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Improving Learning Processes in Meteorology with Computational Modelling

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Teaching introductory meteorology: the problem

Advanced computational knowledge and technologies play a fundamental role in the development of modern research in meteorology. In depth learning of such computational skills is a difficult cognitive process that requires a strong background in physics, mathematics and computer programming. However, the analysis of meteorological phenomena is an important curricular aspect for a wide range of courses taken by students who do not have this kind of advanced scientific background.

A new step forward: embedded computational modelling

The corresponding learning environments and pedagogic methodologies should then involve sets of computational modelling activities with computer software systems which allow students the possibility to overcome their lack of advanced mathematical or programming knowledge and focus on the learning of meteorological concepts and processes taking advantage of basic scientific computation methods and tools.

This expectation is supported by the results of many research efforts (see, e.g., Blum, Galbraith, Henn & Niss, 2007; Handelsman et al., 2005; McDermott & Redish, 1999; Slooten, van den Berg & Ellermeijer, 2006), which have shown that the learning processes in various areas of science, technology, engineering and mathematics can be effectively enhanced when students are embedded in atmospheres with activities that approximately recreate the cognitive involvement of scientists in modelling research experiences. Fundamental to the implementation of these modelling cycle pedagogies is an early integration of activities with computational knowledge and technologies, a goal that in particular should be achieved in introductory meteorology courses.

To reduce the level of cognitive opacity associated with mathematical or programming knowledge, several computer modelling systems have already been developed (Neves & Teodoro, 2010; Teodoro & Neves, 2011). Among such systems, Modellus* is particularly well suited to achieve this goal because it is a domain general environment for explorative and expressive modelling with the following main advantages: 1) an easy and intuitive creation of mathematical models using just standard mathematical notation; 2) the simultaneous exploration of images, tables, graphs and object animations; 3) the attribution of mathematical properties expressed in the models to animated objects; and finally 4) the computation and display of mathematical quantities obtained from the analysis of images and graphs.

Innovative learning activities with Modellus

In this work, we describe a set of computational modelling activities on introductory meteorology developed with Modellus for a course gathering students from several undergraduate university degrees: environmental engineering, marine sciences and biology. We report on the student's receptivity to the integration of this computational modelling approach and discuss its effect on the learning process.

References

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* Modellus Internet Website: http://modellus.fct.unl.pt/

Solar Radiation

In this set of learning activities, students used Modellus to model Planck's law, Wien's law and Stefan-Boltzmann law. These laws were then applied to estimate the black body equilibrium temperatures of the Earth and the Sun.

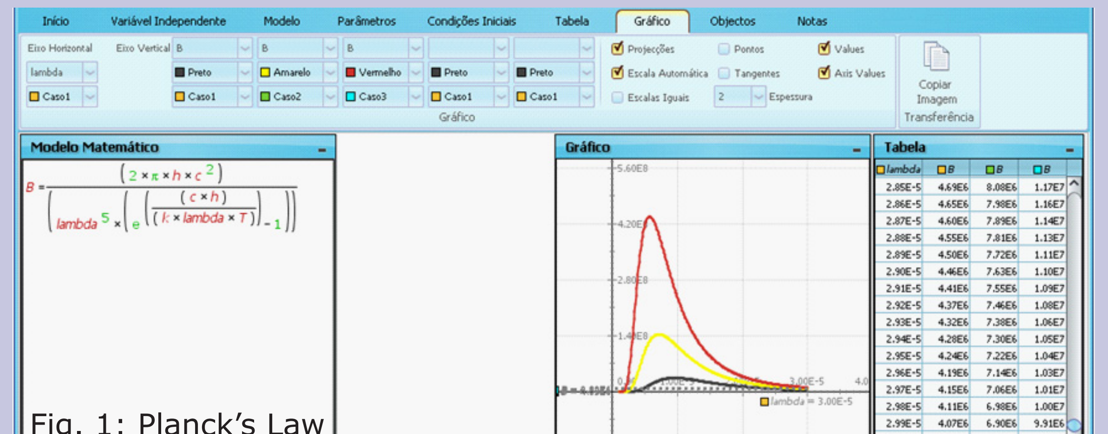


Fig. 1: Planck's Law

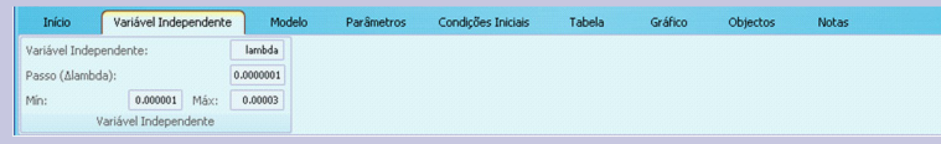


Fig. 2

Fig. 3

The PDF protocols illustrated a sequence of steps necessary to create the models with Modellus. For example, to visualise Planck's radiation curves students completed the following procedure:

1 - Write Planck's radiance function B in the Mathematical Model window (Fig.1).
2 - Define the wavelenght λ as the independent variable (Fig. 2).
3 - Define as parameters h, c, k and the temperature T (Fig. 3).
4 - Define the settings of the graph and table with three different temperature values as three different cases (Fig. 1).

