Facilitating student understanding about climate science: El Niño as an online case study

Neil J. Holbrook, Department of Physical Geography, Macquarie University and
Elizabeth Devonshire, Centre for Flexible Learning, Macquarie University
Neil.Holbrook@mq.edu.au E.Devonshire@fhs.usyd.edu.au

Abstract: El Niño – Southern Oscillation (ENSO) has been shown to be the dominant factor affecting year-to-year climate changes globally, and may dramatically affect rainfall patterns around the world. In the education of climate scientists, it is critical that they comprehend the complex concepts that underpin ENSO. This paper discusses an online practical (tool) developed to teach undergraduate students the fundamental principles that underpin not only the average state of the ocean, but also ocean variability associated with ENSO. Results from two formal student evaluations of this practical, one by third year physical geography students and the other by second year physics students, will be presented and discussed.

Introduction

El Niño – Southern Oscillation (ENSO) has been shown to be the dominant mode of year-to-year climate variability globally, and has been linked to drought across eastern Australia. Physically-based models (formulated with a set of fluid dynamic equations) are very useful research tools for investigating and quantifying climate variability, and change (e.g. Trenberth 1992), such as ENSO. These mathematical (numerical) models may be used not only as evaluative tools of past climate changes, but also as tools to predict future climate changes. For example, recent computer (numerical) modelling studies have demonstrated that the timing of ENSO events may be predicted up to 1-2 years in advance (e.g. Zebiak and Cane 1987; Cane 1992). Furthermore, models designed to aid understanding of important processes operating in the natural world have also been successfully applied in teaching and learning contexts (e.g. Riera et al. 2002; Whitford 2002; Bell, Fowler and Stern 2003). The application of discipline-based research models in a learning context is termed research-led teaching (Jenkins 2000; Brew 2003).

In educating students about these concepts, and particularly those students studying to become climate scientists, it is critical that they comprehend the complex principles and feedbacks that underpin ENSO. In the past, these concepts have been taught using a traditional lecture format only. This approach is not ideal, as verbal explanations do not always provide students with sufficient cues or information from which to develop understanding of the abstract concepts being discussed. One of the most instructive ways of teaching the mechanisms that underpin ENSO (and climate change) is through explanation of the fundamental principles that formulate climate models, and by evaluating model simulations against real world observations. With the aid of a Macquarie University Teaching Development Grant (MUTDG) in 2001-2002, an interactive interface was developed for the online visualisation of a series of computer model simulations (Holbrook 2002). This development was initiated to enhance the lecture explanations, engender student understanding of the important concepts, and facilitate remote access. This paper describes the design of the learning activity and discusses the results from two formal student evaluations of this practical, one by third year physical geography students and the other by second year physics students.

The shallow-water model

It has been shown that ENSO can be well-represented by coupled (atmosphere and ocean) computer climate models of *intermediate* complexity (e.g. Zebiak and Cane 1987; Philander 1990). These numerical models utitise a mathematical formulation of the upper ocean dynamics that includes the large-scale propagation of equatorial Kelvin waves and planetary scale Rossby waves (formally called a *shallow-water model* – so-named because the horizontal scale of the planetary scale waves

(100s-1000s of kilometres) is much larger than the vertical scale (ocean depth ~4 kilometres)). The 'baroclinic' formulation of the model (used in this study) assumes a 1 ½-layer vertical density structure (an active upper layer of lower density above a motionless lower layer of higher density, separated by an interface called the *pycnocline,* which is permitted to move vertically in response to changes in the surface wind stress forcing). Such models have demonstrated that planetary scale wave propagation is important to the understanding and prediction of interannual global climate variability, in particular, associated with the ENSO phenomenon. The online practical adopts a research-led teaching approach as it uses a research tool developed by Dr Neil Holbrook (the component ocean *shallow-water model*) to facilitate understanding of the important ocean dynamic principles in the interannual variability. The model acts as a mini-computer laboratory of the world's oceans and its variability.

The online practical

The online practical, using the shallow-water model of the tropical-subtropical oceans forced with observed wind stresses, was designed to:

1. introduce students to the fundamental concepts associated with Kelvin and Rossby waves and their interactions in the tropical oceans;
2. enhance students understanding of the important dynamical processes linking the atmosphere and ocean on interannual time scales;
3. enable students to test and evaluate their own hypotheses of these processes in response to various forcing and boundary conditions; and
4. enable students to visualise results from a series of computer model simulations.

