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ABSTRACT

This paper reports on a project involving the development and formative evaluation of an interactive World Wide Web-based learning tool. The interactive graphing tool (IGT) permits students to sketch a graph on screen using a mouse and responds to a wide range of common graph types. The IGT facilitates an iterative approach to understanding graphical representations of knowledge by actively involving students in the construction of these representations and multiple modes of feedback. The examples provided in this paper relate to reaction kinetics and chemical equilibrium in undergraduate chemistry. However, the graphing tool is applicable to many other academic disciplines with similar needs to foster the development of student understanding of graphical representation of knowledge. Topics discussed include: the design of the IGT, including the IGT and student learning and the IGT structure; formative evaluation of the IGT, including goals of formative evaluation, methodology, the modules, student formative evaluation results, formative evaluations from academic staff, and problems and solutions; and future directions. Two figures illustrate the default curves for the IGT and the screen capture of the prototype IGT. (Author/DLS)

An Interactive Graphing Tool for Web-based Courses

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Abstract: This paper reports a project involving the development and formative evaluation of an interactive Web-based learning tool. The interactive graphing tool (IGT) permits students to sketch a graph on screen using the mouse and responds to a wide range of common graph types including logarithmic, exponentials, curves, and straight lines. The IGT facilitates an iterative approach to understanding graphical representations of knowledge by actively involving students in the construction of these representations and multiple modes of feedback. The examples provided in this paper relate to reaction kinetics and chemical equilibrium in undergraduate chemistry. However, the graphing tool is applicable to many other academic disciplines with similar needs to foster the development of student understanding of graphical representations of knowledge.

Introduction

Over the past few years two components for delivering courses via the WWW have emerged—the server-side applications (e.g., WebCT®, FirstClass®, TopClass® and Melbourne IT Creator®) and the client-side applications with which the learner interacts. While considerable efforts have been invested in developing course management software which functions from the server-side of course delivery to facilitate the linking of course content, Web pages, logging of student activity and reporting of student interactions only minimal (institutional or commercial) efforts have been made on developing pedagogically sound applications on the client or student-side. There remain two important issues affecting the application of new technologies which are crucial if there are to be any lasting improvements in student learning outcomes and the success of on-line courses. They are the:

- need to embed sound educational pedagogy into on-line courses; and
- facility for the content provider to be provided with sound pedagogical tools which are simple to implement.

This paper addresses the need for course designers (usually a lecturer appointed because of her or his content expertise rather than computer programming ability) to have available educational tools which engage students actively in learning and are simple to deploy. At the Multimedia Education Unit (MEU) in The University of Melbourne work has been focused upon developing generic learning tools which reflect sound educational pedagogies which are easy for non-programmers to use and implement. The interactive graphing tool (IGT) is one element in a suite of educational tools being developed by the MEU as part of the Learning Engines project [Fritze & McTigue 1997]. The remaining sections of the paper discuss the basic functionality of the IGT and the results of formative evaluations with students and academic staff.

The Design of the IGT

The IGT and Student Learning

The interactive graphing tool (IGT) has been designed and used within a framework that links the literature on student learning to that on understanding symbolic representations of scientific phenomena. The IGT is designed to actively engage students in constructing relationships between time-dependent data. For example, the macroscopic properties of matter and the symbolic representations used by chemists to represent those processes. While this paper focuses on the formative evaluation of the IGT, the use of such a learning tool must be seen as being incorporated into a computer-aided learning module which is merely part of a variety of curriculum experiences. In considering the design of any interactive learning tool it is here that the principles underlying constructivism are invaluable. These principles can be summarised as follows [McNaught, 1993]:

- Students have prior well-formed frameworks of ideas about many of the topics they study in science.
- Learners build up personal, internal conceptual maps as a result of interactive processes between each learner and her or his environment.
- Our frameworks embrace our sociocultural environment as well as our physical environment.
- Learning occurs as an active construction of meaning as a result of reflection on experiences.
- 'Reflection' is one of those concepts which deserves to be reflected upon. It does not just mean thinking over an experience, but implies a conscious integration of experience into an existing framework.
- The process of reflection is not purely rational; motivation and interest are essential.

