LEARNING ABOUT CONTROL SYSTEMS BY MODEL BUILDING – A BIOLOGICAL CASE STUDY

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Abstract

To assist students' understanding of control systems, we have developed an interactive model-building program, suitable for many disciplines and student backgrounds. Students are challenged to build and explore the operation of an on-screen model, and audit trail data are analyzed to identify and resolve areas of student difficulty.

Keywords

Control systems; Qualitative modelling; Audit trail analysis; Multidisciplinary; Blood pressure feedback systems; Curriculum target.

Policy, initiatives and educational practice

Changes in educational policy

Tertiary institutions are increasingly challenged by the diversity of educational and cultural backgrounds of students. This is especially the case in Health Sciences, where classes include both undergraduate and graduate students with a broad range of backgrounds (arts, law, commerce, physical and biological sciences and engineering). Students with disparate entry levels of academic experience and achievement need to be provided with the tools to deal with complex control systems usually found in biological sciences.

Most physical sciences deal with determinate control systems in their teaching. However, in biology the complexity of operation of basic control systems often means that we must deal with what are classified as 'ill-defined systems' with non-linear and discontinuous behaviour. Such systems are difficult to describe satisfactorily with mathematical functions and these systems are also influenced by other variables which are poorly understood. Thus students in the biological sciences having backgrounds in engineering or physical sciences, with their more mathematical approach, need to adapt their learning to deal with these systems.

Successful students in examinations may have good recall of individual mechanisms and factual information, but may not develop a good understanding of the underlying principles of the behaviour of whole systems. The latter is one of the most difficult learning areas for students and teachers (Rosenberg *et al.*, 1991) and understanding control systems is a key element of such learning.

We have used blood pressure control as a model system, in particular the reflexes that stabilize human blood pressure during changes in posture. This is an example of an 'ill-defined system' that has been the subject of extensive modelling attempts using mathematical approaches, but we have found that our students in their early years do not use such models effectively and seem to be lost in their complexity.

A new teaching approach in biological and medical sciences

Our new approach is to introduce a qualitative conceptual framework for a model that is suitable for introducing complex control systems to students in the biological and physical sciences, economics and engineering. In other words we facilitate the students' building of the 'big picture' of a complex system before going into the details. Such an approach has also been taken to bring teaching into alignment with practices in new curricula that increasingly rely on problem-based learning, problem-solving, student-centred learning, and self-paced learning.

Like students in many disciplines, those in biological sciences have problems in understanding both the principles of the operation of control systems and then the application of these principles to the real-world complex systems. Biological sciences was previously regarded as a soft learning option, but the growth in biological knowledge has meant that concepts have become increasingly difficult to understand as systems are unravelled through research. It is always a challenge to teach difficult concepts in an engaging manner. This project is a direct response to student and staff difficulties with the teaching of biological feedback control. This approach might equally well apply to fiscal modelling in economics or to a complex engineering principle.

We take a basic approach to understanding the behaviour of a control system by having students develop the logical arrangement of system components. Students are challenged to build and explore the operation of an on-screen model of the blood pressure control system. Students make logical assemblies of blood pressure detectors (receptors), signalling circuit components (neurones), and output mechanisms (in heart or blood vessels).

A case study — understanding control of blood pressure

The immediate trigger for this project was to replace practical classes in which students investigated the control of blood pressure in anaesthetized rabbits. Originally these classes were very successful in assisting students to develop manipulative skills and experimental techniques and ways of investigating control systems by interrupting the control pathways. However, despite having one tutor for every eight students, these classes were not so successful in assisting them to understand the overall operation of the blood pressure control system. Later, in line with a world-wide move to reduce animal experimentation, it was replaced by class demonstrations and then a video of the experiment shown to a class in a lecture theatre. However these rather passive sessions were of limited success. Students learned effectively neither about experimental design nor the analysis of the control system.

We have identified the specific needs for this project by analyzing students' answers to an examination question on the control of blood pressure and determining their major misconceptions. Not only is this an essential step in deciding that the students' difficulties justify the investment of time and effort into a multimedia solution, but also guides the development of the program, as well as providing a basis for future comparative analysis of the extent of misconceptions after such a program is incorporated into a curriculum.

