Simulating chaos:

an evaluation of the driven pendulum experiment

Eileen Scanlon,* Shelagh Ross** and Canan Tosunoglu*

*Institute of Educational Technology, Open University
**Open University Regional Centre

This paper reports on the use of the Driven Pendulum software as part of the teaching for the Open University course Discovering Physics *and provides an account of some of the findings from its evaluation as part of the learning experience provided to students. A driven damped pendulum is a suitable instrument for experimental studies of chaotic motion. The main aim of the simulation was to allow students both to observe some of the generic features of chaotic motion, and to explore ways in which these may be represented graphically. This simulation formed the basis of a three-hour experiment for students which provided them with a number of learning opportunities, e.g. the opportunity to build up state-space trajectories for various types of pendulum motion, in order to appreciate the advantages of the state-space representation for analysing complicated behaviour, and providing consolidation of ideas about oscillations, damping and resonance. An evaluation of the Driven Pendulum at the residential school in 1995 was conducted as part of a university-wide project run by the Computers and Learning Research Group investigating computer use in learning science and technology, and developing evaluation methodologies. It was both formative in that the evaluation results were used to redesign the notes guiding students through the activities, and summative in that we were able to draw some conclusions about the role played by the simulation in students' learning. The students were extremely positive about the contribution made to their learning by the program, and students' performance indicated learning gains. However, the observation data suggested that students were unclear about the distinction between complex and chaotic behaviour.*

Introduction

Computer simulations offer opportunities for learners by providing a model of a realistic situation for them to manipulate. At the Open University we have many years of experience of helping learners to use such simulations in physics teaching, and evaluating the results (see, for example, Every and Scanlon, 1984). We present here an account of an attempt to use a computer simulation to help beginning students of physics to learn about chaos.

The Driven Pendulum software

A driven damped pendulum is a suitable instrument for experimental studies of chaotic motion. Blackburn *et al* (1989) describe one such instrument consisting of a mechanical pendulum driven by both steady and alternating torques, together with interface electronics for data logging and graphic displays. The course team for the introductory physics course *Discovering Physics* decided to use a computer simulation of a similar system at the residential summer school which offers both laboratory sessions as well as problem-solving and computer-based activities. The students used the driven pendulum simulation as part of a series of short experiments each lasting about three hours. The computer-simulated experiment was programmed by the Centre for Educational Software, and the underlying mathematical model produced by the Physics department at the Open University.

The main aim of the simulation was that students should observe some of the generic features of chaotic motion, and explore ways in which these may be represented graphically. This simulation provided students with a number of learning opportunities, for example the opportunity to build up state-space trajectories for various types of pendulum motion, in order to appreciate the advantages of the state-space representation for analysing complicated behaviour, and providing consolidation of ideas about oscillations, damping and resonance. A subsidiary aim was that the inclusion of simulations in the residential school programme could give all students some hands-on experience of computer use.

The program

The simulation screen consists of three windows (see Figure 1). The first window displays the graphs, and the student has a choice of different displays such as angle as a function of time, component of angular velocity as a function of time, and component of angular velocity as a function of angle. The third of these options, called the state-space representation, is used extensively in the experiment. The second window is a pendulum animation, and the third window has pendulum parameters. The graphs window and the pendulum window can be re-sized by students to help them see the details of the motion of the pendulum, but most of the students we observed used the sizing shown in Figure 1. The development of the graph can be seen by the students, and the pendulum animation also provides visual information about the motion of the pendulum. Students can specify the parameters (pendulum mass, length, initial angle, initial angular speed, pivot amplitude, frequency, and experiment duration) and determine how many samples per drive cycle will be used to form the graph, and whether to observe the display in real time or in fast processing. The level of damping can be determined by selecting low, medium or high damping buttons, or students can specify the exact level of damping by turning on 'Exact damping' in the View menu. An additional pop-up menu provides students with facilities for examining the motion of the pendulum in detail. For example, they can use an autoscale facility to change the range of axes of the graph, a default facility to go back to original display-range of the axes, the fit damped curve facility to measure decay time of the oscillations, and the memorize facility to superimpose the previous graph on the present one.

