shifting sands

Proposed changes to the New Zealand Draft Curriculum have seen the Nature of Science strand gaining more importance. ***Anne Hume*** *(University of Waikato) with scientists,* ***Giovanni Coco*** *and* ***Malcolm Green*** *(both of National Institute of Water and Air - NIWA), use a contemporary example of how scientists gained an understanding of beach cusp formation to give teachers a better understanding of how to implement this strand, and a context for its delivery.*

In July 2006, the draft New Zealand Curriculum (MoE, 2006) was released to schools and the wider educational community for consultation. This release followed a review and redrafting of the existing national curriculum policy (MoE, 1993) and accompanying curriculum statements, including the Science in the New Zealand Curriculum (SiNZC) (MoE, 1993). At first glance the most obvious change to the reader is the collapsing of the former curriculum framework document and the separate curriculum statements into one all-encompassing document. The structure of the curriculum is similar to the former SiNZC with the retention of learning areas, strands, achievement aims and objectives, and eight levels of achievement, but there are some differences in content and emphases. For example, *Learning Languages* has been added as an eighth learning area and the essential learning skills replaced by the key competencies.

The background to the science learning area in the document has been condensed to a two-page description of what science is about, the reasons for studying science and the content of the learning strands. A significant point of difference between the existing SiNZC and this draft is the proposal to reduce the original six learning strands to five. The four contextual strands of *Living World, Planet Earth and Beyond, Physical World* and *Material World remain*, but the single integrated strand *Nature of Science* replaces the two original integrating strands *Making Sense of the Nature of Science and its Relationship to Technology* and *Developing Scientific Skills and Attitudes*. The science achievement aims have been reduced from four to three in the contextual strands but the *Nature of Science* strand contains four aims. It appears that the *Nature of Science* strand is assuming greater importance in this new interpretation of the science curriculum and taking centre stage as

> … the over-arching, unifying strand. Through it, students learn what science is and develop the skills, attitudes and values that build a foundation for further study. They come to appreciate that scientific knowledge is at the same time durable and tentative; they learn how science worker carry out investigations, and come to see science as socially valuable knowledge system. They learn how science ideas are communicated and to make links between scientific knowledge and everyday decisions and actions. (MoE, 2006, p. 20).

What implications does this greater focus on the nature of science in the draft curriculum statement have for the science programmes that New Zealand science teachers deliver and students experience if this new emphasis is retained in the final form of the SiNZC ? Past experience in New Zealand would suggest the impact of this change on classroom practice is likely to be minimal. When the nature of science was introduced in the SiNZC (MoE, 1993) as a strand, research into the implementation of that curriculum into classroom programmes revealed that significant numbers of teachers struggled to make sense of this strand (Baker, 1999). As a consequence they did not usually incorporate it into their teaching (Loveless & Barker, 2000) and were effectively ignoring the strand in their teaching and learning programmes. Thus inclusion of the nature of science in the national curriculum statement did not automatically transfer into classroom practice. To help rectify this situation, Baker (1999) and Loveless and Barker (2000) suggested that the nature of science strand needed rethinking in any future review of the curriculum statement, and that teaching resources to support the implementation of this strand would be of value to teachers.

This lack of teacher understanding and experience with the nature of science and non-implementation in classroom programmes are evident in the international literature too. Ryder (2001) points out that many science teachers will need to develop their own understanding of the nature of scientific knowledge and how the scientific community works before they can effectively teach such aspects of the curriculum in the classroom. Among his recommendations for support are teacher training and the supply of resource materials, including case studies of historical or contemporary scientific developments. However, Lederman (1999) observes that even when teachers appreciate and understand views of science consistent with those advocated by current curriculum reforms, their conceptions of science do not necessarily influence their classroom teaching. Teachers need specific instructional strategies that make the nature of science explicit through discussions and reflections. Loveless and Barker (2000) suggest a range of scientific activities could be sourced for New Zealand teachers and developed into rich learning opportunities for students. For example, instances of science-in-the-making could be used as exemplars in their teaching and learning programmes. Teachers do have a number of historical instances to draw on, such as Fleming's 'discovery' of penicillin, the development of the Plate Tectonics theory, and ideas on philostogen, but research suggests that use of contemporary science examples can heighten student interest and awareness of the dynamic nature of science (Hipkins et al., 2001).

