ASTutE: COMPUTER-AIDED TEACHING OF MATERIALS BALANCING

David W. Edwards, Fiona M. Lamb, Vian S. Ahmed, Steve J. Rothberg
Loughborough University • Loughborough, LE11 3TU, United Kingdom

The ASTutE (Automated Student Tutorial Environment) project[1,2] has created a computer-based tutorial resource that has been successfully used to teach material balancing. This ASTutE software works alongside tutors to help meet the challenge of teaching students with increasingly diverse backgrounds while student-to-staff ratios continue to rise at the same time. The project is managed and staffed by the faculty of the Engineering Teaching & Learning Support Centre[3] at Loughborough University,[4] which is one of the leading institutes in the United Kingdom that encourages implementation of new technologies in teaching. ASTutE is being developed in conjunction with the engineering and science faculties at Loughborough University, with initial trials in the chemical engineering, mathematical sciences, and mechanical engineering departments.

Students use ASTutE interactively to check their answers to problems or as a detailed help system, but access only as much help as they require. Chemical engineering problems are often complex and best solved by following a prescribed method; ASTutE uses a variety of interactive information displays and question types to break such problems down into stages, guiding students to the solution. This approach encourages students to develop a methodological approach to problem solving. There are usually many ways to solve chemical engineering problems, and ASTutE provides feedback tailored to the responses of an individual student following one of many possible routes through a tutorial problem, consistent with their understanding of the topic. ASTutE solves simple, recurring student misunderstandings and difficulties, freeing academic tutors to deal with the more complex issues arising from the problems. A key feature of ASTutE is the ease with which tutors can quickly write new, or modify existing, problems by editing a simple template.

This paper describes the use of ASTutE at Loughborough to teach first-year chemical engineering students material balancing. This computer-aided learning (CAL) approach proved highly satisfactory for both staff and students and has a great potential for enhancing student learning.

MOTIVATION AND AIMS FOR A TUTORIAL RESOURCE

Chemical engineering, unlike many subjects in United Kingdom (UK) universities, has not been subject to an increase in student numbers. There has been an increase in the administrative load, however, and there is intense pressure for the professors to pursue and publish research. These two factors have reduced the available time for teaching, and coupled with increasingly diverse student backgrounds has left those professors who use traditional teaching methods struggling to cope. In order to maintain quality, which is now subject to rigorous external assessment, professors have needed to develop new teaching strategies.

Tutorials have been particularly affected by these pressures—most UK chemical engineering departments can no

David W. Edwards *is a Senior Lecturer in the Department of Chemical Engineering at Loughborough University. He teaches material and energy balances, process economics, design, and optimization. His research interests are in feasibility assessment, safety and loss prevention, and focus on inherent safety, envionmental protection, and cost estimation.*

Fiona M. Lamb *is Centre Manager of the Faculty of Engineering Teaching and Learning Support Centre at Loughborough University. The Centre supports staff wishing to integrate innovative learning technologies into the curriculum.*

Vian S. Ahmed *has a BEng in Civil Engineering from the University of Hertfordshire and a MSc in Construction from Loughborough University. She is currently preparing her doctoral thesis on "Adopting Strategic Approaches for the Development, Implementation, and Evaluation of Computer-Aided Learning Tools in Construction."*

Steve J. Rothberg *is a Senior Lecturer in the Department of Mechanical Engineering at Loughborough University, teaching and researching in the areas of engineering mechanics, noise, and vibration. His active interest in CAL has included supervision of the ASTutE project and a key role in the creation of Loughborough's Engineering Teaching and Learning Support Centre.*

© Copyright ChE Division of ASEE 2000

longer offer small-group tutorials. Yet tutorial work has always been an essential component in the consolidation of students' understanding of lecture material, particularly in subjects that are new to them. Traditionally, sheets of problems were handed out and then small groups of students discussed and solved any difficulties with the problems, guided by an academic tutor. The material balances module, described in this paper, was once taught entirely by solving tutorial problems. But because of the increase in group sizes, "discussing and solving difficulties" on an individual basis has become more and more difficult; students are less motivated to attempt problems, and tutorials degenerate into problems classes where the tutor solves the problems with little student interaction. This is unsatisfactory for those students of lower ability and those with nontraditional backgrounds—those who might hold vocational qualifications, or have graduated from a conversion course from arts to engineering, or have returned to academe after a long period outside of full-time education. These students require even more individual help than was available in the past, at least in the critical early stages of chemical engineering education.