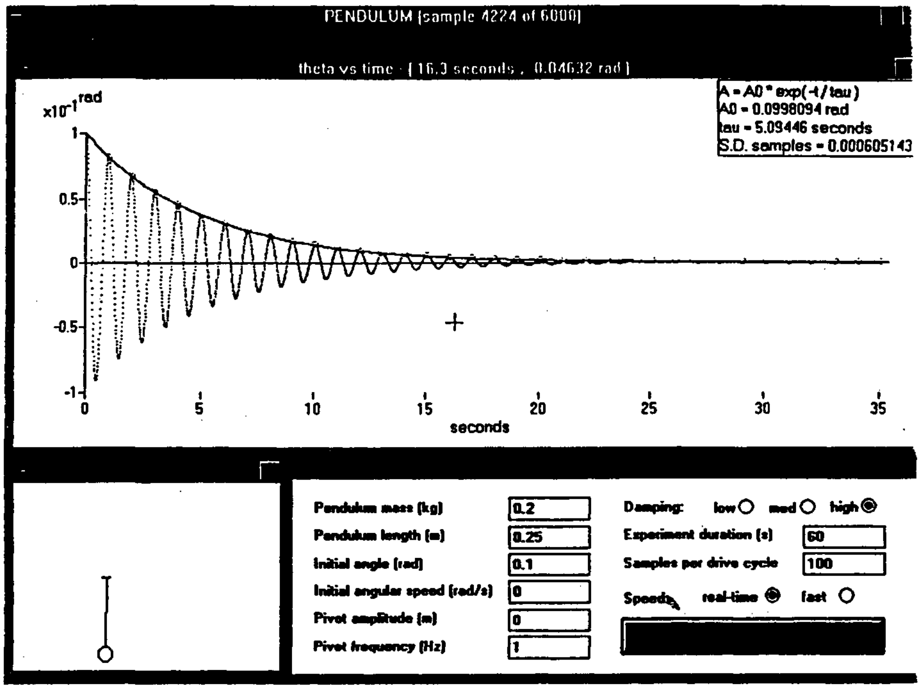

Figure 1: The three windows of the simulation screen

The evaluation

We conducted an evaluation of the Driven Pendulum at the residential school in 1995. This involved 38 students (19 pairs). Specially designed questionnaires were given to students before and after the experiment was administered in order to collect data on the students' attitude to certain aspects of the simulation, and to collect performance data. Thirty complete pairs of pre- and post-experiment questionnaires were returned. In addition, data collected included video (three pairs) and audio recordings of students at work on the simulation to allow an investigation of how the students interacted with the software, and to gain access to the conversations which the pairs had while using the simulation. This approach has been found to be particularly helpful in analysing the impact of educational software on learning outcomes (see, for example, Scanlon *et al*, 1993a and 1993b). Individual and group interviews with students and tutors were another line of data-collection which provided some insights into the software's contribution to student learning. This evaluation was conducted as part of a university-wide project run by the Computers and Learning Research Group which is investigating computer use in learning science and technology, and developing evaluation methodologies (Jones *et al*, 1996). It was both formative in that the evaluation results were used to redesign the notes guiding students through the activities, and summative in that we were able to draw some conclusions about the role played by the simulation in students' learning.

The questionnaire results were reassuring in that only four out of thirty students did not find the experiment notes clear. Twenty-six students reported that the software was motivational. Students were asked what they had learned from the experiment. Nineteen detailed responses were given to this question, all but one of them positive (for example, '[I learned] to ask more questions about the relationship between the range of resonance frequencies and the degree of damping, and how continuously varying a parameter can move a system from chaotic to merely complicated behaviour'.) Students were given a list, and asked to select their view of the most important advantage of doing this experiment in the form of a computer simulation. Half of the students felt the most important advantage was that they would learn more in the same amount of time, and almost the same number (14 out of 30 students) that it gave better understanding of the material.

Observations revealed that, as they used the simulation, many of the students were interested in the underlying model, and that they wanted to experiment to see what it was like. Many used the simulation to check the theoretical equations. Both the questionnaire responses and the observation data illustrated that some confusion existed over the critical damping condition when damped pendula were observed, and some of this was due to students using different scales for their observations.

All students were also presented with a mini-quiz after they completed the experiment. They were presented with two different types of graphs of five selected parameters. The first type were angle-versus-time graphs of selected parameters; the second was of state-space trajectories of the same set of parameters. After they finished the experiment, the students were asked to match angle-versus-time and state-space representations for the same set of parameters. Scores for each item on the mini quiz ranged from 67 per cent to 88 per cent, giving support for the view we formed from observations and interviews that the experiment was successful in terms of providing help with an understanding of the motion of the pendulum and its representation.

Conclusions

The students were extremely positive about the contribution made to their learning by the program, and there is some evidence that it indeed did help their learning. However, the observation data suggests that many of the students were still unclear about the distinction between complex and chaotic behaviour, and many would have liked to spend more time on the experiment. We found the mix of methods of evaluation used provided us with a rich picture of how students had gained from their experience of simulating chaos.

References

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