correct diagram, we move on to using the diagram and Newton's second law to solve the problem. Despite the fact that the stated problem is two-dimensional (the velocity and acceleration are perpendicular to each other), using Newton's second law boils down to a one-dimensional problem since all forces act along a single line. After having drawn the free-body diagram, I instruct my students to pick a direction for *positive* for the single dimension. I usually tell them that they make fewer sign errors if they go with the direction of the acceleration. However, I also tell them that the real world does not care what we physicists choose to call positive! (Students do run into sign errors when they read a word like *decelerate* and think that a must be *negative*. The acceleration is *only* negative if the chosen positive axis is opposite in direction to $\vec{a}$.) With *down* as positive in the diagram, the "picture side" says that $F^{(net)}$ simply becomes $mg - F_N$. Turning to the "elsewhere" side of the second law, the students must determine that, because the car moves on a circular path, $a = v^2/r$. Putting everything together then gives $m(v^2/r) = mg - F_N$. Now, the students can use this single equation to solve both parts (*a*) and (*b*) of the problem by simply inserting the relevant mass in for m and solving for F_N. I try to stress doing a little algebra before plugging in numbers; although this is tough to get across to introductory students. Holding back on numbers, solving for the normal force gives $F_N = m(g - v^2/r)$. For part (a), F_N = 5800 N and for part (b), F_N = 410 N (both with two significant digits only). If students hold off on plugging numbers in for the various parameters, they will discover in part (*c*) that the answer is independent of the mass. Letting the normal force go to zero means that the weight is the only force providing the centripetal force needed for the car to round the hill. If the car goes too fast, meaning too large a *v*, *r* must increase (because *mg* cannot change) and the car leaves the road. Solving part (*c*) with $F_N = 0$ gives $v^2 = gr$, from which we obtain $v = 31$ m/s.

I will conclude this paper with a few disclaimers. There are many fine high school physics teachers who do indeed give their students a proper grounding in using Newton's second law to solve physics problems. However, my experience is that too many of my students who have taken a high school physics course have a "plug and chug" mentality when it comes to tackling physics problems. There is, of course, a "plug and chug" mentality in many of my students who have not taken high school physics. However, they are easier to acclimate to the proper way of using Newton's second law than the other students. I should also point out that my field of research is not physics education and that the experiences I write of here are limited to my own interactions with students and the scores of discussions I have had with colleagues. My goal in writing this paper is merely to offer physics educators yet one more idea for how they might better facilitate students' understanding of Newton's second law.

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Giancoli, D. C. (1998). *Physics: Principles with applications* (5th ed.). New Jersey: Prentice Hall.
Okun, L. B. (1989). The concept of mass. *Physics Today*, *42*(6), 31-36.

Ideas in Brief

Summaries of ideas from key articles in reviewed publications.

Whiteboarding

This is a useful way to gather evidence about student understanding in conjunction with a laboratory activity. It also mirrors the oral presentation process in which scientists engage at conferences.

After a lab exercise, Erekson (2004) asks each group of students to summarise (e.g., sketch the key features of a graph, rather than plotting the details) their work on a whiteboard. He prepares the 600 mm x 800 mm boards by purchasing a 2400 mm x 1200 mm sheet of shower panelling and cutting it into six pieces.

Groups are then invited to present their work to the class. Group members summarise procedures, discuss their findings, and invite questions from other students and the teacher. It is this last step that is the most valuable. Teacher questions might include: "Why . . .?" "What does . . . mean?" "What would happen if . . .?" The teacher also bounces the presenters' replies off the student audience. For example, questions such as "Do you agree with that?" and "How would you explain that?" can assess understanding across much of the class.

Time typically doesn't allow every student group to present every time, and Erekson (2004) aims for about three group presentations each lab, ensuring that all groups get a turn over a period of time. This teaching/assessment (as opposed to a grading) tool guides subsequent instruction, and works best in a non-threatening environment where students do not feel uncomfortable if they do not understand, or are not always correct.

Editor: I find this an excellent technique, during a hands-on enquiry task, to allow students to share and discuss their experimental designs. Overhead transparencies can be a substitute for some, or all, groups.

Reference

Erekson, T. (2004). Assessing student understanding. *The Science Teacher*, *71*(3), 36-38.