Any computer-based learning tools we build in order to assist student learning must require students to actively interact with new material in ways which require reflection. It is not sufficient for students to understand an argument or explanation in a detached way. They need to make decisions in their work which show clearly what their own knowledge constructions are. This has serious implications for the design of IMM where there has been a heavy reliance on recognition rather than construction in the design of question or problem formats. It is our belief that IMM will only assist student learning when the tasks we design are based on the constructivist principles outlined above. The IGT has the potential to:

- engage the student actively in the construction of knowledge,
- allow for a variety of student inputs,
- provide an iterative approach to learning,
- provide immediate and appropriate feedback, and
- be simple and straightforward for a lecturer/ teacher to embed in computer-based media.

In many text books and IMM packages graphs are used widely to explain relationships between variables. The use of animations of graphs are widely used to explain how relationships vary over time, so that three variables are illustrated. However, students do not build these relationships themselves; they observe the developer's image of them. At best, they may be asked to select between various graphical representations in a multiple choice question.

It has become clear to us that giving students IMM which included a learning tool by which they can build they own images of the relationships between variables and then get feedback from the computer about how useful their images are would be a real advantage in enhancing their learning [Kennedy & McNaught 1997].

IGT Structure

The IGT has been developed in ShockWave® using Macromind Director®. The graphing tool is a ShockWave object which requires a Web browser (Netscape Communicator) with the current Shockwave plug-in installed. In a Web environment it has the potential to provide students with the opportunity to express the relationships between variables in an active learning environment which provides appropriate feedback, and can be linked to multiple representations (e.g., video images of chemical processes or animations) of scientific concepts.

All curves drawn by the IGT including logarithmic and exponential shapes are simulated by the use of Bézier curves [Plant 1996]. The range of current default curve styles are shown in [Fig. 1]. Each curve has a default set of values which include the start and end points, start and end angles, an optional critical point may be defined, and a mid point. A wide range of curve shapes can be generated by changing these parameters. In chemistry the range of curves that can be simulated include those used in reaction kinetics, chemical equilibrium, and pH titrations. The location of the pen tool is shown at the top of the graph and is updated as the student draws the graph. Errors are corrected by using the eraser tool or redrawing the graph.

