A Computer-Aided Instruction Module on Polymers†

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Received July 28, 1992

Polymers is a subject studied as an elective unit by senior high school students in Israel who major in chemistry. Motivated by lack of adequate means to model dynamic processes and 3D structure of polymers, the hazard and cost of experiments with polymers, and the need for different complexity levels, we have developed a computer-aided instruction (CAI) module on polymers. The module consists of three topics: organic chemistry, polymerization, and structure and characteristics. Three "information organizers", concept map, database, and index, enable easy navigation and access to information. Each topic ends with a set of problems, for which immediate responses are provided. The use of graphics and animation enables a vivid display of molecular structure and polymerization processes. The module has been assessed by teachers using two tools, a questionnaire and the Card Traversal Graph, and was found to respond to needs that originally motivated us to develop the software.

1. INTRODUCTION: COMPUTER TECHNOLOGY FOR TEACHING CHEMISTRY

Computers provide adequate solutions to several problems involved in teaching chemistry in general and the polymer subject in particular. Some of them are listed below.

Experiments Hazard and Cost. Carrying out laboratory experiments using polymer syntheses is problematic since most of the reactants are toxic or carcinogenic when not handled properly. Teachers, therefore, refrain from demonstrating this type of reaction in classrooms. As suggested by Lunetta and Hofstein,[1] computer simulation is especially appropriate when experiments are difficult, time-consuming, or dangerous to perform. Smith and Jones[2] indicate that the potential hazard of exposure to chemicals and the difficulty of doing experiments at an acceptable cost in the allowed time inhibits the exposure of chemistry as a modern, dynamic field in which the students would want to make a career.

Lack of Textbook Capability of Displaying Dynamic Processes. Textbooks create images of chemistry by using words, tables, graphs, and still photos, but they are missing the dynamic element which is so important in understanding chemical processes and concepts. Animation and video are exactly the domains in which state-of-the-art microcomputers are most capable of performing.

Need for Viewing a Large Knowledge Body at Different Complexity Levels. The growing body of information and knowledge has underscored the need for handling it at gradually increasing levels of detail and complexity. Hodson[3] has used chemical databases as a tool through which students are encouraged to explore their own ideas, manipulate information, and test their hypotheses.

Exercise and Feedback. Breneman and Parker[4] use the computer as a tool for exercises in general chemistry that enable students to gain a feel for concepts at a level not previously possible. Dori, Dori, and Yochim[5] have embedded challenges within their ICAI human physiology modules that are aimed at assessing the student's level of comprehension. Facing several of the problems listed above while teaching the subject of polymers for twelfth grade students in Israel, we have taken advantage of the benefits that computer-aided instruction can potentially provide. A CAI module on polymers and various aspects of its development are the topic of this paper.

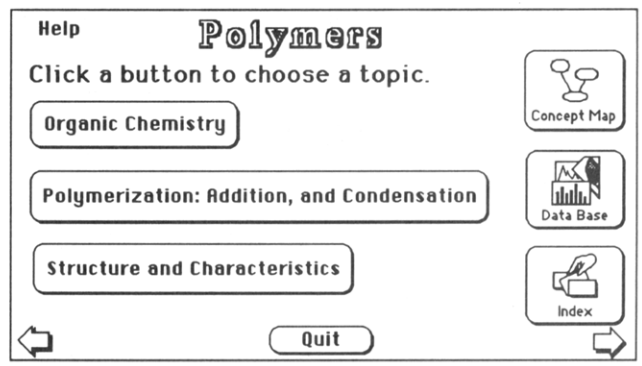

Figure 1. Polymer module main menu.

2. TEACHING POLYMER CHEMISTRY

Realizing the effect of molecular size is the key to understanding the behavior and physical properties of polymer large molecules and their usefulness. Nevertheless, the principles of polymer chemistry and physics are often taught in lecture format. Several alternative teaching methods have been proposed. Rodriguez et al.[6] used bead models to illustrate qualitative differences in molecular weight and between polymers and copolymers and experiments with a dialysis "bag" with a semipermeable membrane to show the difference in permeability between small and large molecules. Chapman and Fleming[7] have conducted a computer-assisted introductory course to polymer chemistry. It consists of interactive computer lessons and computer tests. They concluded that there is a demand for in-depth polymer chemistry courses from which users can choose specific areas to study and that supplemental materials such as text and study guide are important to provide enough additional information.