In conversation with local scientists from the National Institute of Water and Atmospheric Research (NIWA) about the nature of science and how they work, it occurred to me that their work here in New Zealand might be a source of valuable instances that illustrate the nature of science. We decided to work together on such an example to find out how useful this strategy may be in helping teachers understand the nature of science and gain an appreciation of how scientists think and work today.

The following account presents a cameo of science 'as it is happening', and tells the story of how New Zealand scientists as members of the international community of scientists are exploring new theoretical approaches to questions that have proven difficult to answer. In the context of a puzzling physical phenomenon in coastal environments, known as 'beach cusps', the story demonstrates the tentative nature of science and how ideas and approaches change over time in response to observations of the natural world. When theory can no longer predict or satisfactorily explain observed phenomena then scientists begin to look for alternative strategies and ideas, even new paradigms (theoretical frameworks) that offer more fruitful results. Scientists in this story tell how a 'revolutionary' perspective on how dynamic systems such as coastal shorelines operate in nature like coastal shorelines is beginning to change the way in which they investigate the environment. The successful application of the new paradigm in a field experiment that provided evidence to explain how beach cusps formed convinced our scientists that this was a paradigm worth adopting in their investigations of complex environmental systems here in New Zealand. The paradigm is giving them the means and tools to reach better understandings of how other dynamic systems in the environment may work.

The Beach Cusp Story (as told by the scientists)

It is not enough for environmental scientists to "simply" generate knowledge; we are increasingly asked to make predictions that can support decision-making and policy development (Lancaster and Grant, 2003). We can do this in some cases, but we are always ultimately limited by gaps in fundamental knowledge and deficiencies in the way we think about the natural world. Furthermore, the natural world is often greatly influenced by anthropogenic factors (related to the activities of humans), which are difficult for physical scientists to come to terms with (Haff, 2003).

The current mainstream approach to science is based on reductionism, which has an intrinsic and obvious appeal: discovering the unifying equations that explain every system, and allow predictions at any temporal and spatial scale. To the cynic, this has resulted in us knowing "more and more about less and less" which allows for a proliferation of specialties (including, in the coastal science field, distinctions between field experimentalists, laboratory experimentalists, theoreticians, numerical modellers, applied modellers, to name a few) (Gallagher and Appenzeller, 1999), but does not necessarily increase our predictive skills.

However, a new approach has recently gained ground, which we have embraced in our research on nearshore and surf zone dynamics at one of New Zealand's Crown Research Institutes. The new approach is based on the idea of "complexity", and it has been developed through work on the humble beach cusp…

Beach cusps

Beach cusps are the scallop-shaped or "lunate" indentations often seen along the shoreline on sandy beaches, forming a repeating pattern of ridges and bays of striking beauty and regularity (Figure 1). They can extend for hundreds of metres, with the distance between consecutive "horns" (the ridge between the scallop-shaped bays) being usually tens of metres. Beach cusps have been reported worldwide (Europe, Australia, Japan, east and west coasts of the USA).

The search for an understanding of how beach cusps are formed and what governs their appearance (for instance, their spacing, height, distance horns protrude offshore and so on) has led to a new way of thinking – a new paradigm – taking root in coastal science.

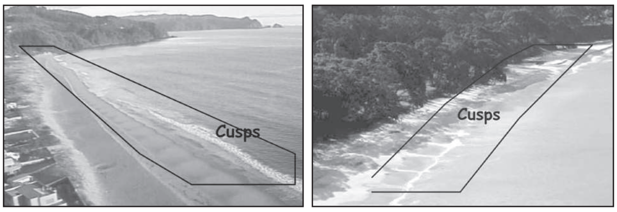

Figure 1: Beach cusps at Tairua Beach (left panel, http://www.niwascience.co.nz/services/cam-era/) and Waihi Beach (right panel, courtesy of S. Douarin), New Zealand.