Fig. 4: Wien's Law

Fig. 4 : Using Modellus graphical tangents, students were able to determine the value of λ for which the tangent to the radiance graph is horizontal, and thus find the corresponding maximum radiance value. Repeating this procedure for several different temperatures T, it was possible to verify Wien's law, namely, that the product λT is constant.

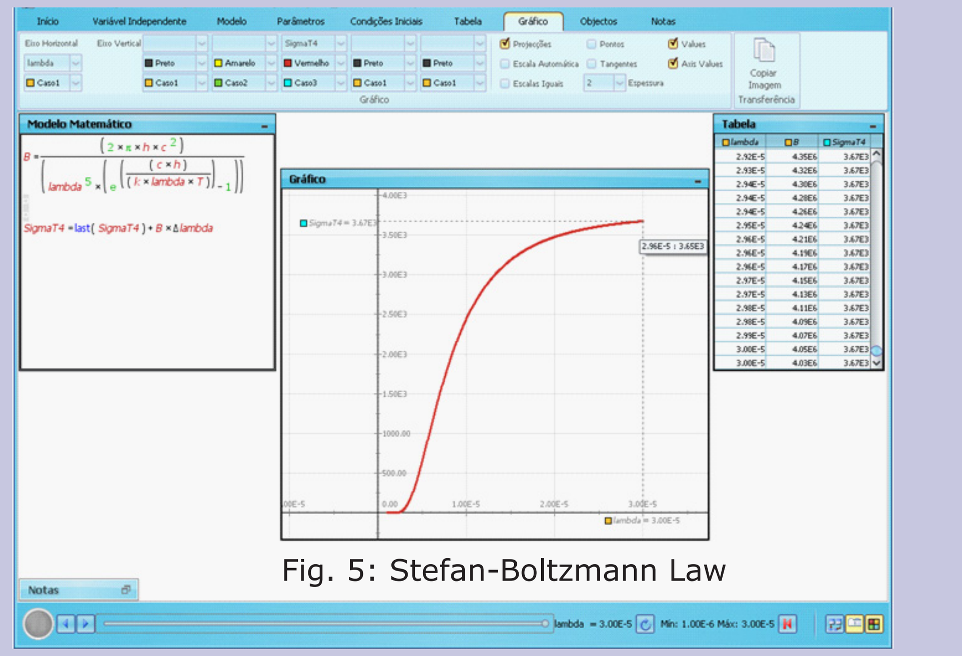
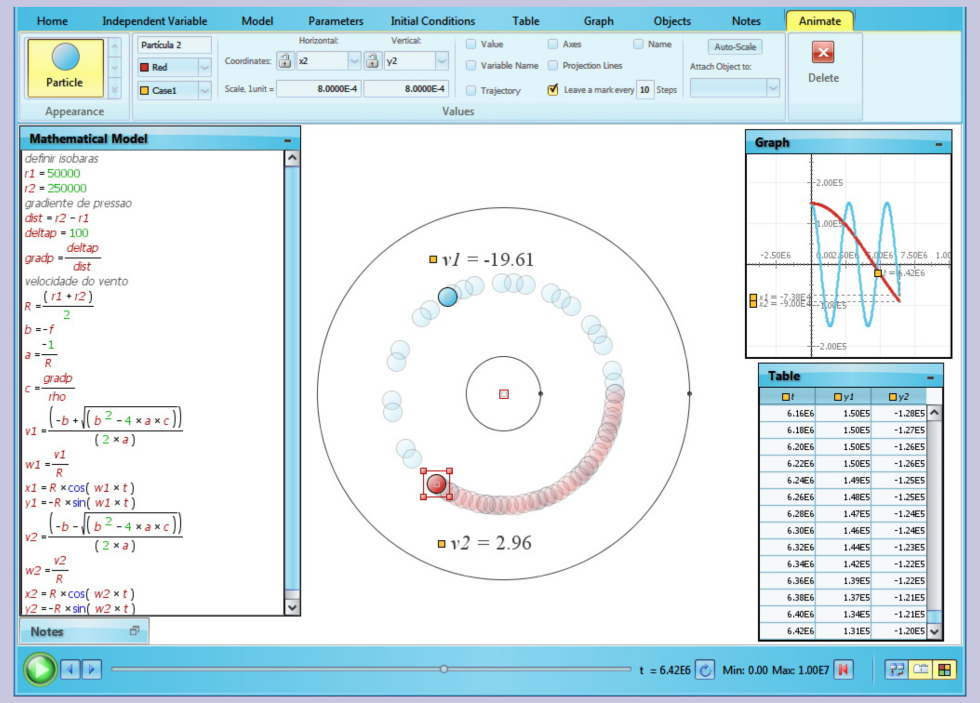


Fig. 5: Stefan-Boltzmann Law

Fig. 5: For students which do not know how to integrate Modellus shows this concept in a graphical way. In this case the students can verify that the area under the radiance curve is equal to the product σT^4.