Pedagogical issues

We take a constructivist approach by allowing students to build their own model systems, within the bounds of the physical constraints that govern the behaviour of the system. The computer is a key component of this approach when it is used as a cognitive tool (Jonassen and Reeves, 1996).

The pedagogical principles and interface design issues considered in development of computer programs involving model of secretory cells have been described previously (Weaver *et al*, 1996; Kemm *et al*, 1997) and many of these have been followed in this project.

We have also chosen to present the program in a collaborative learning environment, with 2-3 students per computer. We have found this most effective as judged by the noisy computer laboratory, fingers pointing at the screen and lively interactions between students, (independently judged to be about the problem and not extraneous life issues).

We use the computer program effectively as an expert system that assists students' construction and testing of their model by providing construction tools and feedback screens indicating success or failure of their model and hints on possible changes they might make. Students may find deficiencies in their model, a need to adjust misconceptions, suggest modifications in the expert model for future implementations, or exhibit misunderstandings in common with other students. On completion of the model, students are given tasks with a strong element of reflection in their use of the tutorial as they try 'What if?' scenarios and elaborate on the knowledge into new areas.

Principles used in software design

The essential feature of the program is to present the information in a simple qualitative manner that could be used to give a global view of the control system. This conceptual framework can then be used by students to add specific details of the mechanisms or indeed to better understand a mathematical simulation of the system at a later time, such as would be appropriate for engineers.

Teaching programs are always based on either explicit or implicit assumptions about learners and learning and the desired cognitive outcomes. Some issues we have tried to address are to provide:
Allowance for prior pertinent knowledge and understanding, including differences between undergraduate and graduate student intakes and for students from diverse disciplines.

Student Control over Learning and problem-solving strategies (Evans, 1991). *Substantive feedback* on students' attempts at tasks in a way that encourages *active* reflection on both the content and learning or problem-solving strategies (Butler and Winne, 1995).

A sense of challenge, excitement and appropriate effort.

Tasks for the student, and approaches to teaching, that actually encourage students to understand the concepts and principles underlying control systems and that can be extended to different body systems.

Encouragement of problem solving and exploration and extension of principles learnt.

Encouragement to explore alternative solutions, eg “what if?" ?

Implementation methodology

Targeting the curriculum need

The first stage in development of this tutorial was to identify the need in our curriculum. We analyzed essay answers to an examination question set for target students in 1996 to identify the major problems with this topic. In consultation with the examiner, each exam response was analyzed against a checklist of requirements, and statistical data was collected to ascertain where problems occurred. We found that students experienced difficulty understanding the concept of the model/circuit, and displayed problems with the signalling sequence of reflex control (ie. detection of imbalance must occur before reflex correction can take place). Compilation of this data also allows us to evaluate future cognitive outcomes of implementation of this tutorial.

Model-building in cognitive steps

Students are required to create and position components of an electrical (neural) circuit to create a control system which will allow a person to maintain the blood supply to the brain when they change posture.
To create components, the students are given a graphical example of the component, and a button to click:

Figure 1: Example of a

These components consist of receptors (signal detectors), input (afferent) neurones, processors (interneurones), and output (efferent) neurones. (see Figure 2).

Figure 2: Model building components

For practical (and logical) purposes, students were guided into sequential construction. Our educational approach is to provide feedback at every stage, and this is in the form of a simple animation of the system working (ie. electrical impulses moving around the connected components of the system), followed by textual feedback. The textual feedback is always in the format of a positive statement (what is correct so far), followed by a statement about what is not yet correct, and a hint about what to consider next. (see Figure 3).

Figure 3: Example of a feedback panel

We anticipated that students would be challenged by this model, due to the complexity of the system. We limited some of the attributes eg. choice of neurotransmitters, and prompted consideration about these attributes later in the program with questions. Our approach was to concentrate on the concepts (structural model) first, then introduce the details later, to avoid overloading the students at any one stage. The components incorporated in the model (see Figure 4) were:

1. 2 signal detectors
2. 2 input pathways
3. 2 central processor types
4. 3 parallel output pathways
5. 2 target types

Figure 4: Completed model on screen, showing complexity of parallel output.

Field-testing and evaluation

The first stage in programming was to prepare the tools necessary for construction of the model. Each stage of the model-building exercise was identified using extensive flow charts, and animated and textual feedback for every stage was prepared.