Regular waves and a weak alongshore current in the surf zone are required for cusps to form, and they are more prone to develop on steep beaches. Once cusps have developed, their shape appears to control water flow up and down the beach face: incoming waves (the "swash") meet the offshore-protruding horns and split sideways (Figure 2a), then water piles up in the bays and returns back to sea (the "backwash") in the form of a narrow jet (Figure 2b and Figure 1, right panel). It is also known that storms destroy cusps, as do strong alongshore currents in the surf zone. Also, when cusps develop on a beach composed of mixed sediment grain sizes, an interesting (and still unexplained) phenomenon occurs, with the fine material occupying the cusp bays and the coarse material gathering over the cusp horns.

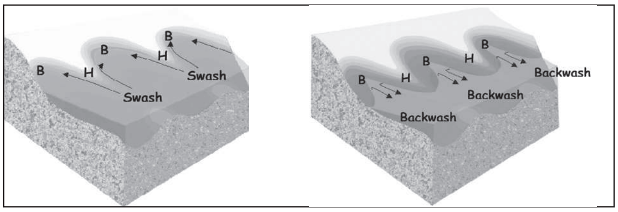

Figure 2a & 2b: Water motion over beach cusps. Left panel shows the swash associated with an incoming wave splitting around cusp horns. Right panel shows backwash in the form of a narrow jet concentrated in the cusp bays. Beach cusp horns are indicated with H, beach cusp bays are indicated with B.

The mystery of beach cusps: a history of contrasting theories

Beach cusps have attracted the curiosity of scientists for nearly a century (Jefferson, 1899; Johnson, 1910). Some of the early hypotheses to explain beach-cusp formation were only simplified attempts at explaining a "complex puzzle" and were rapidly discarded because of an obvious lack of agreement with field observations. Up until the mid 1970s there was no real advance in understanding how beach cusps form.

Then, theoretical advances in wave dynamics[1] suggested that "incident" waves – the waves that we see and surf on – actually drive a range of other wavelike or rhythmic water motions in the surf zone. In general, these other motions would not have the same period as the incident waves that excite them, and would not be the same amplitude, either. In fact, it would not usually be possible to see them with the eye, but it would be possible to detect their presence by measurement with sensitive oceanographic instruments, such as current metres and pressure sensors. The idea soon arose that these subtle, rhythmic motions could in turn be "imprinted" on the underlying sand to produce corresponding rhythmic morphologies, such as beach cusps.

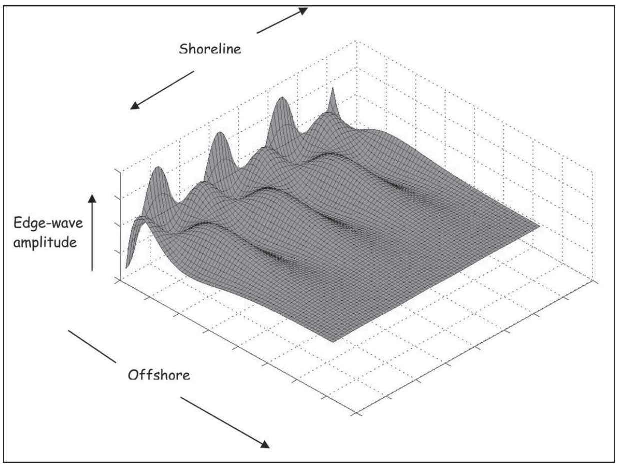

Figure 3: 3D-view of an edge wave. At the shoreline (where the edge-wave amplitude is largest), there is a periodic pattern, oscillating in the alongshore direction, that resembles the shape of the shoreline when beach cusps are present. Notice that the vertical scale (which represents the edge wave amplitude) has been amplified in the figure to show the periodicity in the pattern. In reality, the amplitude of edge waves is very small (centimetres or less). Because of this, and the multitude of other wave-like and chaotic motions that are normally present in the surf zone and that are superimposed on any edge-wave pattern, the casual observer cannot see an edge wave with the naked eye.

