

Overcoming geological misconceptions

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Introduction – concepts of active learning to overcome geological misconceptions

The application of common analogue materials in everyday use to demonstrate the unusual behaviours and reactions of rock masses is the focus of this paper. Analogies help in the construction of mental representations and appear useful in dispelling more persistent misconceptions (Newton, 2000). Pedagogic principles of active and experiential learning (McConnell *et al.*, 2003), class engagement and personal enquiry underpin the methods outlined to reveal real constructions of real behaviour of real materials.

In the following examples we describe and utilise the inquiry initiated instruction model (Clark and Carpenter, 2006) which is a theoretical framework for class interaction. This method demonstrates how interactions and engagement in synchronous classroom situations - individual and group exploration of analogue materials, explanation of outcomes both expected and unexpected, elaboration of principles and finally evaluation of student perceptions and learning - have led to improvement in understanding of the complex interaction of factors outlined above for rock deformation.

Interaction (and engagement) in class between students and their peers, between the lecturer/demonstrator and students, and between students and materials is fundamental to achieving deep understanding. The demonstrations, experiments, experiences and engagement described below are the keys to improving student learning and overcoming misconceptions. The purpose of the interaction is to demonstrate and discuss various methods of involving class members during classroom presentations. Such interactions are essential to engage students, in order to raise their interest, to encourage them to think and to discover what the common misconceptions are. Engagement promotes interest and motivation; its purpose is to capture students' imagination and motivate them to want to find out more, to both inquire and to learn (Bybee, 1997).

Exploration by experimentation provides students with common, hands-on, investigative activities that allow them to build on their prior knowledge and experiences by exploring ideas, including their own. Having the students explain their findings to others completes this stage. Explanation is the concept development stage which presents new information in a way that is linked to activities and student explanations of the exploration stage. Here the teacher may discuss student explanations and introduce relevant new concepts. Discussions and concepts should be clearly linked to the engagement and

exploration activities and student explanations, as in this way students are provided with a learning environment that encourages them to explain their ideas and challenge their understandings. Students can then build or construct their own knowledge based on their prior understandings and modified by the relevant scientific concepts introduced by the teacher.

As a finale to the learning experience, elaboration gives students the opportunity to extend their new knowledge to other contexts. These may include other hands-on activities or pencil and paper exercises. They reduce the tendency of students to associate concepts with specific situations, and enable them to identify relationships in different circumstances (Osborne and Wittrock, 1985) and students learn to apply their new understandings to different contexts in a problem-solving environment. In a final evaluation of concepts and conceptions learned, students' understandings may be assessed and any lasting misconceptions addressed.

Rocks and ice are brittle substances which fracture and break when subject to an applied force. In geological classrooms, quarries, mines and field exercises, hammers are designed to break apart rock samples. The noise, effect, outcome and vibration associated with rock fracture are concepts commonly understood by students and the general public alike. An icebreaker is used to smash through pack ice to reach the geographic Pole, whilst an ice pick is used to break-up an ice pack to cool a refreshing martini. We all intuitively know the reaction of such substances to breaking force, yet both rocks and ice also demonstrate evidence of very different behaviours under different circumstances.

Rocks flow as lava and magma when hot, or as lahars and mudflows when cold and wet. Likewise, ice flows in glaciers and icesheets. More enigmatically, rocks clearly flow to form curved and convoluted folds. Carey (1954) first outlined the theoretical basis for the understanding of rock flowage under the terms of material creep and rheology – not the most illuminating terms for a most common geological and material response to deformation. The way that rocks do this is thus less intuitive and involves the understanding of deep time, deep crust, high pressures, rock properties and varying temperatures and the way that all of these factors interact to produce sometimes unusual outcomes. Rheological flow is not a simple concept to demonstrate or grasp and students commonly accept, without understanding, the basic principles of natural rock deformation.

We know that seemingly brittle materials will flow under different physical, chemical and material/environmental conditions but the ability of materials to creep under the influence of relatively small forces applied over very long time scales is less intuitive. The vastness of the geological timescale, and the influence of time on other fundamental features like chemical and material cycles, climate change, tectonic movements and biological evolution all require a solid understanding of deep geological time. Everyday materials that behave differently under stress can demonstrate the formation of commonly observed geological phenomena such as folds and faults. The following sections thus describe simple experiential and investigative demonstrations and activities with materials and objects like toilet rolls, bananas, newspapers, honey and bread that can provide lasting memories for students.