In Israel, chemistry is studied from tenth grade to twelfth grade, in either a 3- or a 5-h a week course (in classes which major in chemistry). Students who choose the enhanced (5-h a week) course, are supposed to take three elective units from

† This research was supported by the Center for Absorption in Science, Ministry of Immigrant Absorption, State of Israel, and by the Fund for Promotion of Research at the Technion.

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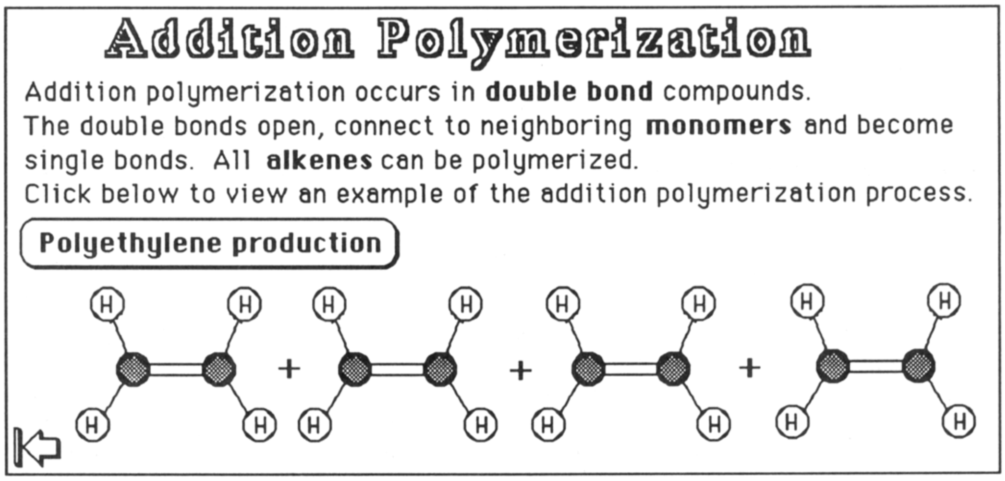

Figure 2. Addition polymerization: animation of polyethylene production, phase 1.

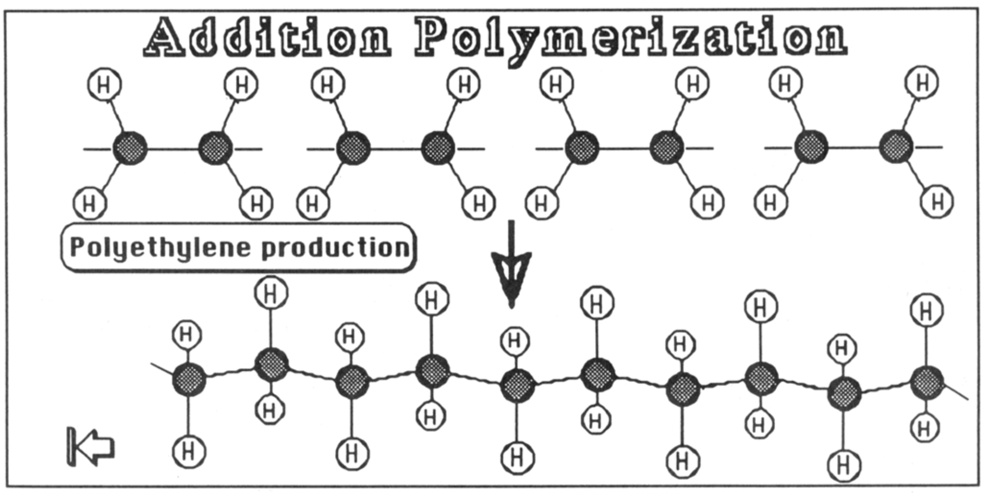

Figure 3. Addition polymerization: animation of polyethylene production, phases 2 and 3.