The first author thought that CAL might offer a way of enhancing his teaching and overcoming these difficulties. He collaborated with the ASTutE developers to produce the material balances tutorial resource, with the aim of making these tutorials more effective for all involved.

To achieve this aim, several criteria for the tutorial resource were identified:

- *It must be integrated into the curriculum.*
- *It should be incorporated into existing courses without major modification, retaining the use of existing problem sheets.*
- *Tutors should be able to quickly and easily write or modify problems without recourse to special software and with a minimal "learning curve."*
- *It should be available at all times for use both in and outside of time-tabled sessions.*
- *The student interface must mirror the pencil-and-paper approach as much as possible.*
- *Students must find it easy to use and be able to work at their own pace, taking the learning route they are best suited to.*
- *It should solve the majority of difficulties for the majority of students, freeing tutors to deal with more complex issues.*

It was found that these criteria could be best met by programming a bespoke system in the multimedia authoring language, Authorware.[5]

THE ASTutE TUTORIAL ASSISTANT

ASTutE encourages students to systematically tackle a problem in much the same way as they would on paper. This generally consists of reading the text and then working through the following steps: 1) create a diagram, 2) discover the problem data and add it to the diagram, 3) set a basis for calculations, 4) formulate equations to use, and 5) solve the equations. ASTutE replicates this method by displaying the problem text and then offering help, which is provided in five key stages corresponding to the steps above.

ASTutE was designed to be used in different ways according to student needs and abilities. Three scenarios are described below to show this flexibility.

Scenario 1 • The initial screen of an ASTutE problem, shown in Figure 1, presents students with an answer box in which to enter their answers. In this simplest scenario, ASTutE is used as an answer-checking system. Strong students who have already successfully completed a problem may log on simply to check their answer or perhaps to look through the model solution before moving on to the next problem. This is the quickest route through the problems written in ASTutE.

Scenario 2 • When students experience difficulty at a certain point in a problem or are uncertain about their chosen method, pressing the "I'm stuck" button on the initial screen brings up a help menu of key stages, shown in Figure 2. Students choose any key stage(s) of help they require—for example, choosing a basis. ASTutE provides specific help,

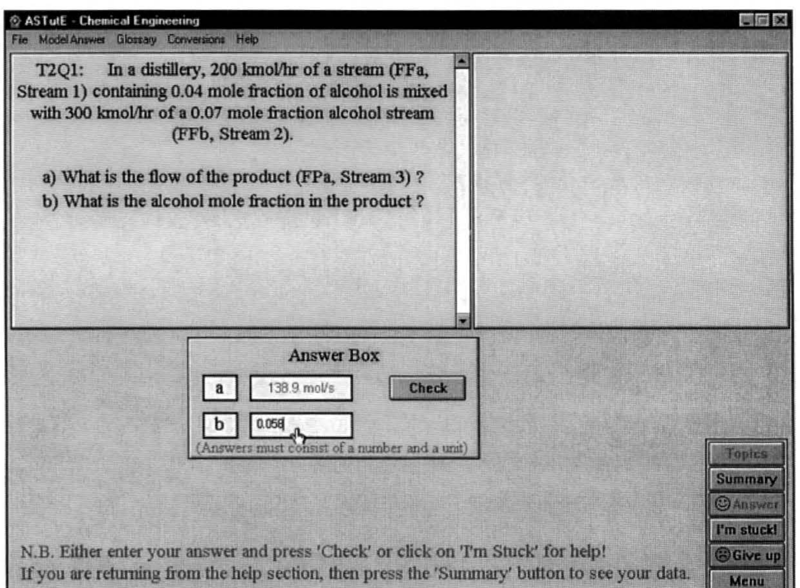

Figure 1. *Initial ASTutE screen displaying the answer box. The student can either input answers directly or click on "I'm stuck!" to access the detailed help system.*