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Time's ticking toilet roll

In this simple exercise, the linear progression of geological time and its vastness are both demonstrated and engaged with by learners and the teacher using one single (and hopefully but not necessarily) double-strength toilet roll. The concept is to ask the class to gradually unravel the toilet roll by handing it from person to person around the classroom. This example uses demonstration, engagement, inquiry and elaboration, to investigate prior understandings and individual perceptions of geological time. Whilst the unraveling action is occurring a brief introduction may be given by the demonstrator, for example as follows.

To initially engage the students, ask the question, 'who does the shopping in your house?' You may get an answer, but if not you can lead on by suggesting that the shopper should thus be used to buying everyday commodities like bread, milk, and toilet rolls? Having raised the issue of such a common everyday commodity as a toilet roll, the next obvious question might be to ask if anyone can guess how many sheets of paper there are on one toilet roll? Further banter about rough versus smooth, cheap versus expensive and patterned as opposed to plain can be used while most of the roll should by now have been passed through the hands of all students and should be strung out for 20 or 30 metres around the room. The answer if not guessed is then given that there are about 250 sheets on an average toilet roll.

The next question for the students is 'how old is the Earth?' and amongst the many answers the correct one of roughly 5000 million years, may be given. Another simple arithmetic question can then be asked, while the teacher possibly holds up any of the remaining toilet rolls. This is that 'if the toilet roll represents the Earth, how long in time does one sheet represent?' The correct answer of course is that approximately 20 million years (5000 million/250) is represented by 1 sheet and this should soon be provided by those students not challenged by simple mental arithmetic.

The vastness of geological time and the significant milestones which occur within the geological record can now be outlined in a variety of ways and to a greater or lesser extent depending on interest, engagement or simply the amount of time available. The first phase is to do a simple count back along the extended toilet roll. Making sure that the 'free' end that started the unravelling represents today. Then it is a relatively quick and simple exercise to show that 5 sheets will represent 100Ma, 25 sheets 500Ma, etc. and the end of the Precambrian is soon revealed.

The vastness of the Precambrian Era representing more than 80% of the timescale (and rock record) is one of the many interesting features which are readily apparent, as is the insignificantly small scale of the Holocene and Pleistocene. This becomes much more apparent if we try to add human history to the end. It represents not much more than the perforations on the last sheet.

Geological periods can also be demonstrated by the students who happen to be holding the three sheets that represent the Tertiary period, the five to twenty sheets showing the age of the now extinct dinosaurs and the emergence of first soft-bodied (30 sheets) and then shelly (25 sheets) life forms in the geological record. If enthusiasm and engagement levels can be raised sufficiently to become involved in higher level 'interpretation' activities, students might be asked to discuss or outline their favourite Periods in the geological timescale, they can 'act-out' significant events such as mass extinctions or orogenies, or they

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might choose a geographic location and find its 'age' on the roll, or the location of their favourite geological time period.

In Australia, where we first used this learning activity, the small scale of aboriginal occupation from about 50-60,000 years ago can be demonstrated by tearing off (or using a volunteer to tear) the final sheet of the toilet roll and equating that occupancy to the size of the jagged perforation. Similarly, the even less significant period of European occupation of Australia can be envisaged as the fine expiration of dust from that act of tearing the last toilet sheet, and thus the new settler Australians who currently occupy the land can be perhaps unkindly but humorously be described as representing the 'dust on the toilet roll of life on Earth!!!!'

This exercise has now been demonstrated in many venues and many countries. It is particularly useful when demonstrated to a wider audience of interested but usually poorly geologically informed members of the general public. Ordinary citizens feel able, often for the first time, to be able to grasp the longevity of the geological timescale and the rock record that represents it. If nothing else, after this demonstration we consider that you will never sit on the toilet and look at the toilet roll in the same way again!!!!

As a final suggestion for active learning, many more toilet rolls can be distributed to the audience or class and they can be challenged to design a learning activity about any other geological phenomena with a toilet roll or any other everyday familiar object.