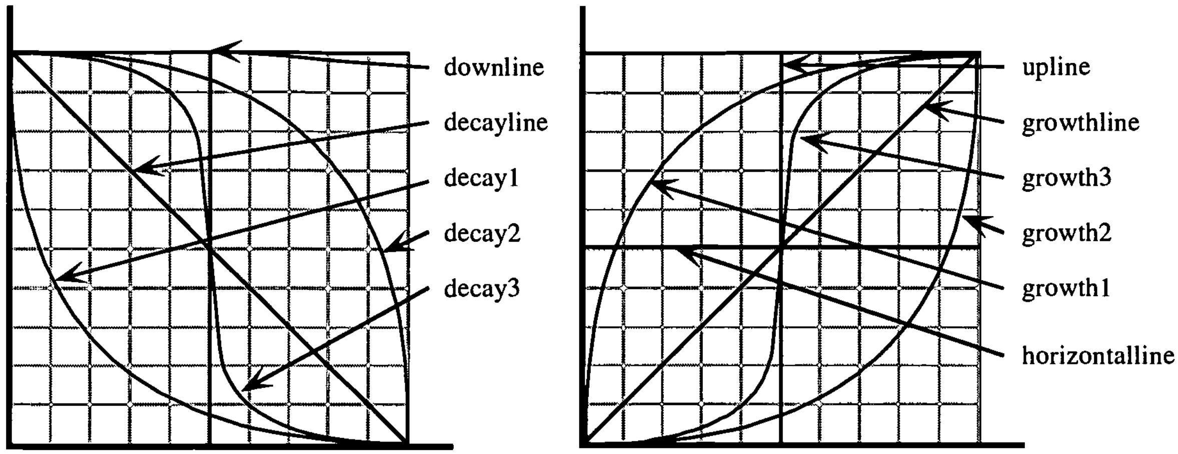

Figure 1: Default curves for the IGT

The axis for each graph can be set along with a suitable scale. The tool is able to pre-draw a wide range of curves also. To address any potential mechanical problems with using the mouse, the sketched graph is immediately redrawn by the IGT object. The process of redrawing student input is smoothed by 'snapping' the graph to the grid at 16 pixel intervals—the student has to be accurate but not precise.

Formative Evaluation of the Interactive Graphing Tool

Goals of Formative Evaluation

This study focused on two groups—students and academics. The specific goals of the formative evaluation with students focused on:

- their responses to the general on-screen layout, navigation and behaviour of the IGT (in particular the mechanics of using the mouse to draw the curves);
- comments on the nature and function of the feedback provided;
- the difference between the IGT and other forms of CFL representations of graphical information including static graphs or animations of graphical information;
- perceptions of the IGT as a tool to influence their learning outcomes;
- the difficulties encountered in using the IGT; and
- how the IGT might be improved.

The focus for academic staff was on all of the above plus the ways in which the IGT might be used in particular academic disciplines:

The Studies

The students who took part in the formative evaluation were self selected from first and second year undergraduate science (all names are fictitious). All were experienced users of the first year ChemCAL computer-aided learning package [McTigue et al. 1995] developed at The University of Melbourne. Students were paired and asked to complete four small modules—a tutorial module to gain experience in using the software, followed by three modules which investigated kinetics and chemical equilibrium. Students were asked to comment on each of the broad areas listed above as they worked through the modules. The first author was present at each session (to observe, ask questions and assist if the software crashed—it didn't) and all student responses were recorded using audio tape. Written notes were taken during and after each session—which required approximately 35 to 45 minutes per pair.

The academics who took part were either involved in courseware development at the university or known to the first author. The evaluation data was generated by the use of a questionairre. This was the less successful of the two evaluation processes—the major problems being time constraints on the academics and significant cross-platform and software issues (discussed later).

The Modules

All of the objects which are part of the Learning Engines project are designed to communicate (e.g., text input or user interactions) with each other. In [Fig. 2] there are two objects on screen. The top one which is shown in [Fig. 2] as a straight line graph is the IGT. The lower one is the Tutorial Item Set (TIS) object. This contains the text of the question (left box in [Fig. 2]) and generates the comments box (right box in [Fig. 2]). The IGT facilitates sketching graphs on screen using the mouse and the TIS object contains the question scripts and the functionality to respond to input from both students and the academic. The two learning tools facilitate an iterative approach to developing student knowledge constructions between non-graphical and graphical representations of knowledge.