Students use ASTutE interactively to check their answers to problems or as a detailed help system, but access only as much help as they require. Chemical engineering problems are often complex and best solved by following a prescribed method; ASTutE uses a variety of interactive information displays and question types to break such problems down into stages, guiding students to the solution.

solving the student's particular difficulty without solving the whole problem.

Scenario 3 • Weak students are led interactively, step by step, through a problem by accessing the help system from start to finish. They learn how to tackle a problem with logical methods, which will help them solve future problems.

ASTutE is a tutorial system and not an assessment system, and is therefore designed to be as flexible as possible. For example, the student is not required to create the diagram in order to be able to gain help on setting a basis for calculations, because these stages are independent. But the student will need to set the basis for calculations before solving the equations. Also, students are always able to input the final answer and can exit the help system at any point. This encourages the students to work on paper and try to solve the problems themselves, referring to ASTutE only as needed.

The feedback given to a student at any point is tailored to his or her individual responses. Students typically make one of a limited number of possible mistakes at any stage in a problem, and so the necessary feedback options can be identified relatively easily by a tutor. If an unpredicted but common difficulty emerges, the tutor modifies the existing problem template to incorporate it.

By catering to different student needs, strong students are not held back and the weaker ones are not too embarrassed to obtain the intensive help they need. It would be too ambitious and inefficient, however, to attempt to solve every conceivable difficulty for every student, so the tutor is always available to address the more complex or unusual misunderstandings.

QUESTION TYPES AND DIAGNOSIS

ASTutE supports an extensive range of basic question types, including multiple choice/response, text/number entry, hot spot, and drag-and-drop. Some of the complex questions types that have been created from these basic questions types are

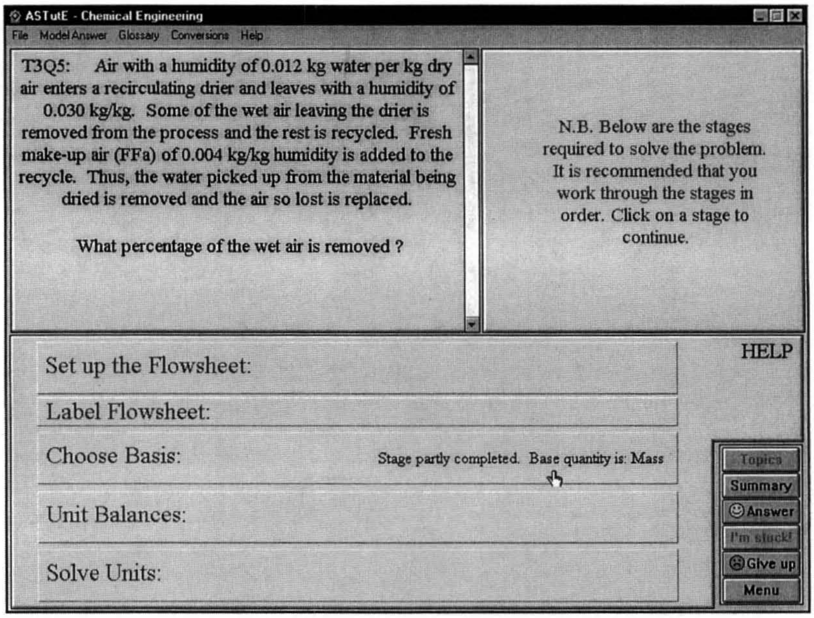

__Figure 2.__ The five key stages of a materials balance problem. A student has partially completed the "Choose Basis" stage, which then displays some summary information.