One example of these unseeable (with the naked eye) rhythmic motions is the "edge wave" (Figure 3). Once predicted by wave theory, their existence was gradually confirmed by careful measurements in both the field and the laboratory. One of the striking things about edge waves is that their pattern at the shoreline resembles the pattern of beach cusps, and it is a fairly simple leap to imagine that edge waves imprint themselves onto sandy bottoms to

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[1] The study of wave motion and forces associated with waves.

form beach cusps. This idea quickly took root, and more and more observations appeared in the literature suggesting a link between beach cusps and edge waves. Eventually, the mystery of the formation of beach cusps was taken as solved – in reductionist terms a clear example of progress in scientific understanding driven by increased knowledge of underlying fundamental processes (in this case the processes related to wave dynamics).

The search was now on to apply the "imprint paradigm", in which hydrodynamic patterns are assumed to imprint themselves onto an underlying sandy substrate to form a corresponding morphology pattern, to explain the formation of other parts of the beach and surf zone. The same kind of thinking that was apparently successfully applied to beach cusps was now being applied to explain other rhythmic morphologies (shapes and forms) that are seen at the beach, such as multiple sandbars (Short, 1975), crescentic bars (Holman and Bowen, 1982), rip channels (Bowen and Inman, 1971), and so on.

Meanwhile, a new way of thinking was emerging in other areas of science, based on the idea of "self-organisation". The underlying idea, which was being applied in disciplines ranging from chemistry to social sciences to astronomy, is that complicated processes are not necessarily needed to form complicated patterns. Instead, complexity in nature can arise from simple processes, from interactions between simple processes, and from interactions between processes and form[2]. This idea of self-organisation underpins the new paradigm known as 'system science'. In this paradigm a system is defined as

> "…an entity that maintains its existence and functions as a whole through the interaction of its parts. However, this group of interacting, interrelated or interdependent parts that form a complex and unified whole must have a specific purpose, and in order for the system to optimally carry out its purpose all parts must be present. Thus the system attempts to maintain its stability through feedback. The interrelationships among the variables are connected by a cause and effect feedback loop, and consequently the status of one or more variables, affects the status of the other variables. Yet, the properties attributable to the system as a whole are not those of the individual components that make up the system"
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> (Assaraf & Orion, 2005, pp. 519-521)

Here is how beach cusps are explained under the new paradigm, which was first proposed by Werner and Fink (1993).

Start with a smoothed shoreline, such as occurs after a storm has passed. Here and there along the shoreline there inevitably will be slight bumps or "perturbations", perhaps associated with a piece of driftwood, or maybe just due to a random large wave in the preceding storm. Over the bumps, the swash is decelerated (as it climbs the bump), and so the sand being carried up the bump by the swash is deposited, thus causing the bump to grow slightly higher. At the same time, backwash off the bump accelerates, causing a slight scour hole, and another "relative" bump to emerge on the other side of the hole.

Each successive swash/backwash causes bumps to grow and multiply a little bit more, and areas between bumps to scour. This is an example of a "positive feedback", meaning that the initial perturbation interacts with the flow in such a way that the initial perturbation is increased in size (a negative feedback suppresses a perturbation). Under the action of the positive feedback, all traces of the initial perturbation are eventually lost, and a stable configuration that neither grows nor decays "emerges[3]". Voilá – the fully-developed pattern of beach cusps!

Technically, the cusp pattern becomes stable when net sediment transport – that is erosion and deposition – becomes zero everywhere along the shoreline. At this time, swash falls off the horns in just the right way to counteract deposition that would otherwise be caused by the swash climbing the horn, and backwash circulates around the bays in just the right way to counteract erosion that would otherwise be caused by the backwash accelerating back down the beach face. In less technical terms, the shoreline finds a way to shape itself, and in so doing shape the water flow, that allows the two to perfectly co-exist!