Poster Sessions Using PowerPoint

A poster session presentation is an authentic, performance-based task that allows students to communicate the findings of an experiment or other project, just as professional scientists do. Posters are prepared and displayed for guests (e.g., students, parents, and other community members) to visit, read, and ask questions of the authors. While a little less formal than oral presentation sessions, poster sessions can provide for greater interaction between presenters and visitors.

Baumgartner's (2004) students use PowerPoint software, and the following steps, to create their posters:

- Create a new file using the blank format presentation.
- Choose File/Page Setup/Slides Sized for Custom/Height 36 inches, Width 24 inches/OK. (A standard-sized poster is 48 inches x 36 inches, but typically much more expensive to print.)
- Insert text using the Text Box feature on the Draw toolbar.
- Insert pictures using Insert/Picture/… .

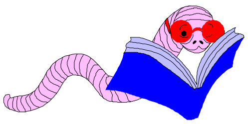
Printing requires access to a colour plotter (a printer capable of printing such large posters), and is not cheap, especially at commercial print shops. Printing costs can be reduced by:

- using the facilities of a local university or non-profit organization.
- using recycled, corrugated paper.
- using white (or at least light-coloured) background (which reduces ink usage).
- producing group, rather than individual, posters.

Plotters are priced in the 3000 USD range, and it may be cost-effective for some institutions to purchase one.

Reference

Baumgartner, E. (2004). Student poster sessions. *The Science Teacher, 71*(3), 39-41.



Research in Brief

Summaries of research findings from key articles in reviewed publications.

Factors Affecting the Teaching of Evolution

Most biologists consider evolutionary theory the cornerstone of modern biology. However, there are large gaps, in the United States, between the understanding and acceptance of the theory of evolution by the scientific community, biology teachers, and laypersons. In one poll, 40% of citizens thought it more appropriate to teach creationism than evolution in public schools, and only 57% of biology teachers consider evolution a unifying theory in biology (Moore, 2000).

Trani (2004) surveyed a maximum of 3 biology teachers in each of 79 public schools (66% return rate) in Oregon, USA to study the interplay between the following variables: acceptance of evolutionary theory, understanding of the theory of evolution, understanding of the nature of science (NOS), degree of religious conviction, and presentation of evolution in their classes. The 90-question survey and scoring guide may be found at Trani (n.d.).

Overall, biology teachers in Oregon had a high level of acceptance of the theory of evolution, high level of understanding of evolution, and moderate to high level of understanding of NOS. While many were religious, overall the sample was average in terms of their religious convictions (i.e., not dogmatic either way), and considered the presentation of evolution to have a major role, and creationism a minor role, in biology courses.

In accord with earlier studies, the following correlations were observed:

- Teachers with strong religious convictions accept evolutionary theory less often than others, and are less likely to present evolution in their classrooms.

- Teachers who do not present evolution in their classrooms are more likely to be those who do not accept evolutionary theory, and not understand both the theory of evolution and NOS.

In addition, the following correlation was found in the results of this study:

- The stronger a teacher's religious convictions, the lower his/her understanding of both evolution and NOS.

A note of caution, though. As with all correlations, these results reflect overall trends, and do not necessarily represent the traits of any individual teacher.

Trani (2004) also concluded that:

- A teacher can be religious and accept evolution, and such teachers have a strong understanding of both evolution and NOS.
- Of concern is the 16% of biology teachers who have either strong or extreme religious convictions, reject evolution on these grounds, and do not present it in their classes, yet have a poor understanding of evolutionary theory and NOS.

Members of this latter group do not present the foundations of biology and, if they did, would probably do so inaccurately, presenting, for example, creationist arguments as scientific principles. Their students are missing out on the opportunity to appreciate the nature of science, including its limitations and that science is not a belief system.

It is suggested that, in the interests of a strong, legitimate science education, schools hire only biology teachers who have a strong understanding of evolution and the nature of science. Also, perhaps biology teacher candidates should be more thoroughly screened in both these areas.

References

Moore, R. (2000). The revival of creationism in the United States. *Journal of Biological Education*, *35*(1), 17-21.
Trani, R. (n.d.). *Darwin's champion*. Retrieved October 23, 2004, from http://darwinschamp.tripod.com/ .
Trani, R. (2004). I won't teach evolution: It's against my religion. And now for the rest of the story…. *The American Biology Teacher*, *66*, 419-427.