'Banana Benders' and the concepts of deformation

Geological structures occur at a variety of scales and include major thrusts, fold-fault belts and mountain ranges in their architecture. Individual structures like folds and faults also occur on the outcrop or hand specimen scale in intricate patterns and reveal the magnitude and aesthetic beauty of structures, without necessarily providing any insight into how (or when) they formed. The incremental development of these types of structures over geological time scales, where they evolve gradually at timescales of mm to cm/year is commonly a further difficult concept to grasp. Geological structures might appear to form in 'an instant' but the geometric, kinematic and dynamic processes of their formation are neither intuitive nor universally explicable.

There are many analogue objects and materials that can be used to simulate the formation of classic geological structures. Layered sponge cakes can be cut and offset to simulate faults, arrays of biscuits or pretzels demonstrate nicely the 3D geometry of natural rock tectono-thermal fabrics and many anisotropic and layered vegetable materials (e.g. celery, cucumber, weatabix, etc.) can be utilised to 'make' simple structures. A well documented example of the illustration of allochthonous thrust

and nappe tectonics is demonstrated in the advanced structural geology textbook by Davis (1996), who used the effect of tossing a pizza too fast across a table to watch (and analyse) what happens to the poorly attached surficial components (cheese, tomatoes, chilli and salami slices). However, in our opinion and with many years of trusty service in the name of explaining the range of structures which can be produced by compressive deformation, there is little to better the banana as the most useful deformation and structure analogue.

Bananas are cheap, readily available, pre-packaged linear bars of ductile (see later definition) material which deform readily and repeatedly to produce an amazing array of natural analogue structures. They can be deformed at room temperature, will yield varying responses depending upon age, maturity and ripeness and are ideal for use in an experiential learning experiment. They can be used as a front of class demonstration showing how layered materials respond to uniaxial compression, but our preference is to hand them out to the students to make their own structures. We have thus developed a sophisticated exercise where the students can not only take control of the deformation situation, but can effectively produce, describe, analyse and report on almost any style of ductile structure.

We have developed a basic routine for mid-level students who need to begin to learn the nomenclature of structures, but also to gain a deeper understanding about how these geometries form. The students generally work singly or in pairs and are each provided with one banana. The aim is to deform it, understand the deformation process, observe the structures forming and then make annotated sketches to describe the array of structures produced. Students are asked to peel the banana, clasp both ends firmly and then slowly to push the hands together until the banana begins to be squashed (deformed). The process is technically a short duration experiment of uniaxial compression of a material bar. Geologists typically carry out such experiments to test the strength and resilience of elasto-viscous materials such as rocks or crystals (Ramsay, 1976), whilst this is a common engineering experiment to test how bars of building and construction materials such as concrete or steel will fail.

The banana bending exercise is always greeted with surprise and enjoyment and the results are consistent. The banana under low stress demonstrates elastic behaviour but will then rapidly fail in a repeatable and predictable manner. Failure usually occurs (as predicted by Navier-Coulomb stress failure criteria) on two weaker zones aligned at about 35-45 degrees to the main compression direction. Strain softening typically means that one of these zones fails first and a dominant or large (relatively) semi-ductile shear zone or fault forms. The conjugate (opposite angle) weakened zone is more resistant and typically becomes a knee-shaped bend or kink zone. An array of minor features develop along with the main structures, and these include layer-parallel slip and extension zones (extension veins), and arcuate radial veins, which will always form around the outer arc of the material that bulges out from between the two shears. The main structure can be described as an antiformal welt or pop-up structure and, depending on the geographic position of the banana when laid down, all of the geometric elements of folds, faults, shear zones, veins and even foliations (compressional fabrics found where the two shears intersect) can be found and described.

The students are generally asked to lay the banana onto a clean surface and then to accurately sketch the structures produced. Fault hade, slip, separation, heave, throw and a myriad of other terms can be used to label the faults, and likewise fold



axial planes, hinges, crests, troughs, limbs, etc., can be used to label the folds. The more advanced students can compare their structures with natural ones in real rocks and can contemplate the rheological conditions needed to produce them. Envisioning of larger scale structures can lead to discussions of thrusting, obduction, wrench tectonics and even major plate interactions or fold belts. This exercise is usually enjoyed and recognised for the many skills, insights and understandings that result. Eventually the banana can be eaten to complete the exercise.¹

The banana bending exercise is one where students get close to the heart of working with structures they have themselves produced. The rock analogues were seen to flow under the imposed stress with an observable (though in fact geologically unrealistically fast) deformation rate. Experiential learning is very high, as is retention of knowledge and skills. Motivation is high and the whole learning exercise is very easy to set up and run.