Now, contrast the reductionist imprint model with the way the self-organisation model is applied to beach cusps: the former supposes a one-way imprinting of process onto form, but the latter talks explicitly of interactions between process and form. Under the new paradigm, the beach cusp is seen to "self-organise" – you can think of the cusp pattern continually reshaping itself to obtain the desired state – from interactions between flow and morphology. No rhythmic pattern in forcing beyond the basic pattern of swash/backwash is needed, and certainly there is no "imprinting" by edge waves required.

The implications of this new approach to the study of nearshore dynamics were terrific: morphology was not the mere "fingerprint" of waves but was instead part of a coherent unified system (flow and sediment) that collectively worked to sculpt shapes and patterns. Nevertheless, the response of the community of nearshore oceanographers to this new approach was, in the best case, skeptical. The numerical modelling approach adopted by Werner and Fink to underpin and quantitatively test the new theory was novel ("cellular automata") and implied drastic simplifications of traditional processes (in some cases even neglecting them) that were considered to be at the core of the discipline of coastal science. As a result, and despite even obtaining wide media coverage, this innovative work and new line of research was mostly neglected by Earth scientists and certainly not pursued to its full extent.

The tide began to turn, however, after a landmark field experiment was conducted. Scientists took a stretch of beach along North Carolina's Outer Banks and flattened the cusps along the shoreline with a bulldozer, then carefully monitored the subsequent reappearance of the cusps using a large battery of instruments. The self-organisation model passed the field testing (Figure 4) and was actually able to predict the occurrence and spacing of cusps better than the edge wave model.

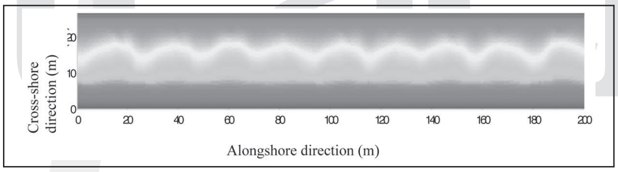

Figure 4: Predictions of the development of beach cusps using a numerical model based on self-organization. The colours indicate depth: offshore is coloured blue and the shoreline corresponds approximately to the yellow line.

But why, really, do beach cusps matter? To most people, they are mere ornamentation, and, admittedly, being able to predict beach cusps is of little practical significance. But the real advance here goes much beyond beach cusps: we have a new way to think of the physical world, and we have developed new predictive models that reflect that new way of thinking.

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[2] Complexity is not the same as "chaos", although the two are frequently confused. Chaos refers, in essence, to the extreme sensitivity of a system to its initial conditions. The classical example is prediction of the weather, which is not possible in any detail beyond 5 to 10 days. The problem arises, not because the underlying physics is not understood, but because the weather can develop in very different ways depending on minute differences in the distribution of temperature, pressure, water vapour and so on, which can never be known with enough accuracy.

[3] The concept of emergence is central to self-organization. It refers to the way the properties of a system "emerge from", but are not the same as, the properties of the system components. For example, consciousness arises from arrangements of neurons, a V-shaped formation arises from geese cheating aerodynamics, crystals arise from lattices of molecules, and so on.

After the success of the beach cusp experiment (Coco et al., 2003), the same self-organisation paradigm was applied to the study of other aspects of beaches and surf zones, which has resulted in successfully explaining and predicting nearshore patterns such as sand ripples and crescentic bars as shown in Figure 5. Some of these studies have obvious practical application, such as the prediction of rip currents, which are hazardous to swimmers. Other practical applications have emerged as the paradigm has spread throughout the Earth sciences, including prediction of nuisance mangrove spread in sediment-impacted estuaries, management of shellfish contamination, and sedimentation of shipping channels.

Scientific thinking had finally shifted – for now.