? ? ? ? ? Your Questions Answered ? ? ? ? ?

This section of *SER* responds to readers' queries, so please submit your question to The Editor at editor@ScienceEducationReview.com . Have that long-standing query resolved; hopefully!

Why don't birds get hit by lightning?

They do.

Michael Crescimanno, Youngstown State University, OH, USA

Lightning strikes many flying objects, such as aircraft, gliders, balloons, and rockets, so there is no physical reason why birds will not be stuck. The flying objects struck include those of very low electrical resistance, such as metal-skinned aircraft and rockets, and others of high resistance, like aircraft and gliders made of non-metallic materials such as wood, fibre-reinforced glass (FRG), and carbon-fibre composites (CFC). The resistance of birds is likely to be intermediate between the two extremes.

There are two modes by which a flying object might be struck by either cloud-to-ground or cloud-to-cloud lightning:

1. The object just happens to be in the lightning's path. Obviously, large objects like modern jet aircraft are far more likely to be struck than small objects like birds.

2. A large metal object can actually trigger a lightning flash if it passes near charged thunderclouds. The large Boeing 747, for example, has a length of 70 m and a wing span of 65 m, and other jets are commonly about 45 m. The trailing wire attached to rockets and used to reliably trigger lightning is usually at least 100 m long. For conventional rocket triggered lightning (RTL), one end of the wire remains connected to ground. For altitude RTL, the wire is taken aloft and its lower end is tethered to ground by a plastic line. Birds are far too small to trigger a lightning flash.

Flying objects would normally avoid thunderclouds. Pilots of aircraft have access to weather data including wind velocity sensors and on-board radar (and some planes have lightning location sensors), and use these with visual information to navigate away from thunderclouds as much as possible. We know that birds can sense electric fields. They will perch on the conductors of medium-voltage transmission lines (up to 33 000 volts) but rarely, if ever, perch on high-voltage lines (110 000 volts and above). Presumably, they sense the higher electric fields from high voltage lines and don't "like" them. So birds, too, may avoid flying too close to thunderclouds by being able to sense the high electric fields that precede the development of a lightning flash. Of course, birds can also see the thunderclouds and sense the strong winds near them.

In summary, there is no physical reason why birds should not be struck by lightning. However, there are several reasons why lightning strikes to birds may not occur frequently. Birds are physically small and so present a small target. Being small, a bird does not trigger a lightning flash. Finally, birds can probably sense the presence of charged thunderclouds and so avoid flying close to them.

Mat Darveniza, The University of Queensland, Brisbane, Australia

How can one assess a guided discovery lesson?

Editor: Please see the article "Assessing Learning in a Student-Centred Classroom Environment," by Gary Simpson, on p. 85 of this issue.

Indeed, a very catalytic question, I think. First, we need to ask ourselves why we want to assess, and what costs we allow for these reasons. The costs of assessments are very high, as they immediately bring to the learner a special learning attitude: "If you teach me what you already know, and if you also want me to tell you back what you want to hear (what you already know), then I expect you to teach me very clearly what you expect me to learn." In other words, the price of assessment-driven education is that it freezes the mind of the student as (s)he is not supposed to learn topics based on interest, or because the topics are important in themselves.

Problem-oriented learning and, even better, existential learning, starts from the opposite direction. Students need to find and define clearly the reasons why they are going to learn a certain topic. An open mind is the best condition for real learning. Assessment should just have the function of establishing the quality of the prior learning process, both for improving the student and the teacher roles. Both should feel committed to optimizing the various parameters of the learning process and the learning product. Consciousness of these parameters is vital and should be part of the teacher-student interaction itself.