Wind Velocity



In a gradient wind the motion of a wind particle is circular. The two circles in Fig. 5 represent two circular isobars in a high pressure centre. The distance between the two isobars is 200 km and their pressure difference is 1 hPa. The magnitude of the gradient wind velocity is one of the solutions v of the following equation:

$$f\,v - (1/\rho)\,\Delta p/\Delta n - v^2/R = 0$$

Fig. 5: Gradient wind. When the speed solutions are both positive the physical solution is the one with the smallest value.

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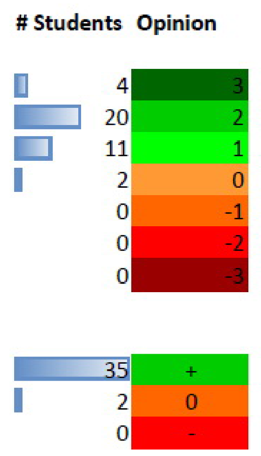
Meteorology: Computational Modelling with Modellus (2nd Semester 2009-2010)

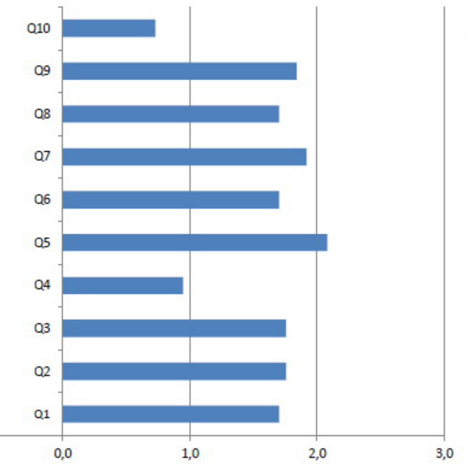
Questionnaire

Give your opinion (encircling the adequate number) about each one of the following assertions, using a scale from −3 to +3, where −3 represents being in "complete disagreement" and +3 being in "complete agreement", representing the remaining negative values being in "partial disagreement" and the remaining positive values being in "partial agreement".

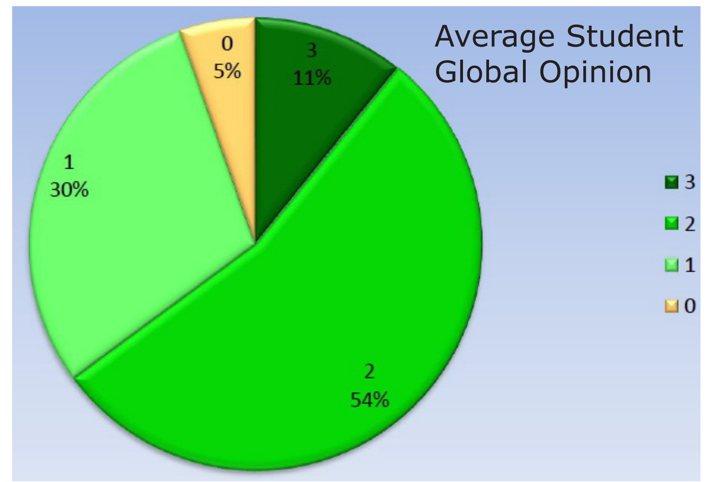
1. Introducing the computational component in the learning process was useful for your professional trainning	−3 −1 0 +1 +3
2. The relative time percentage given to the computational classes was adequate	−3 −1 0 +1 +3
3. Introducing the computational component was useful for the learning process of Meteorology.	−3 −1 0 +1 +3
4. Doing the activities in groups of 2 or 3 would had more advantages than doing the activities individually.	−3 −1 0 +1 +3
5. During classes, the teacher's guidance and support to the several groups was sufficient and adequate.	−3 −1 0 +1 +3
6. The problems analysed in the computational activities with Modellus were interesting and motivating.	−3 −1 0 +1 +3
7. The activities with Modellus in PDF format are well conceived and interesting.	−3 −1 +1 +3
8. Modellus is a useful software to help the learning of mathematical-physics models.	−3 −1 +1 +3
9. Modellus is easy to learn and is user-friendly.	−3 −1 +1 +3
10. Modellus could be used in other disciplines of your course, with adequate activities.	−3 −1 +1 +3

Comments and suggestions about the computational activities:





Average Student Opinion per Question



Conclusions

We have made a successful implementation of a set of innovative activities based on computational modelling with Modellus in the Meteorology and Climatology course taken by 2nd year students of the Marine Sciences and Environmental Engineering courses at the Faculty of Sciences and Technology of the University of Algarve.

Globally, students reacted very positively to the activities, considering them to be important in the context of their course and professional trainning. The computational activities with Modellus presented in PDF format with embedded video guidance were also considered to be interesting and well designed.

Modellus has been successfully tested as a software tool that allows students to work as authors of mathematical physics models and simulations, not as simple browsers of computer simulations. Models can be presented as differential equations solved by simple numerical methods and students can appreciate the differences between numerical solutions and analytical solutions. For students, Modellus was indeed seen as helpful in the learning process of mathematical and physical models. It was also found to be easy enough to learn and user-friendly.