The use of systems thinking software for research-led teaching of biogeochemical cycles: preliminary findings

Robert J.G. Mortimer and Michael D. Krom

School of Earth and Environment, University of Leeds.

Abstract

STELLA systems thinking software can be used to enhance learning in the GEES subject areas. This paper presents an example where STELLA has been used within final year undergraduate and Masters modules on biogeochemical cycles. Student feedback was generally very positive, and students found that the opportunity to build and test their own models enhanced their understanding of the Earth System. Some implementation issues occurred, which resulted in negative feedback, but these can be solved relatively easily. STELLA has potential to be used in a wide variety of learning and teaching across Geography, Earth and Environmental Sciences.

Introduction.

The STELLA computer programme (iSee Systems, Inc) has been used previously to enhance learning and teaching by modelling a wide variety of Earth systems and processes (e.g. Bice, 2001; Crawford-Brown and LaRocca 2006; Menking, 2006; Sheldon, 2006). It is a flexible, icon-based e-tool that allows students within the GEES subject areas to model relatively complex processes. It helps to bridge the gap between Geoscience research, which makes increasing use of modelling, and learning and teaching, which as a rule does not (Menking, 2006). It has been shown to help develop students' skills of: hypothesis formation and testing; integrative thinking; numeracy; and problem solving (Menking, 2006, Crawford-Brown and LaRocca 2006; Sheldon, 2006).

This paper describes how STELLA was used to enhance research-led teaching of biogeochemical cycles at undergraduate final year and Masters levels. One module was essentially a sub-component of the other, and hence they are discussed together. The aim of the course was to foster a modern Earth System Science approach in which the students were able to explore the integrated and holistic nature of biogeochemical cycles (Johnson, 2006). The basic rationale for incorporating STELLA was a simple one, namely that students benefit from active learning (Cox, 1994), and that creating, exploring, and testing their own models is better than listening to them being described in a lecture. Additional aims were to foster closer linkage between research and teaching, and to allow students to further develop skills of hypothesis formation and testing, integrative thinking, numeracy, and problem solving.

Method.

The STELLA software was embedded into the two new related modules, SOEE3110 Earth System Science: Biogeochemical Cycles and SOEE5232 Biogeochemical Cycles of the Earth System. The total class size was 65, and included students taking a variety of environmental and Earth-related degree programmes.

The software was introduced into the course in three ways. Students:

1. were given training in the use of the software to create simple models.
2. had familiarity with STELLA models reinforced, by using them as explanatory and illustrative tools during lectures.
3. were set two assessments using the software: the first was a three-stage model-building assessment; the second explored scenario testing and model limitations.

Prior to the STELLA training session, the course included two hours on box modelling to start students thinking about systems and how they might be described (Sibley et al., 2007). The STELLA training session itself lasted a further two hours, during which time students were introduced to the software and shown how to build basic models. During this session, the students constructed a model of the water cycle that was then used during lectures the following week.

The next section of the course covered the carbon cycle and, in parallel with lectures, students were set a three stage STELLA assessment to design a simplified model of the carbon cycle. The first stage of the model was relatively prescriptive, and was designed for students to practise and reinforce their modelling skills whilst starting to think about the carbon cycle. They were asked to follow quite detailed instructions in order to model expected and actual long term trends of atmospheric carbon dioxide. This was handed in for formative feedback and returned quickly so that students could progress to stage two of the model.

For stage two, students were given more general instructions, and were asked to add the impact of respiration and photosynthesis on carbon dioxide levels. The aim of this stage was threefold: to continue to develop students' modelling skills; to develop their numerical skills (mathematical functions required); and to encourage them to start thinking about the inter-relationships of processes within the carbon cycle. This was again handed in the form formative of feedback before students tackled the final stage of modelling, which was the summative assessment. For this final stage, students were asked to add the ocean carbon cycle to their model, based on their understanding of the processes covered in the lectures (Figure 1).

Later in the course, lectures on the phosphorous cycle introduced the concept of using STELLA for scenario testing (future and past; Figure 2). Students were then set their second assessment, where they had to use a model of the carbon cycle to test potential future scenarios. In addition, they were asked to explore the limitations of the model, something that Sheldon (2006) points out is a key part of developing student understanding of what models can be used for.

Feedback was gathered for the course as a whole using a standard proforma, but students were also asked to provide specific comments on the STELLA modelling component.

Results and Discussion.

The mean marks out of 5 given by the students for different aspects of the module are summarized in Table 1.

These results demonstrate that the module was a success, particularly given various teething problems that commonly occur for new modules. Specific feedback on the STELLA modelling component is presented in Table 2.