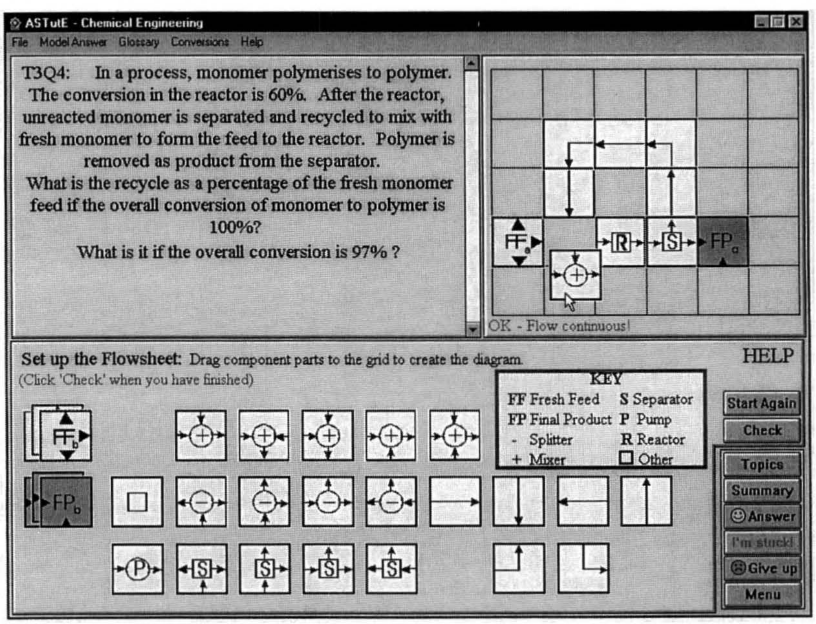

__Figure 3.__ The "Set up the Flowsheet" stage of a materials balance problem. A student is just about to complete one of the many possible correct flowsheet configurations.

Number-Unit Entry • Students must provide suitable units with a numeric answer. The Dynamic Teaching Solutions project[6,7] developed the implementation. An example is shown in Figure 1.

Diagram Creation • Drag-and-drop allows flow sheets to be built up and labeled. This question type is illustrated in Figure 3.

Math Entry • Complex mathematical expressions can be entered in an easy and familiar way, as developed by Beilby.[8]

Multiple Response • Although this is a very straightforward question type, the diagnosis is complex. ASTutE allows the tutor to give specific feedback to any multiple response combination offered by the student.

WRITING PROBLEMS

ASTutE runs as an executable file, reading in problem data from text files. Tutors do not need to learn to use any special software. The text files are created or modified using any spreadsheet package. The tutor opens a problem template and follows the instructions in this file to write a problem.

ASTutE MATERIAL BALANCES TRIAL

We have used ASTutE in the Department of Chemical Engineering to provide additional tutorial assistance for material-balances teaching. Problem sheets were handed out in the normal way to a first-year class of 55 students who attended weekly 1.5-hour tutorials in a computer lab with 40 networked PCs running ASTutE and other CAL software. The first set of simple problems were presented in the first two weeks, using proprietary CAL software called Question Mark Designer.[9] Then, for the rest of the semester of 11 weeks, ASTutE was used. During the sessions, tutors circulated around the room and were available to help with the more intractable and/or uncommon problems that ASTutE could not solve. The tutors would also bring interesting issues that arose to the attention of the whole class.

Although we recommend *Elementary Principles of Chemical Processes*[10] as a text that students might like to consult as part of their learning process, ASTutE is self-contained and not tied to any particular book.

We believe that drawing and labeling diagrams is the key to understanding and then solving material balance problems, so these are the first two of the five help key stages shown in Figure 2 —"Set up the Flowsheet" and "Label Flowsheet."