The first draft of the program was tested on 200 Medical students, working in pairs in a scheduled class. Students were observed by the program developers, and completed a written questionnaire at the end of the session. At the same time, electronic audit trails of student progress through the model construction were collected. These audit trails were matched to questionnaire responses.

The audit trails tracked student viewing of feedback panels seen by students, so that we could map exactly which path was taken to reach the complete model. Importantly, this was only a very selective collection of data - not every button click was stored, to limit the amount of information collected to a manageable and interpretable amount. The feedback strategy was structured to be easily tracked by audit trails, so that the same misconception often leads to the same feedback.

Students took some time to familiarize themselves with the program, but were generally able to complete the given tasks in the time provided. It was apparent that some students quickly became frustrated when they felt they were unable to move on, and became less likely to read instructions or textual feedback. The level of sophistication of the model, and lack of familiarity with the symbols used, was such that they were overwhelmed by so much new information.

Questionnaire analysis

The questionnaire responses generally reflected the students' enjoyment in the interactive task of constructing their own model, although most experienced difficulty with this procedure. The questionnaire also asked students for suggestions for improving the tutorial, and many took this opportunity to make some excellent suggestions. Several of these have since been incorporated into the tutorial design, eg. separation of learning to use the program tools from learning the topic, and will be discussed later.

More specifically, students enjoyed the animated sequences, with typical comments that they appreciated the visual representation of the circuit, but had difficulty understanding some of the textual feedback. Typically, they asked for more directional hints, ("Tell me what to do!"). The most consistently-reported difficulty related to students' feeling confident about getting started. This problem was perceived as an early cognitive overload, and dealt with in subsequent modification of the program (see below). Importantly, most students reported that they used the textual feedback in constructing the model, even if most of them still experienced difficulties along the way.

Many reported difficulty in understanding the symbols used in representing components of the nervous system, since this was the first time they had had exposure to these.

Audit trail analysis

Analysis of the electronic audit trails allowed us to collate information from the numbers of groups/pairs of students that received any particular feedback screen more than 3 times. This was used to indicate difficulty in moving past a particular model-building stage. Repeat viewing of the same textual feedback does not necessarily indicate that no new attempt has been made – eg. in some cases positioning an element in any of 3 different sites will give the same feedback response. This was a deliberate choice, helpful for identifying the same error in audit trails eg. placement of component gives same form of error.

Figure 5: Frequency plot of number of student groups returning for repeated (>2) viewings of feedback panels at various phases of model construction. (Total number of student groups = 93; Total number of feedback panels = 88)

Using this audit trail analysis, we were able to identify areas of greatest difficulty, and revisit these.

Evaluation

Interpreting audit trail data

The data generated by audit trail analysis and by scoring of student questionnaires (both cognitive and affective) following the prototype testing was used to redesign some aspects of the software. In particular, as illustrated in Figure 5, it was possible to identify crucial sites of confusion in the model construction process, where repeated viewings of feedback panels significantly above background levels could be detected. The feedback panels for these high frequency viewing stages were edited to remove ambiguities, and in some instances the stages of model construction were simplified. The audit trail data proved invaluable in undertaking this evaluation, and may only be used in this manner if the feedback panels have been formulated in advance to identify and respond to a prioritized hierarchy of student errors. Tracking the characteristics of the feedback panels most frequently displayed in response to student error provides useful data about student understanding. Indiscriminant keystroke logging is unlikely to be helpful in the evaluation process – the volume of data produced is unmanageable and the common patterns of student error cannot be recognized.

In Figure 5, it can be seen that at many stages (47 out of 97), all student groups found that viewing of any particular feedback panel less than 3 times (signified by empty columns) was adequate. The goal of the redesign process subsequent to the prototype testing was to eliminate the spikes apparent in Figure 5 indicating that 10 or more groups of students were revisiting the same feedback panels 3 or more times. With routine ongoing usage of the software, this new practice of frequency analysis will be of use in comparing error patterns generated by student cohorts from different disciplines.