At first glance, it seems that views of the STELLA modelling were highly polarised. However, closer examination of the specific comments reveals a more positive picture. Students who praised the use of STELLA liked the opportunity to do modelling, and found it very useful. Typical comments were:

> *'STELLA modelling was very useful and interesting'*

> *'STELLA is a good learning tool and helped my understanding of biogeochemical cycles'*

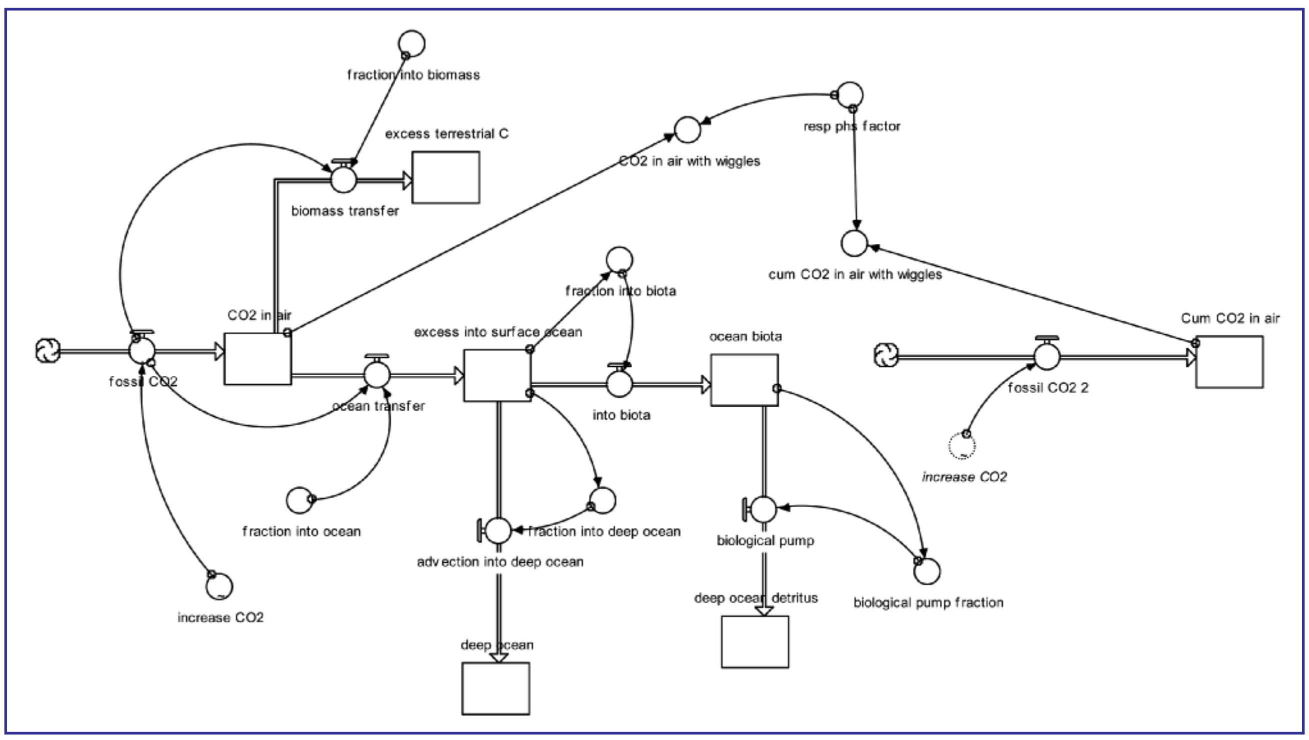

Figure 1: Basic STELLA model of the carbon cycle as constructed by students in three stages, together with example output.