Viscosity sandwich – learning about material flow

The final exercise demonstrated here involves an understanding of the concepts of time, structural geometry and rock flow, which can all be highlighted by the very technical and non-

intuitive terms of viscosity, ductility and rheology. Given the time, background and motivation to learn, these concepts - which are engineering as well as geological - can all be demonstrated quantitatively by formulae, tensors, graphical and schematic drawings. Dashpots, springs, equations, stress strain graphs and long descriptions are commonly and rightly used for the accurate and formal explanation of the processes (see Jaeger and Cook, 1979).

In a less technical sense, the ability of a material to flow under different conditions or with different compositions and thus material properties can be illustrated to perhaps greater satisfaction, again using readily available analogue materials.

Initially, the concepts of viscosity or ductility can be introduced by asking the class to describe the behaviour of materials that flow and bend without breaking, leading to the material behaviour concepts of viscosity and ductility where viscosity is defined as 'being a measure of resistance to flow' and ductility 'the property of a material to deform without fracturing'. Students can then be asked 'real' life and relevant questions such as, for example, 'How does viscosity relate to natural hazards?' They might consider how they have observed (usually on TV) or might understand the flow of rocks and other normally solid materials in geological phenomena such as landslides, volcanoes and glaciers, and how this might relate to the flow of water during tsunamis or flash-floods. They might use this intuitive information then to consider placing these different materials (rock, lava, water) in order, from most to least viscous. Following on from the previous experimental exercise, rocks, ice and even lava flows can be demonstrated to form folds; as with the previous banana exercise, they can use this experience to reflect again on the formation of such folds in nature.

The use of the viscosity sandwich is a simple experiment carried out with readily available (and cheap) materials to demonstrate the rapid distinction between materials of different viscosity. As an aside, the way that manufacturers of the viscous materials have used this property to design the vessels holding them further reinforces the fact that viscosity is an important property in everyday life. The simplest way to undertake this task is to raid the fridge and pantry on the way to class. Six to eight of the following foods and condiments can be found in most kitchens. These include the 'runny' materials used in food preparation such as tomato sauce, honey, margarine, soy sauce, mustard, vegemite, various dressings, olive oil or mayonnaise, etc. To this add a can of beer or soft drink, some slices of bread and even a tube of toothpaste. Other accessories include a knife, board and most importantly kitchen paper for cleaning up afterwards.

All vessels are placed on a front/visible table. One or two students are asked to participate by quickly placing the vessels and their materials in order of increasing or decreasing runniness or stiffness (viscosity). This is usually carried out with much tipping, overturning, squeezing (if plastic), etc. Eventually, the line up is made which usually ranges from most viscous (toothpaste and margarine) at one end to least viscous and thus most runny (beer, water) at the other.

All receptacles are then opened and a sandwich is created again from most to least viscous (including toothpaste which needs to be squeezed). During the process discussion of design of vessel, solid pour or squeezey, large opening or very restricted

(e.g. soy) can be discussed. The students are then usually asked if they will sample this delicious morsel and, of course, will usually do so if the demonstrator will do it too. This is a fun but informative event with many insights into the range of factors involved in viscosity, e.g. flow rate, temperature (runny honey when hot, squeeze of toothpaste needed – added pressure).

Conclusion

Some geological and scientific phenomena are so different from everyday reality that their understanding can be problematic. The size of the sun or solar system, the scale of geological time, the rate of mountain building or erosion, the architecture of an oil field or aquifer and the pressures at depth in the earth's crust are a few such phenomena. We have found that the use of common everyday materials in activities like those described help the students 'experience' the properties and responses and hopefully transfer this towards an understanding of the more abstract phenomena they represent. Thus active and experiential learning techniques using everyday materials and objects may lead to better understanding and help overcome misconceptions.

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Footnote

1. We are currently finding this experiment example difficult to carry out. Unfortunately, there is a crisis in Queensland with the devastation of the banana crop by Cyclone Larry off the coast of Queensland in March 2006. This has led to a severe dearth of available bananas in Australia. Prices have risen significantly to \$15.99/Kg, and the local papers have revealed headlines such as (*The Australian*, June 16, 2006) "Supplies slashed, prices rocketing and banana thieves making a killing" and beware Banana Rustlers. As far away as Bright in Victoria signs have been seen on grocery stores "No bananas are kept on these premises at night".

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