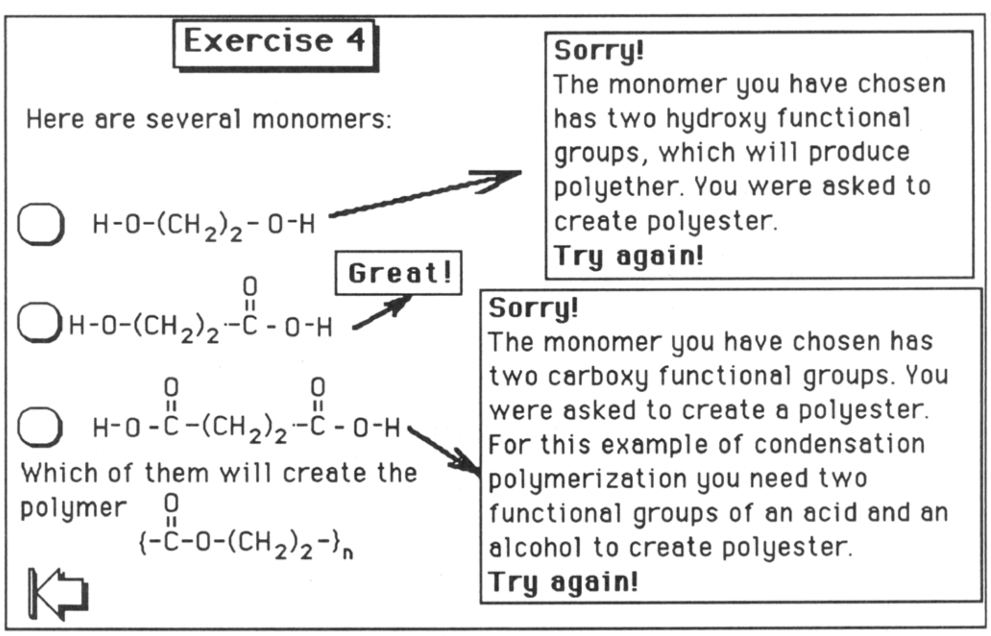

Figure 4. Example of a problem card at the end of a topic. The text boxes appear in response to clicking the appropriate buttons on the left.

a list of topics that includes chemical industry, polymers, proteins, electrochemistry, and carbohydrates.

We have found that our students encounter two main difficulties while studying the polymer subject. The first problem is understanding the properties of macromolecules that are related to their three-dimensional structure. The second problem is that the models used in the classroom do not provide any clues as to the characteristics of the resulting polymer and its relationship to the originating monomer.

The use of microcomputers seem to be an adequate solution to these needs. Nevertheless, Hounshell and Hill[8] indicate that the use of microcomputers in public schools is still sparse