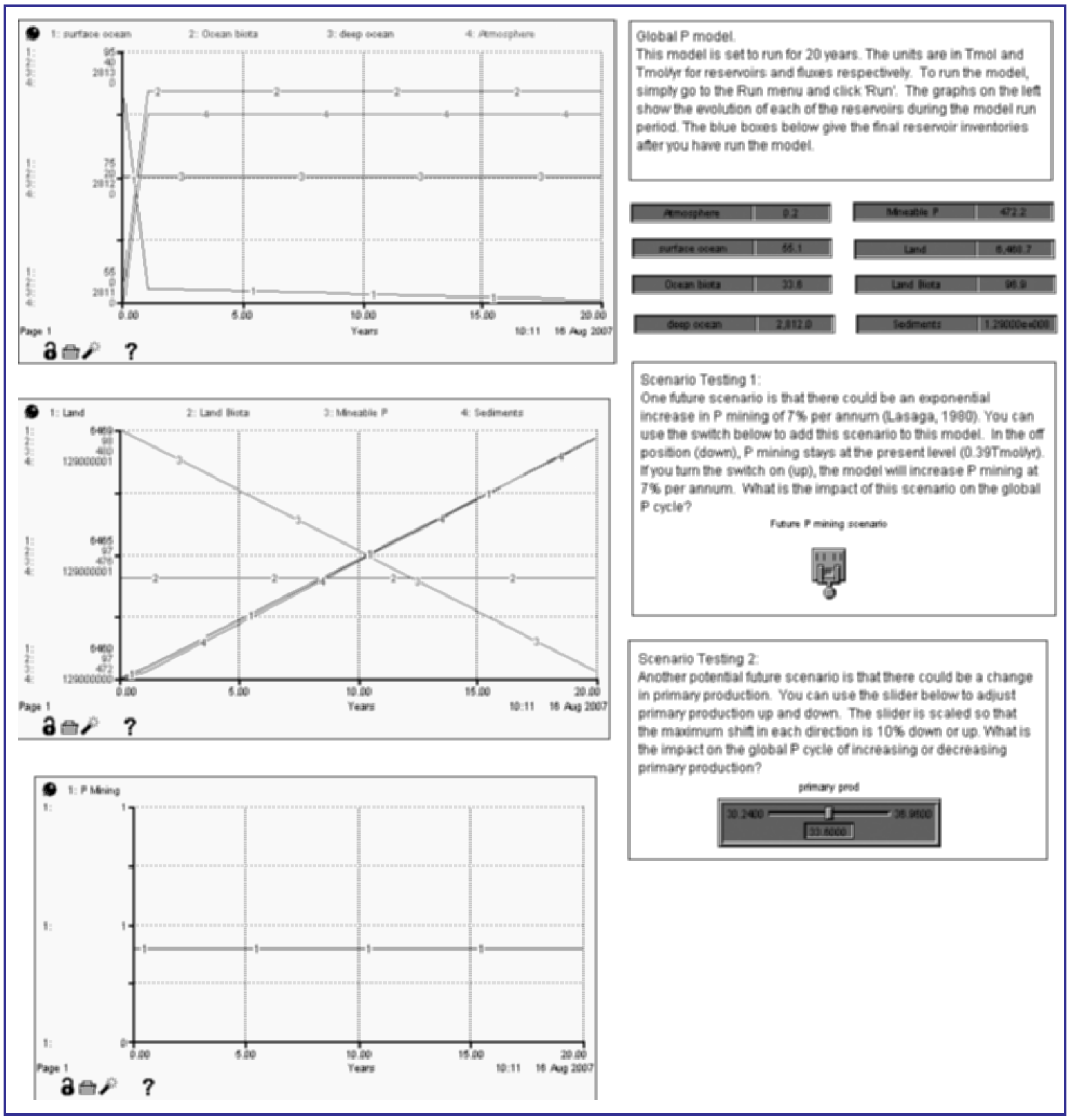

Figure 2: Interface from phosphorous model showing example of scenario testing possible with STELLA

'STELLA is good…we don't normally get the chance to use computer models. And actually be able to understand it!'

'STELLA modelling is interesting and helps you understand the links between the systems.'

'I believe the modelling is a good part of the course and must be kept'

'The work has been interesting and the modelling has been good. Using the modelling software and seeing the real implication of changes to the systems was really good.'

'I enjoyed the STELLA modelling- allowed us to look at different scenarios – helped with understanding.'

Comments were often framed with general comments about the global and holistic nature of the modules, and it is clear that the STELLA was beneficial in this respect. For example:

Was the material presented in the course interesting and relevant?	The assessment requirements are clear.	The amount of work is about right	Was the lecturing style lively and interesting?	There is adequate access to required learning resources.	Overall this is a good module.
4.2	3.7	4.1	3.8	3.5	4.1

Table 1: average evaluation of module by students (49 respondents out of a total of 65 students registered on modules (5 = strongly agree; 4 = agree; 3 = no opinion; 2 = disagree; 1 = strongly disagree)

Total number students providing feedback:	**49**
No. students who made specific positive comments about the STELLA modelling	31 (63%)
No. students who made specific negative comments about the STELLA modelling	25 (51%)

Table 2: numbers of students commenting on STELLA modelling component

'Broad nature of course forces you to think of the Earth system as a whole.'

'Modelling work was excellent; helped understanding of course. Very good summary module for BSc Earth System Science.'

'Covers wide range of topics, all linked and relevant to global system; it was good to have the opportunity to try modelling.'

'Holistic view of Earth System [was the best feature of this module]'

Several students praised the STELLA assessment, and particular the rapid feedback that was provided:

'Modelling was good: new and interesting. STELLA modelling assessment was clear and straight forward.'

'Doing the modelling is a good idea as something to take pressure off exam.'