***Set up the Flowsheet* (Figure 3)** • Students create flowsheets by selecting individual elements from a library in the bottom half of the screen and placing them anywhere on the grid in the top right-hand corner. They receive instant feedback as components are placed—for example, if flow is discontinuous. Elements can be repositioned or removed at any stage. When students are satisfied with their flowsheet, they click the "Check" button and more feedback is given for flowsheets that have the wrong process units or are topologically incorrect. The tutor can provide specific feedback for specific errors.

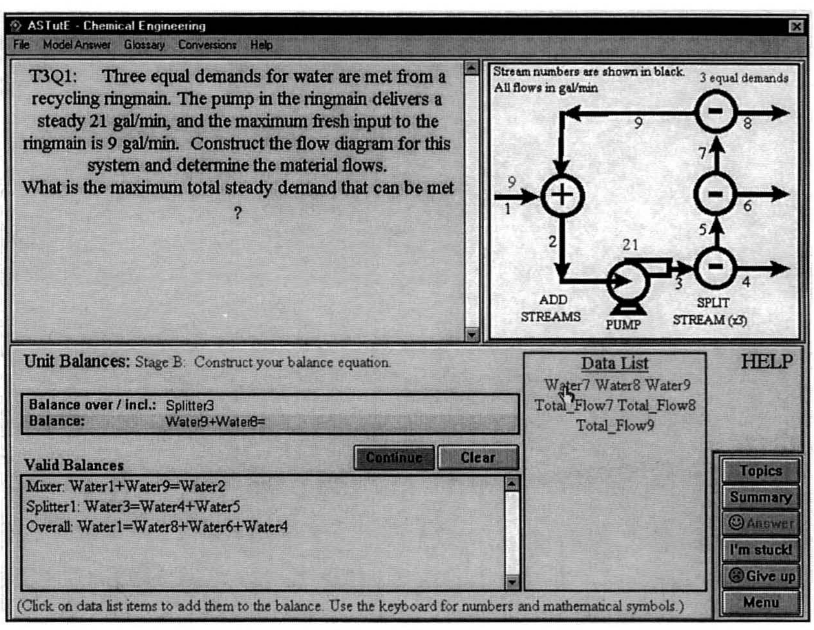

Figure 4. *The "Unit Balances" stage of a materials balance problem. Students can write as many equations as they feel necessary using the stream numbering system displayed on the annotated diagram. Each equation is checked for validity against the chosen basis.*

When a student has constructed one of the (usually many) topologically equivalent correct flowsheets, ASTutE presents its standard version, which will be used from this point on. An example of a standard version is shown in Figure 4. Students must satisfy themselves that the standard diagram is equivalent to theirs. This encourages understanding of flowsheets and good drafting practice.

Label Flowsheet • Students first identify the chemical components in each stream of the standard flowsheet. Then they indicate where data specified in the problem text (which might refer to a stream, a unit, or the whole process) should be labeled on this flowsheet. On successful completion, a new annotated standard diagram is provided. In the example shown in Figure 4, the three pieces of data are: the input flow of "9" (gal/min), labeled above stream 1; the "21" (gal/min) flow through the pump; and the "3 equal demands" legend above the three splitters.

Choose Basis • First, students decide whether they will solve the problem using mass, moles, or volume flows. ASTutE gives appropriate feedback for each choice. Then students must select a stream, a component(s), and a flow value to use as the basis for their calculations. ASTutE comments on the desirability of their specified basis. All feedback has been written by the tutor in the problem text file.

Unit Balances • Students formulate balance equations, over flowsheet units or any part of the flowsheet, in terms of component or total flows. First, the site of the balance is specified—for example, over the entire flowsheet ("overall") or a unit ("mixer," "splitter," etc.). Then, as shown in Figure 4, the balance is constructed from the relevant in-flows and out-flows. In the equations, Water3, for example, represents the flow of water in stream 3. Each equation is checked for validity and against the chosen basis by ASTutE. Students may enter an unlimited number of valid equations and they are all added to the "Valid Balances" list.