Piet Kommers, University of Twente, The Netherlands

Guided inquiry projects, or experimental investigations, can best be formatively assessed through teacher observation, guiding questions, and the use of checklists and/or rubrics. The content of the evaluation instruments will depend on the nature of the task given to students. Summative assessment for guided inquiry is best achieved with a teacher-made rubric. On p. 108 you will find an example of my rubric for evaluating guided inquiry experiments at the high school level. Students should be provided with the rubric at the beginning of the inquiry. This allows them

Scoring Rubric for Science Performance Task

Dimension	Score Possible	Score Actual
Problem Definition		
A. The prediction or problem is correctly written. The variables are clearly identified.	3	
B. The prediction/problem is stated adequately & variables identified.	2	
C. The prediction/problem is poorly stated. Variables not identified.	1	
D. Unclear prediction/problem statement. No ID of variables.	0	____
Experimental Design		
A. The design matches the description of the stated prediction/problem. It tests what it should. Independent & dependent variables are clearly identified. Procedure is clearly described so that it is replicable. A control is included and described.	5	
B. The experimental design generally matches the stated problem. Some attempt is made at variable control. Procedures are complete, if not well described. Minor clarifications are needed.	3	
C. The design matches the problem to some extent. Very little attempt at control of variables. Procedures are incomplete. Major design modifications are needed.	1	
D. The experimental design doesn't match the stated problem, is very incomplete or missing, or there is no attempt to control variables.	0	____
Data Presentation		
A. Data are well organized and presented clearly in an appropriate manner.	3	
B. Data are organized and presented appropriately. Minor errors or omissions may be present.	2	
C. Poorly organized data. Inappropriate presentation. Major errors or omissions present.	1	
D. Poorly organized data. Unclear or missing components.	0	____
Data Analysis and Conclusions		
A. The analysis and conclusion(s) relates to the stated prediction/problem. The conclusion is accurate (i.e., it is supported by the data).	3	
B. The conclusion(s) is supported by the data and related to the stated problem. Minor errors in interpretation or statement are present.	2	
C. The conclusion(s) is supported by the data and related, to some extent, to the stated problem, but major errors may be present.	1	
D. The conclusion(s) isn't well related to the prediction/problem, not supported by the data, or is missing.	0	____

Name: ______________________________ Lab Group Name or #: ___________ **Your Total:** ________

Scale Interpretation

12-14 = EXCELLENT 9-12 = Proficient 7-8 = Marginal, can improve Below 7 is Unsatisfactory to understand what is expected, and to evaluate their own progress and performance as they work.

For Further Reading

Performance Assessment for Science Teachers (n.d.). Retrieved July 18, 2004, from http://www.usoe.k12.ut.us/curr/science/Perform/PAST3.htm#General .

RMC Research Corporation. (2000). A*ssessment: Adopting, adapting, or developing an aligned assessment for your lesson*. Retrieved July 2, 2004, from http://www.rmcdenver.com/useguide/assessme/aindex.htm .

Schroch, K. (2004). *Kathy Schrock's Guide for Educators: Assessment and Rubric Information*. Retrieved July 20, 2004, from http://school.discovery.com/schrockguide/assess.html .

Ann Wilson, Louisiana Department of Education, USA

Further Useful Resources

National Center for Case Study Teaching in Science

http://ublib.buffalo.edu/libraries/projects/cases/case.html

The use of case studies in science holds great promise as a pedagogical technique for teaching science, because it humanizes science, well illustrates scientific methodology and values, develops students' skills in group learning, speaking, and critical thinking, and makes science relevant. This site promotes the development and dissemination of innovative materials and sound educational practices for case teaching in the sciences.

TryScience http://www.tryscience.org

Investigate, discover, and try contemporary science and technology through interactivity with over 400 science and technology centres worldwide. Sections comprise *Adventure*, *Experiments*, *Field Trips*, *Curious?*, and *Live Cams*.

GenEdWeb http://www.dairycrc.com

A new resource designed to help senior secondary students understand biotechnology and related issues, using research in the dairy industry as an example.

The Water Cycle http://ga.water.usgs.gov/edu/watercycle.html

A comprehensive coverage of the water cycle, including a diagram that may be printed in 36 languages and in-depth discussion of 15 topics.

About Fuel Cells http://www.utcfuelcells.com/fuelcells/index.shtm

Information about how a fuel cell works, fuel cell systems, types of fuel cells, fuel cell benefits, and links to related resources.

Enigma On-Line Science Simulations

http://www.ucles.org.uk/assessmentdirectorate/ial/enigma/simulations

Simulations of six practical experiments for secondary students: *Rabbit Genetics*, *Water Weed*, *Ball and Ramp*, *Magnetic Fields*, *Electrolysis*, and *Marble Chips*.

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