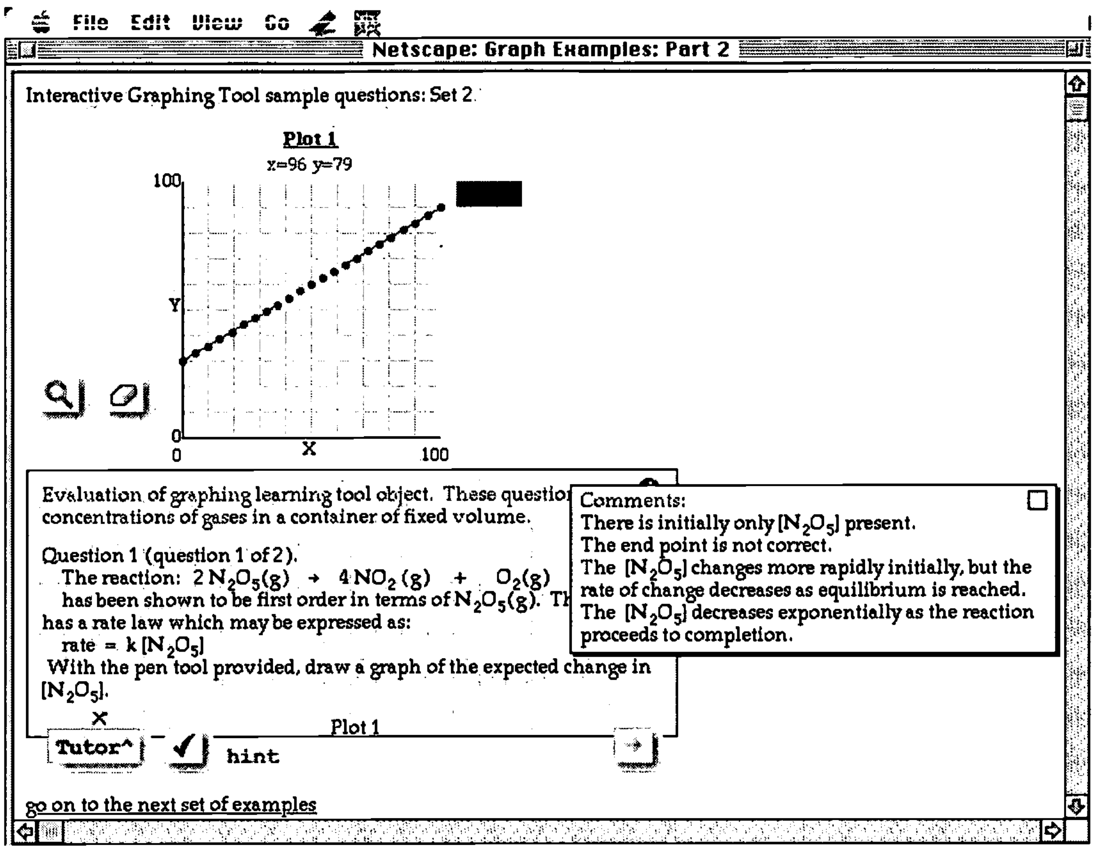

Figure 2: Screen capture of the prototype Interactive Graphing Tool

Figure 2 [Fig. 2] is a screen capture image of one screen. The straight line is illustrative of a response by a student. The question being asked of students is:

Question 1 (question 1 of 2).
The reaction:. $2 N_2O_5(g) \longrightarrow 4 NO_2(g) + O_2(g)$ has been shown to be first order in terms of the $N_2O_5(g)$.
The reaction has a rate law which may be expressed as:
rate = k $[N_2O_5]$
With the pen tool provided, draw a graph of the expected change in $[N_2O_5]$.

Factors such as; Where does the graph start?, Where does it finish?, What is the shape of the curve?, became immediate problems for students to solve. This is quite unlike selecting from a series of possible answers as in a multiple choice question. The feedback to the student depends upon input (what the student sketches) and comments defined by the content expert. The tutorial item in this example has been scripted to respond to the following components of any curve drawn by a student including the:

- start point (0,0) and end point (100,100) of the curve;
- start angle (>70°) and end angle (defined by the general form, decay1) of the curve;
- general form (decay1) of the curve (see [Fig. 1] for the generic shape of a decay1 curve).

Feedback can be as complete or as minimal as desired by the content expert. In the current version multiple levels of feedback may be specified in the TIS object. The TIS object analyses key parameters of the student input provided by the graph object and provides the appropriate response in the *Comments* box in [Fig. 2].

Student Formative Evaluation Results

The formative evaluation carried out with students in this instance has indicated that students find this type of task more challenging than conventional multiple choice selection problems. Construction is much harder than recognition. Quotes from student interviews support this statement.