Lectures on atmosphere and ocean climate modelling, including lectures on ENSO modelling, were presented *prior to* the students undertaking the online practical, providing a framework for the activity. These lecture notes are also available online. The practical was designed to be accessed remotely, independent of the instructor, with all of the information and feedback provided online. Students nevertheless complete the practical individually in a computer laboratory on-campus, with the instructor present to facilitate understanding as required. The practical comprises of two parts: Part I: Steady-state ocean; and Part II: Time-varying ocean.

Part I: Steady-state ocean

In Part I, students are required to test their ideas and hypotheses regarding the steady-state ocean against various idealised shallow-water model simulations of the ocean bounded as a rectangular box, under different *forcing* conditions. The activities that the students undertake in Part I follow a similar voyage of discovery as the pioneering experiments of Henry Stommel (1948). The model experiments enable the students to:

1. force the ocean with a steady, latitudinally-varying, east-component (only) wind stress of the form that drives the Southern Hemisphere subtropical gyre circulation (westerlies in the south through to easterlies near the equator);
2. switch on/off the rotation of the earth, i.e., Coriolis parameter, f [s^{-1}], is either $f = 0$ or $f \neq 0$;
3. choose a constant Coriolis parameter, $f =$ constant [s^{-1}];
4. choose a latitudinally-varying Coriolis parameter, $\partial f/\partial\varphi \neq 0$, where the Coriolis parameter $f = 2\omega\sin\varphi$ [s^{-1}], ω is the rotation rate of the earth [s^{-1}], and φ is the latitude [$^{\circ}$]; and
5. switch on/off the horizontal pressure gradients in the ocean model.

Part II: Time-varying ocean

Part II investigates the time-varying (non-steady) ocean and is divided into two components. The first component revisits an *idealised* study by McCreary and Anderson (1984) involving several model experiments. These experiments investigate the ocean's response to: (a) non-seasonal wind stress forcing; (b) seasonal wind stress forcing; and finally (c) wind stress forcing that includes either (i) symmetric or (ii) asymmetric oscillations in time. The model ocean's response is diagnosed by depth variations in the pycnocline (the pycnocline defines where the vertical density gradient of the ocean is a maximum) at the eastern boundary of this idealised ocean, as a function of time. The process of undertaking these experiments demonstrates the importance of the seasonality and subtle variations in the forcing and response, to the irregular nature of ENSO.

The students' learning activities throughout the practical culminate in the second component. Students are exposed at this final stage to a *realistic* simulation of ENSO variations across the Pacific Ocean between 1980 and 1989. This shallow-water model simulation is forced with European Centre for Medium-range Weather Forecasting (ECMWF) wind stresses during the decade, and incorporates realistic continental boundaries. The component provides animations of El Niño/La Niña variations that are comparable with observed events during the decade, in particular the timing of the historic 1982-1983 El Niño event. Additional diagnostics include: (i) time-longitude plots of pycnocline depth variations across the Pacific Ocean, which clearly show latitudinal variations in the propagation of long Rossby waves and their speeds; (ii) an animation of the evolution of the pycnocline depth along the equator, showing the eastward propagation of the Kelvin wave deepening of the eastern Pacific pycnocline during the onset of the 1982-1983 El Niño event; and (iii) an online Rossby wave speed calculator.

Assessment

There are both *formative* (i.e., feedback provided on the student work without contributing marks) and *summative* (i.e., where assessment contributes marks to their final results) components to the assessment within the practical. The summative component is contained in Part I of the practical. The students complete this assessment task online and are required to choose the (single) correct hypothesis from 10 possible options in each of the three case studies presented. The information leading up to the hypotheses has been designed to give the individual students a conceptual understanding that provides them with sufficient opportunity to propose the correct answer. Providing the correct answer gains the student a single mark and confirms the reasoning for this correct answer. An incorrect answer gains no mark and the student is asked to try again, without the opportunity to score the mark.

The remainder of the practical, in particular Part II, currently provides formative feedback and does not count towards their final grade. In the laboratory context the student is facilitated with the opportunity to discuss the modelling exercises with the instructor and other students.

Student evaluations

The online practical was implemented in two undergraduate units of study in two separate disciplines at Macquarie University. The practical was trialled initially in the third year atmospheric science unit, *Global Climates*, within the Department of Physical Geography during second semester 2002. The practical was subsequently also conducted in the second year physics unit, *Scientific Modelling*, within the Department of Physics during first semester 2003. While the focus of the physical geography unit is on understanding the components, connectivity and feedbacks within the climate system using a climate system model, the physics unit is concerned with all forms of scientific modelling, where the climate model is only one example.