Solve Units • Students see a grid with rows for streams and columns corresponding to components and with their selected basis value in the appropriate cell. They must fill in the component flows in each stream in order to complete the material balance. ASTutE checks that all flows entered in the grid correspond to the chosen basis. At any point, students may answer the problem or display a summary of help stages completed so far. When the student either solves the problem or "Gives up," a model answer consisting of text and diagrams written by the tutor is displayed.

TABLE 1
Student Performance on Materials Balancing Coursework

Statistic	*Year 1997-98*	*Year 1998-99*
Number of students	57	53
Number that Achieved Full Marks	13	12
Number that Achieved Greater than 70%	48	47
Average Mark, %	87	84
Minimum Mark, %	32	56

TABLE 2
Student Scoring of ASTutE's Usability (Scale of 1 to 5)

Interaction with courseware (difficult to easy)	4
Navigating through ASTutE (difficult to easy)	3
Manipulating the interface (difficult to easy)	4
Presentation of diagrams and pictures (poor to good)	4
Presentation colors (uncomfortable to comfortable)	4
Clarity of information presented (vague to clear)	4

TABLE 3
Student Scores for Interest and Confidence in Subject Matter

Score	*1*	*2*	*3*	*4*	*5*
Interest	0%	0%	70%	25%	5%
Confidence	2%	5%	49%	42%	2%

EVALUATING ASTutE

Informal Observations

Student attendance at the CAL sessions was better than that at the conventional tutorials held in previous years, and attendance did not deteriorate through the semester. Most students said that they liked the sessions. A conventional tutorial that was offered each week as an alternative to the CAL sessions was usually attended by only a few, if any, students. The students were much keener to attempt the problems rather than waiting, as they had done previously, for the tutor to present solutions. We feel that this is the most important benefit of using CAL—the students attempt the problems. It is unclear if this is because they like using computers, or because CAL presentation is more interesting than problem sheets, or they dislike writing attempts at solutions that might be seen to be incorrect in class, or the help system is immediately accessible, or computer interaction is less threatening, or for some other reason.

An unexpected benefit of the CAL approach was that many of the students naturally formed into working groups. They helped each other learn, using the computer as a shared resource/tool.

The software met all the development criteria—in particular, the most important factor of handling frequent or simple questions and thus freeing tutors to give individual help and to answer difficult and peculiar questions. The attitude of the staff was therefore extremely positive.

We were surprised that the CAL software was rarely used outside of the timetabled sessions. This may be because the students have a lot to do already and have no time for extra work, or that access to computers was difficult, or that they obtained the full benefit in the timetabled sessions.

A common student complaint, expressed many times over the years of teaching material balancing, is "I cannot start difficult problems." Students still had this complaint. ASTutE development will further address this issue by helping students deconstruct the problem text, discover its meaning, and translate it into a diagram.

Assessment Feedback

We switched from conventional problem classes to problems presented in CAL sessions in one semester. We took the view that freshman students would not know there was an alternative approach, so a clean break with tradition would be possible. In order to check our impression that the students were learning as well as they had in previous years, we gave them a conventional paper-based test after four weeks of CAL-based material balancing teaching. The test consisted of two difficult questions to be completed in a short time. Most students complained that they were not given enough time, but most of them got good marks, and some turned in excellent papers.

The students attempted and handed in written coursework in the eighth week. This was an old exam question that had been personalized for each student by changing the data in the question. Table 1 summarizes the results for the trial year (98/99) and compares them to those from the previous year when CAL was not used. Both the proportion of the class achieving full marks and the proportion achieving first-class performance were almost identical for the two years. The average mark was down slightly in 98/99, but the lowest mark was significantly up, whereas there were four students in 97/98 who scored less than the lowest 98/99 mark. This indicates that the CAL approach particularly helped weaker students. We were most encouraged by these results.