Figure 5: Rhythmic morphology in the nearshore region. Left panel shows sandy ripples of different spacing and orientation (courtesy of A. Saulter). Right panel shows crescentic bars in the surf zone (http://www.niwascience.co.nz/services/camera).

Use of this story in the classroom

I believe an account of science in action, like the Beach Cusp story above, can be invaluable not only for teacher education but also as a means of motivating students to engage in science learning (Hume, 1997). This story, presented at a suitable level for students, introduces scientists as people working to understand and explain phenomena that are highly visible features in our natural world. How many non-scientists walking along the beach have observed sand cusps and admired their symmetry, or surfers who have used the presence of cusps on certain beaches to indicate the nature of the wave action and behaviour at that location? The environmental context of this story, and the human side could raise student curiosity as they experience scientists' attempts to come up with new ways to explain the sand cusp mystery. Once students are engaged in the story, the context can be used to introduce or reinforce many scientific concepts applicable to students in their schooling as they naturally arise in the unfolding of the story.

Links to the draft curriculum

The science concepts within this story can be readily linked to the Nature of Science achievement aim Understanding about science which states that "students will learn about science as a knowledge system: the features of scientific knowledge, the processes by which it is developed, and the ways in which the work of scientists interacts with society." The story's account of the failure of existing theories and approaches in solving problems and answering questions in the environmental sciences, the subsequent search and testing of new ideas and perspectives, and the acceptance of a new paradigm that gave greater promise of new research directions and discoveries provide strong insights into science as a knowledge system. These insights include understanding that scientific knowledge is

(a) tentative (subject to change)
(b) empirically based (based on and/or derived from observations of the natural world)
(c) subjective (theory-laden)
(d) necessarily involves human inference, imagination, and creativity (including the invention of explanations)
(e) necessarily involves a combination of observations and inferences, and
(f) is socially and culturally embedded. (Lederman, 1999, p. 917)

The context of beach cusps and the environmental sciences lends itself to the *Planet and Earth and Beyond and Physical World* strands with applications to the understanding of Earth cycles and their interactions and how physics applies to real world situations. The concepts involved would probably be best suited to students working at levels 7 and 8 of the curriculum (Years 12 and 13).

We are very interested in teacher feedback about the usefulness of this story, both in terms of promoting your own understanding of science and as a potential context for student learning. If such stories prove to be of value to you and your students, we hope to continue our teacher-scientist collaboration to produce more of the same for the new curriculum. We look forward to your feedback.

Giovanni Coco and Malcolm Green are supported in this work by the (New Zealand) Foundation for Research, Science and Technology (Contract C01X0401).

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allocating berths on Noah's Ark

Principal Investigators: Professor ***Mike Steel*** ***& Dr Charles Semple,*** *Biomathematics Research Centre, Department of Mathematics and Statistics, University of Canterbury*

If Noah's Ark set sail today, which species would be most deserving of a berth? University of Canterbury mathematicians, Professor Mike Steel and Dr Charles Semple, have received funding to develop mathematical theories and methods that will help solve the so-called "Noah's Ark problem", and assist in the conservation of biodiversity.

Professor Steel says: '"There is a lot of interest these days in trying to understand how much biodiversity is being lost, with thousands of species going into extinction. We are trying to measure that and better understand that process, to decide where resources should be spent to protect biodiversity. Ideally, you would save all species, but in reality that can't happen, so we need to find the best way to keep biodiversity as broad as we can with limited financial resources."

The project has two objectives: first, Professor Steel and Dr Semple will calculate how to maximise future biodiversity, given the extinction risk of each species; second, they will develop and apply models to predict how biodiversity might decline under various extinction scenarios. Dr Semple says, "It's about preserving those species that are biologically diverse, and maintaining as much diversity as possible on a limited budget".

The results are likely to find a wide application, and the team will work closely with biologists who wish to use their findings on their own sets of data, to help solve some of today's big issues in conservation.

(Ref: Marsden Fund Update, no. 36, Oct 2006).