Following completion of the practical, each student group was asked to complete a 'Consultancy/Custom Evaluation' considering various aspects of the online practical material. The Evaluation consisted of 16 questions, 14 of which used a Likert scale (using a five-point scale from 'strongly agree' (=5.0, indicating the most positive response/outcome) to 'strongly disagree' (=1.0, representing the most negative response)), while the remaining two questions were open-ended for written comments. Overall, the physical geography student responses were positive. From 19 returned physical geography student responses, 8/14 of the questions answered by these students gave mean scores of at least 4.0/5.0; 11/14 gave >3.8; and 14/14 gave >3.5. The physics student responses were similarly positive. In this case there were eight returns, with 11/14 of the same set of questions answered by the physics students giving mean scores of at least 4.0/5.0; 13/14 giving >3.8; and 14/14 giving >3.5. An additional question was also included in the physics student evaluation.

Interestingly, the responses to some of the questions appear to be a little at odds with each other. For example, a cross-section of the questions concerning content, learning outcomes, and structure of and interest in the practical provided some apparent contradictions, as indicated in Table 1. It is interesting to note that although the last example listed question gave a lower mean score, the larger standard deviation for physical geography students nevertheless highlights the larger spread of responses to this question.

Question	**Mean score (standard deviation): Physical Geography**	**Mean score (standard deviation): Physics**
The modelling practical enhanced my understanding of the course material.	4.26 (0.65)	4.25 (0.46)
The model simulations helped my understanding of the principles behind the steady-state ocean.	4.21 (0.79)	4.13 (0.35)
The model simulations helped my understanding of the principles behind El Niño dynamics.	4.26 (0.65)	4.25 (0.71)
The model simulations helped my understanding of the principles behind Rossby waves.	4.32 (0.67)	4.38 (0.52)
The presentation of the material helped my understanding of ocean physical processes.	4.26 (0.65)	4.25 (0.71)
I would like more practicals of this type.	3.53 (1.07)	3.88 (0.64)

Table 1: Sample mean and standard deviation (in brackets) of the responses from the two separate student evaluations of the online practical

The open-ended questions asked questions about the best aspects of the practical and the aspects of the practical that could have been improved. Many of the students commented positively on the usefulness of the animations and the interactive aspects of the practical.

Examples of physical geography student responses to the question of ‘What were the best aspects of the practical?’.

- The interactive aspects of the practical allowed the theory explained to become tested.
- It was interesting. It reinforced and enhanced understanding of material from the lecture – without the practical the lecture would not have meant as much.
- I really enjoyed the simulations. Diagrams and simulations really help to show what we’ve been reading – much more than going through pages of text. All the reading with the practical was full-on, but with patience it helped to convey what was being shown. Just a matter of really reading it – can’t just skip through!

The responses by physical geography students to ‘What aspects of the practical could have been improved?’ were balanced. Here is one such example:

> Maybe a little less reading in the practical … was good to understand but it became a bit much. It’s a lot to take in all at once. That said, it will good to go back when the end of the year comes around use it to summarise what’s going in. Also, the formulas (although necessary) are a bit scary. For those of us who don’t know them off by heart ☺ and what they mean, then it’s overwhelming … way too many to learn. Just saying what they are would probably be better. On the whole, a great prac – very useful ☺.

Little written feedback was provided to either of these questions by the physics students.

Discussion and conclusions

Results from the two student evaluations of this online practical, while only measuring student reaction at the completion of the activity within the context of a single sitting, indicate that the design, implementation and delivery achieved the stated objectives. Taken as a whole, the student responses demonstrate quite clearly that the practical was received positively and was appreciated. The apparent contradictions to the overall positive response was observed in the more generic-type questions which considered the practical as a whole primarily in terms of student enjoyment. From the overall responses, it is clear that the students felt that the practical enhanced their learning and understanding of the fundamental principles associated with ocean processes and ENSO dynamics. These findings reaffirm the value of computer-generated visualisations and interactive learning designs for facilitating student engagement about abstract scientific principles. Ultimately, these teaching techniques can encourage students to adopt a deeper approach to their learning (Ramsden 1992).