'Feedback (given on STELLA models) gratefully received… gives useful feedback'

'The feedback and modelling [were the best feature of this module]*, as it forces understanding.'*

'Interesting module; really fast feedback on STELLA modelling assessment.'

[The best feature of this module was] *'the rapid and continuous feedback that the assessments provided'*

Number of students making negative comments about STELLA modelling:	**25**
Total number of negative comments:	29
Need STELLA on more PCs/restricted access to cluster	6 (21%)
Difficulties printing from STELLA	2 (7%)
More STELLA training wanted	5 (17%)
More clarity needed in STELLA assessment guidance notes	8 (28%)
More clarity needed in STELLA marking criteria	8 (28%)

Table 3: Summary of negative feedback on STELLA modelling

In contrast, the negative comments (See Table 3) were about three specific aspects of the STELLA modelling (hardware/software issues; training/clarity of instructions; level and marks allocation for first assessment). Several students who praised the modelling highlighted these aspects as things for improvement.

All of these criticisms have been taken on board for future years, but they are essentially implementation issues. Hardware and software issues (28% negative comments) are inevitable when introducing new electronic resources. Changes to the assessment guidelines will alleviate the printing problems next year. Access to PCs remains an issue and highlights the need for both sufficient hardware and enough STELLA licenses.

The issues of more STELLA training (17% of negative comments), and better clarity of guidance notes (28%) reflect differing levels of computing ability amongst the students. Some students found the modelling software very easy to use, while others didn't. Introduction of an additional voluntary training session is probably the best way to solve this problem in future years.

The final set of negative comments concerned the assessment criteria. After speaking to the students, it is clear that these comments came from students at the upper end of the ability spectrum who wanted more marks to be available for constructing more complex/accurate models, and who felt that too many marks were given for good presentation. These criticisms are valid, but reflect the fact that the level of the assessment was set with no prior knowledge of how the students might find systems thinking software and construction and testing of models. With the benefit of hindsight from this first year, the course and supporting materials will be modified for future years, to alleviate this problem.

Conclusions and recommendations.

Overall, the introduction of the STELLA software to teach biogeochemical cycles was very successful. Positive student feedback outweighed negative feedback, which was largely down to implementation problems (that were perhaps to be expected). Feedback in subsequent years will be compared with this first cohort to check that these problems have been resolved. The basic aim was realised, with student feedback showing very positive responses to active-learning. Students gained new modelling skills, but also enhanced existing skills of problem solving, integration and numeracy.

Most of the students were more computer-literature than expected (France and Fletcher, 2007), and many enjoyed the chance to do modelling. As with previous studies, the majority were enthusiastic and some really began to be creative and take ownership of the course (Menking, 2006). Similarly, the small number of students who were less enthusiastic tended to construct models with minor errors or timing issues that they were then unable to critically analyse and correct (Menking, 2006).

STELLA is a very flexible tool that can be used to model a wide variety of different systems in the GEES subject areas, both within the physical and social sciences. It also has the ability to allow students to explore links between physical and social processes (e.g. link between society, sustainability and the carbon cycle). As with any implementation of e-learning, some investment of time is needed by staff to learn how to use the software and to build models to support the learning and teaching (France and Fletcher, 2007). However, student learning can be enhanced significantly and STELLA can be used to drive independent-learning that ultimately makes courses more efficient.

Aknowlegements.

Teaching Quality Enhancement Fund support of £4200 was gratefully accepted.

References.

Bice, D.M. *(2001). Using STELLA models to explore the dynamics of Earth systems: experimenting with the Earth's climate system using a simple computer model. Journal of Geoscience Education, 49: 170-181.*
Cox, B. *(1994). Practical points for University teachers. Kogan Page Ltd, London.*
Crawford-Brown, D., & LaRocca, S. *(2006). Teaching systems principles and policy applications using a reduced-scale carbon cycle model for global warming. Journal of Geoscience Education, 54: 301-311.*
France, D., and Fletcher, S. *(2007). E-learning in the UK: perspectives from GEES practitioners. Planet, 18: 3-5.*
Johnson, D.R. *(2006). Earth system science: a model for teaching science as state, process and understanding? Journal of Geoscience Education, 54: 202-207.*
Menking, K.M. *(2006). Creation of a computer modelling course for undergraduate Earth Science Students. Journal of Geoscience Education, 54: 464-470.*
Sheldon, N. *(2006). Teaching quantitative skills and integrative thinking in earth sciences using object-oriented computer models. Planet 17: 44-47.*
Sibley, D.F., Anderson, C.W., Heidemann, M., Merrill, J.E., Parker J.M., and Szymanski, D.W. *(2007). Box diagrams to assess students' system thinking about the rock, water and carbon cycles. Journal of Geoscience Education, 55: 138-146.*