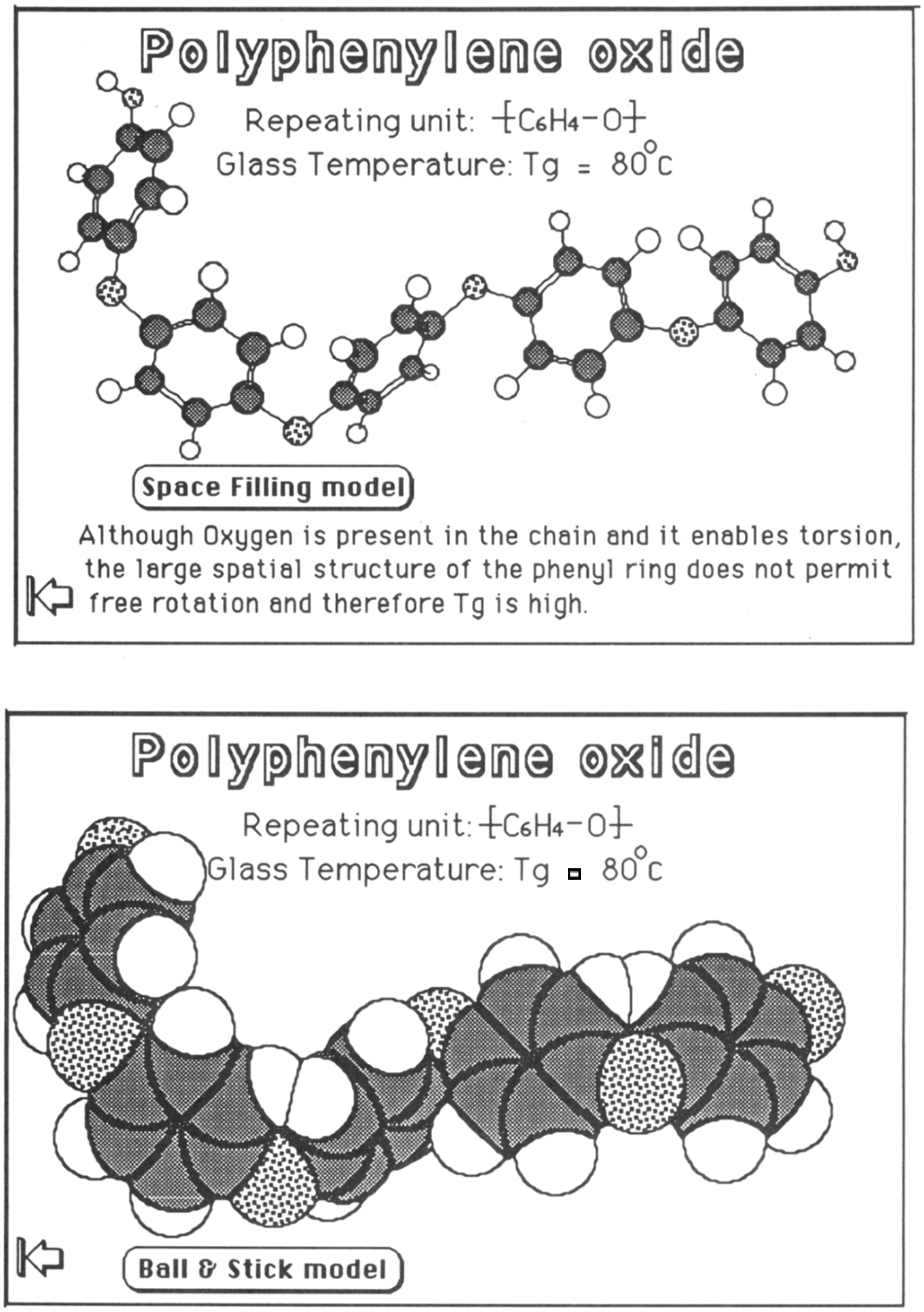

Figure 5. Relations between monomer structure and polymer characteristics exemplified on polyphenylene oxide. (Top) Ball and stick model. (Bottom) Space-filling model.

since the technology is quite expensive and proven software is lacking. The situation in Israel is similar, and just recently several groups have started to develop computer-aided instruction modules in a variety of topics in chemistry.[9-11]

3. STRUCTURE OF THE POLYMER MODULE

We have developed a computer-aided instruction module on polymers that may serve for mastery learning, enrichment material, and a source for problems and their solutions. It may be used either as a self-tutorial for the individual student or for cooperative learning in small groups. The module, originally written in Hebrew and translated in part into English, is based on the HyperCard authoring environment, operating on Macintosh computers and consists of 180 "cards" (screens). It is built as a knowledge network, consisting of three main topics and three "information organizers", all of which can be accessed from the main menu of the courseware, shown in Figure 1.

The program enables the student to select any topic without imposing a predetermined learning path, enabling students with a variety of knowledge levels to engage in effective learning without loss of time. The topic "Organic Chemistry" serves as a short tutorial for those students not familiar with the basic concepts of organic chemistry or as a basic reference that students can use to refresh their knowledge on terms related to the study of polymers.

3.1. Polymerization Topic. The Polymerization Topic consists of addition polymerization, condensation polymer-

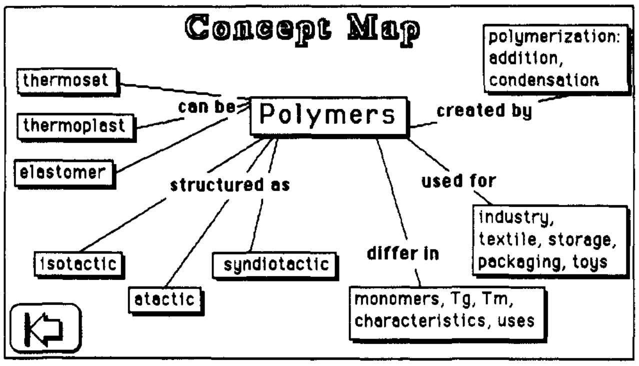

Figure 6. Polymers concept map.

izations, and review problems. Figures 2 and 3 provide examples of an animation showing the production of polyethylene as an addition polymerization reaction. The line of monomers in Figure 2 and the two lines in Figure 3 constitute part of a series of six pictures that are used for animation. Clicking at the button "Polyethylene production" invokes the sequence of these pictures, one fading into the next, making the idea of addition polymerization very clear and concrete. Boldface words in the narrative of Figure 2 indicate that these words are referenced, and clicking on them leads the student to an explanation of the terms, some of which are found in the organic chemistry unit.