The learning design is portable and has been applied in two separate disciplines. It is noted that physical geography students are typically very familiar with geographical concepts and the issues of scale, including for example land-ocean distributions and climate at global scales, through to small-synoptic scale weather systems. On the other hand, physics students may/may not know anything about climate science. However, physics students usually exhibit strong analytical skills and, although they may not be as prepared contextually with the subject matter presented, from discussions with these students during the practical, they appeared to understand the material on a more mathematical level. Despite these discipline-related differences, the success of the practical reinforces the modularity and portability of the design given its application for two separate purposes and contexts: (i) for understanding ocean processes and climate variability; and (ii) as an example of scientific modelling. It also provides a clear illustration of research-led teaching through: (i) the use of discipline-based research as the content for learning; and (ii) the modelling of the scientific reasoning process.

It is widely acknowledged that student approaches to learning are influenced by their perception of the task at hand (Martin and Säljö 1976) and in particular the assessment activities – otherwise known as ‘the hidden curriculum’ (Rowntree 1987; p.48). With this in mind, and given teacher observations and students’ responses to the activity, some alterations to the delivery and assessment of this practical will be implemented in second semester 2003. Firstly, the practical will be divided into two parts and conducted over two consecutive weeks to provide students with time to absorb and reflect on the material, given the complexity of the science. Secondly, a written assignment will be incorporated to assess student understanding and the students’ ability to articulate their understanding within the framework of a written 1000 word report worth 10% of the final mark for the physical geography unit. The incorporation of this additional summative assessment is to encourage an even deeper engagement with the material and challenge students to grapple with and modify their understanding in a more qualitative manner.

Taken together, our findings highlight three specific educational design implications: (i) the positive impact of computer-generated visualisations in teaching students abstract scientific concepts; (ii) the importance of learning activities that align the practices of the researcher with the process of student learning; and (iii) the need to acknowledge the inter-relationship between assessment and learning.

Acknowledgments

Thanks to Leigh-Anne Funnell, Macquarie University Centre for Flexible Learning (CFL), for developing the FERRET visualisation applications and online interface. This online practical was funded by a Macquarie University Teaching Development Grant (MUTDG) in 2001-2002. Elizabeth Devonshire is currently working at Yooroang Garang: School of Indigenous Health Studies, The University of Sydney, Australia.

References

Bell, W. H., Fowler, E. M. and Stein, A. (2003) Coastal seas as a context for science teaching: a lesson from Chesapeake Bay. *Marine Pollution Bulletin,* **47**, 253-259.

Brew, A. (2003) Understanding research-led teaching. *HERDSA News,* **25**(1), 3-5.

Cane, M. A. (1992) Tropical Pacific ENSO models: ENSO as a mode of the coupled system. In K. E. Trenberth (Ed.) *Climate System Modeling*. Cambridge University Press, 583-614.

Holbrook, N. J. (2002) Interactive visualisation of model ocean simulations for the Atmospheric Science and Bachelor of Marine Science teaching programs. Final report re: Macquarie University Teaching Development Grant (MUTDG) awarded to Neil Holbrook: 2001-2002.

Jenkins, A. (2000) The relationship between teaching and research: where does geography stand and deliver? *Journal of Geography in Higher Education.* **24,** 325-351.

Martin, F. and Säljö, R. (1976) On qualitative differences in learning. II – Outcome as a function of the learner's conception of the task. *British Journal of Educational Psychology*, **46,** 115-127.

McCreary, J. P. and Anderson, D. L. T. (1984) A simple model of El Niño and the Southern Oscillation. *Monthly Weather Review*, **112,** 934-946.

Philander, S. G. H. (1990) *El Niño, La Niña and the Southern Oscillation*. Academic Press, Inc.

Ramsden, P. (1992) *Learning to teach in Higher Education.* London: Routledge.

Riera, J., Giménez, M. H., Vidaurre, A. and Monsoriu, J. A. (2002) Digital simulation of wave motion. *Computer Applications in Engineering Education*, **10**(3), 161-166.

Rowntree, D. (1987) *Assessing students: How shall we know them?* London: Kogan Page Ltd.

Stommel, H. (1948) The westward intensification of wind-driven currents. *Transactions, American Geophysical Union,* **29,** 202-206.

Trenberth, K. E. (Ed.) (1992) *Climate System Modeling.* Cambridge: Cambridge University Press.

Whitford, D. (2002) Teaching ocean wave forecasting using computer-generated visualization and animation – Part 1: Sea forecasting. *Computers & Geosciences,* **28,** 537-546.

Zebiak, S. E. and Cane, M. A. (1987) A model El Niño – Southern Oscillation. *Monthly Weather Review,* **115,** 2262-2278.