DK *How is this different from other experiences of CAL materials of dealing with graphs—materials you have already used?*

Anne *You have to actively participate. A lot of time with other CAL materials (either static displays of graphs or animations), you watch it, you take maybe 5% of it in. With this you actually have to sit there and work it out... This is much more active.*

Mike *With the little movies they have in the current CAL labs there's no real insurance that you comprehend what you are seeing.*

The navigational issues and general layout of the two learning objects did not result in any problems. After minimal practice, all students were able to sketch a desired curve shape using the mouse. The feedback and the visual representations of the IGT were seen to be a very positive aspects of the software. For example.

DK *How is this (the IGT) different? This is the kind of question you would find in a book.*

Anne *You are visualising it instead of just seeing a bunch of numbers in front of you.*

Mike *Being able to see it (the graph you draw) helps out, rather than just the equation.*

At the conclusion of the modules students were asked to their impressions of the IGT as a learning tool. In particular "How is this approach different to that you have seen in multiple choice questions, static displays, or animations of graphical representations of graphical information?". Some of the responses were:

Nick *I think it's good for students. I'm surprised to say that because it actually makes it harder for them in that they really have to learn (think) about what they know.*

Mike *This (the approach to graphing using the IGT) makes it into something that is a serious learning tool.*

Anne *...if you do have a problem with it (the graph you are trying to sketch) you can't readily go and ask for feedback (with a book or static display).*

Formative evaluations from academics

The comments from the limited number of responses from academics tended to focus on issues of implementation within a specific academic discipline (e.g., physics staff require sinusoidal curves which are not currently supported), the need for specialised symbols in the text, and the issues of software compatiblity. The latter is a non-trivial problem for those involved in developing Web-based pedagogical learning tools. The internet is not a mature technology. Standards for hypertext markup language (html), computer operating systems, and even internet browsers are problematic. For example, the two major internet browsers have implemented the current version (4.0) of html differently. However, In response to the question "How is this approach different to other forms of representing graphical information, static displays or animations", an illustrative response is:

Rose *The primary difference must be that students can trial their own answers and get feedback on same.*

Problems And Solutions

A number of perceived deficiencies in the current iteration of the software were articulated by the students and academics. These problems included the lack of information on the axes and suitable scales, the initial graph drawn disappears once a new graph is started, and the graph disappears if the screen display is altered (e.g., scrolled in a manner to hide the graph object).

The authors were well aware of the first problem however it was not possible at the time to have this implemented. It will be part of the next iteration of the IGT. The second issue will be implemented in the near future. It is envisaged that once a student response has been checked and found to be not correct, that response will fade to 50%, then 25%, of the original while the student has a second or third attempt respectively. The third issue has been addressed by Macromedia. The latest Shockwave plugin preserves information on the screen. A cross platform font has been developed which facilitates the use of the IGT on a Macintosh or a PC using Netscape Communicator®.

Future Directions

The current work of the project is focused on the development of the authoring interface for lecturers and implementing the changes recommended by students and academics. Improvements currently being implemented include the ability to customise the types of curves recognised for different disciplines and pop-up menus to select the graph set appropriate to the particular content discipline.

The expectation is that the number of graph types recognised by the software will be increased as will be the degree of customisation of the graph types recognised by the software. There is no intention to have the IGT display or respond to sinusoidal curves or curves which are drawn right to left.

While the examples provided in this paper relate to reaction kinetics and chemical equilibrium in undergraduate chemistry, it must be stressed that the interactive graphing tool is applicable to many other academic disciplines with similar needs to foster the development of student understanding of graphical representations of knowledge. It is anticipated that the graphing tool will be used the future in other contexts—in subjects that also have a need to link the macroscopic behaviour of objects or materials with graphical representations of knowledge Discussions have been held with lecturers from pharmacology and physics and the requirements of these subjects have been addressed in the current iteration of the IGT. The comments from students in this study were very positive however, studies are currently ongoing to ascertain any changes to student learning.

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