Each topic ends with a set of five problems, for which immediate responses are provided, rewarding with a pleasant sound and title for a correct answer and explaining the correct answer if an incorrect one was given. This prompt feedback is helpful in that it provides for a remedial learning of the "weak" points. Figure 4 exemplifies this approach with one of the problems that appear at the end of the Addition and Condensation Polymerization Topic.

3.2. Structure and Characteristics Topic. Enhancing students' understanding of the relations between macromolecules' characteristics and their three-dimensional structure is a major goal of our courseware. To achieve this, we take advantage of the graphics and animation capabilities of the microcomputer to demonstrate the relationships between chemical structure and physical properties. We examine factors that affect melting and glass-transition temperatures (T_m and T_g) such as monomer composition and spatial structure; side chains; cis–trans isomerization; isotactic, syndiotactic, and atactic polymers; cross-linking and hydrogen bonds; and stiff vs flexible interchain bonds.

Several types of molecular models were drawn, and the student can switch among them. Figure 5 exemplifies a portion of polyphenylene oxide in two different spatial representations: ball and stick model and space-filling model.

3.3. Information Organizers. A useful information organizer implemented in our work is the concept map.[12] It is a semantic net realized through a directed graph that consists of nodes and edges. Each node represents a concept—a noun or an adjective, e.g., polymers, monomers, thermoset, and isotactic. Each edge is a relator—a verb and/or a preposition that constitutes a meaningful relation between the source concept and the target concept it links. Thus, by arranging the text of the source concept, followed by the relator, followed by the target concept, one can extract statements about the domain. In our case, for example, statements such as "Polymers can be thermoplast" or "Polymers differ in monomers" can be extracted from the map of Figure 6. Concept maps are very instrumental in understanding the relative position of each concept with respect to other concepts. When used in our courseware, it also enables the student to navigate rationally through the program, since clicking at a concept or a relator moves the viewer to the appropriate card.

Another information organizer in the module is the database. Each important polymer in the database, e.g., low-density polyethylene (LPDE), has a card, depicted in Figure 7, in which information related to the originating monomer, repeating unit, T_m, density, properties, etc., is listed in a standard fashion. This fashion enables easy access to any piece of data or information the student wishes to find out about at any point of time during the use of the module. When

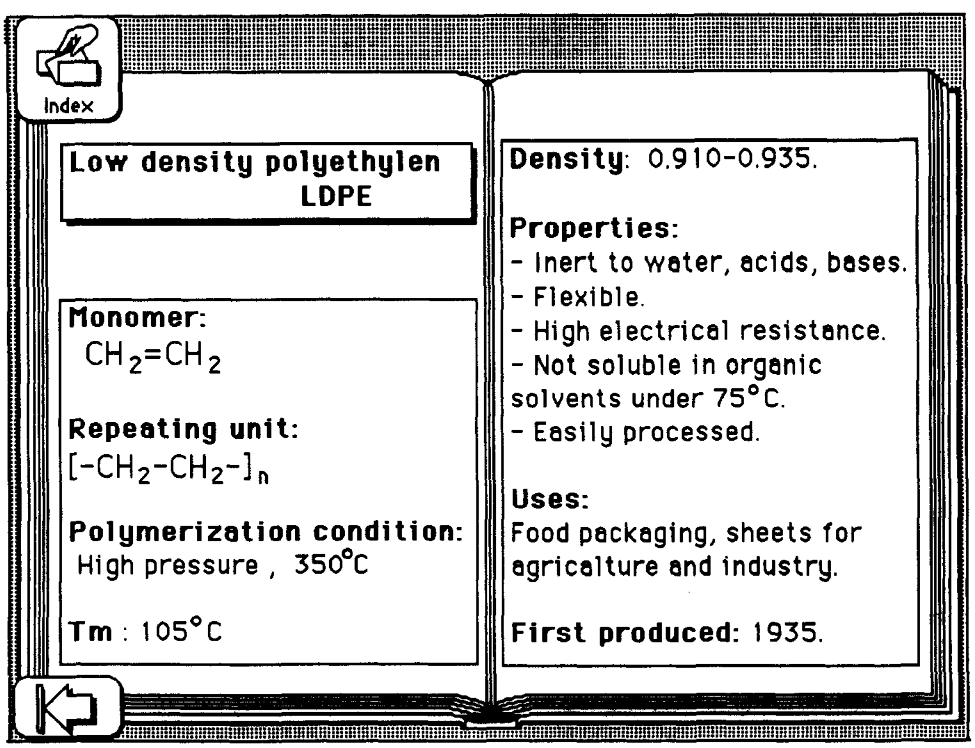

Figure 7. Low density polyethylene example from the database.