Student Session Questionnaire

A class of 43 students was surveyed by questionnaire during and after using ASTutE. The survey data showed that most of the students were confident in using computers, and 80% of the students had used CAL courseware before; ASTutE was the first CAL experience for the rest of the sample.

The students gave scores (lowest, 1, to highest, 5) to different usability aspects of ASTutE. Table 2 presents the distribution of the scores; all aspects of its utility were at least in the satisfactory range.

Students scored ASTutE's effect on developing their interest and confidence in the subject matter. Table 3 shows that ASTutE increased interest and confidence in the subject for 30% and 44% of the students, respectively, while 7% of the them found it reduced their confidence in the subject—these were students who had very little or no confidence in using the computer.

The students' opinion about how ASTutE would be most useful was as

a) Revision material for self-access in your own time and space (36%)

b) Additional tutorial resource, used with the tutor present (27%)

c) A lab session when you are first introduced to the subject (19%)

The percentages for multiple selection were: (b)(c), 8%; (a)(c), 6%; (a)(b), 2%; (a)(b)(c), 2%.

CONCLUSIONS

Both informal observation and questionnaire data indicate that the first group of students exposed to ASTutE were happy to use it as a tool in learning material balances. It was interesting to use and thus encouraged active engagement and a deeper approach to learning.

Staff found the CAL sessions more satisfying than the previous conventional problem classes because they did not have to "replay" their solutions to an unresponsive audience a number of times and could focus on the more interesting and demanding questions posed by the students. While setting up the CAL materials is extremely time-consuming, it only needs to be done once and requires minimal ongoing maintenance work. It is not yet possible to judge if this effort is cost-effective because at this stage it was not practical to split the time spent on software development from that on problem entry. Although CAL increases choice and diversity in the method of learning, it decreases flexibility in content. The possible questions will always be constrained by the capabilities of the software, whereas the combination of the English language, numbers, and freehand sketches are practically unconstrained for setting questions and describing solutions.

Although we have only limited data so far, the learning outcomes as measured by formal coursework, tests, and examinations, all indicate that the students learned at least as much using CAL as they did when taught by conventional methods. The CAL approach seems to be particularly helpful for weaker students.

Overall, ASTutE has proved to be a useful tool for teaching material balances—one that we will continue to use and enhance. Most importantly, the students attempted the problems presented in ASTutE, and when all is said and done, engineering is a subject best learned by doing.

ASTutE is still under development, but it could in principle be made available to other institutions. ASTutE runs under Windows 95/98 or NT. Implementation of the software in these environments should be simple. Extra tutor effort would be in proportion to the number and complexity of new problems. More information can be obtained by contacting the author at <D.W.Edwards@lboro.ac.uk>.

REFERENCES

1. Austin, F., and S. Rothberg, "The ASTutE Tutorial Assistant: Efficient, Accessible, and Interactive," *Global J. Eng. Ed.,* **2**(3), 271 (1998)
2. Austin, Fiona, and S.J. Rothberg, "ASTutE: Automated Student Tutorial Environment," *CIT Eng.,* **12**, Winter (1997/98) 6 (1997)
3. http://www.lboro.ac.uk/faculty/eng/engtlsc/main/index.html
4. http://www.lboro.ac.uk/
5. http://www.macromedia.com/
6. Stone, B.J., and N. Scott, Innovation in Teaching Engineering Dynamics: UWA-CPCS, http://www.mech.uwa.edu.au/Dynamics/Promotion.html
7. Dynamic Teaching Solutions Home Page: http://www.mech.uwa.edu.au/Dynamics/default.html
8. Beilby, M., "Making a Feature of Assessment," *Maths&Stats,* **2**(5), 6 (1994)
9. Question Mark: http://www.qmark.com/
10. Felder, R.M., and R.W. Rousseau, *Elementary Principles of Chemical Processes,* 3rd ed., John Wiley & Sons (2000) ❒