Reducing cognitive loads

In response to student comment following the prototype testing, several major modifications were introduced to reduce the cognitive load experienced by students in the early stages of model building. This load, the amount of initial understanding required to undertake the model building exercise, originated from two sources. Firstly, the assumption that students could most efficiently familiarize themselves with the usage of model building tools as they made their first steps in model construction proved to be invalid. It became apparent that to confidently tackle the logical process of model construction, the students first needed to rehearse the usage of the tools available to them as building blocks. To facilitate this, a ‘playground space’ (Figure 6) was created to encourage practice at using the circuit components before embarking on model building. This device separated the model building learning exercise from familiarization with the tools and symbols used.

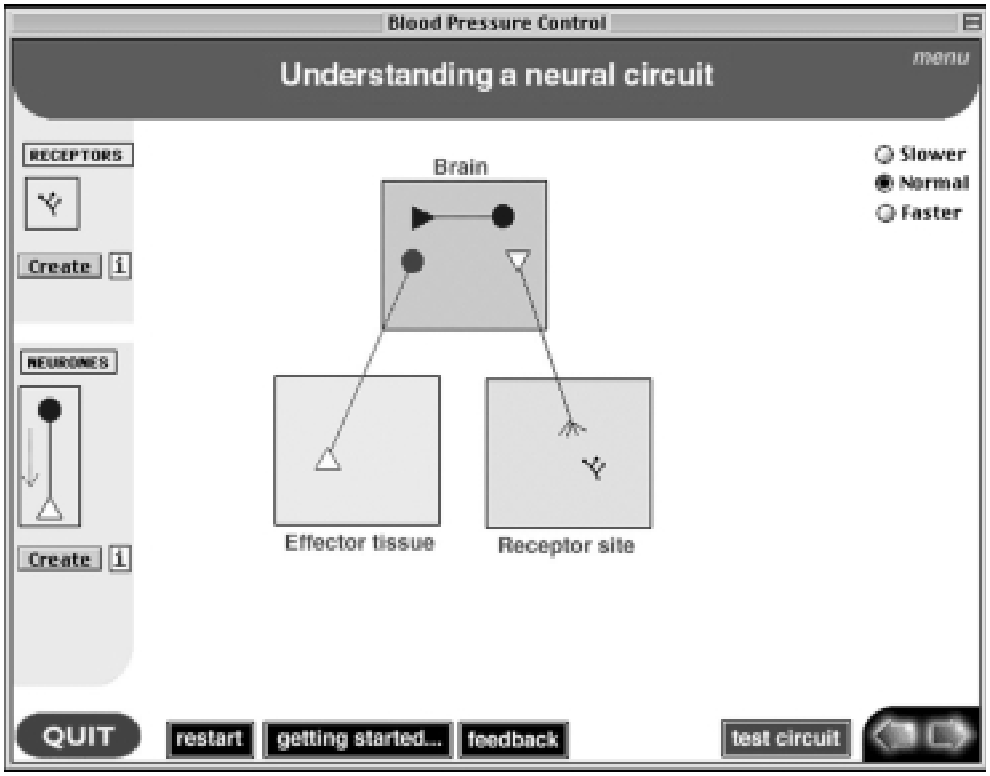

Figure 6: Screen shot of 'playground' area, showing completed circuit

Secondly, it emerged that efforts to ground the model-building in anatomical reality by using specific structural components actually distracted the students from obtaining an overall grasp of the feedback circuit architecture. Thus, the more detailed anatomy of the 'central processors' was made available only to those students who indicated an inquiring interest. Student tolerance for model complexity was gauged by observation and assessment of audit trails and questionnaire responses. It would be expected that different student groups would show different characteristics in this regard. The general practice of progressive unmasking of the complexity of the system on demand, accommodates a broad range of student backgrounds.

Transferability of approach

The approach adopted in helping students to learn about control systems using this software is based on fostering the development of phenomenological understanding. A simulation or mathematically oriented approach is deliberately avoided. The goal is to establish a level of qualitative fundamental understanding which can be overlaid where appropriate with quantitative transfer functions when these are known. Thus the approach is usable in a wide variety of contexts, including those in which mathematical constructs are inaccessible. The emphasis is to encourage student hypothesis formulation and visual testing as the continuity between control system input and output components is represented graphically. The approach lends itself to the description of control systems for which real components can be identified (ie receptors, neurones, blood vessels) rather than systems in which the components are conceptual. The use of task sheets as thought extension exercises provides the opportunity for students to both test and generalize their new-found understanding.

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