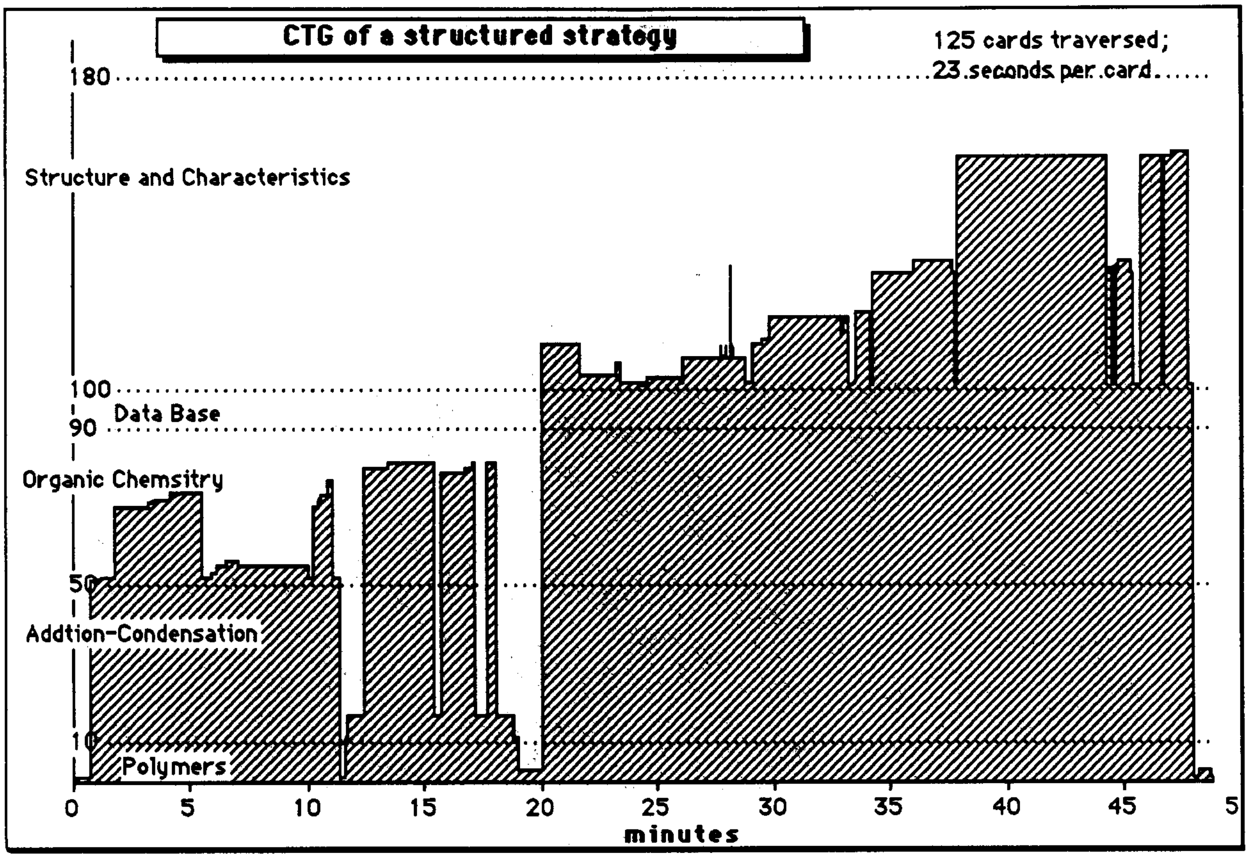

Figure 8. Structured learning strategy exemplified in a session with the polymer module.

done, the student can return to where he or she stood before by simply clicking at the arrow found at the bottom left corner.

4. TEACHERS' ATTITUDES AND COURSEWARE ASSESSMENT

As suggested by Ellis and Kuerbis,[13] we have conducted an in-service chemistry teachers training[14] that was aimed at introducing the teachers to the use of microcomputer technology as a teaching aid. An important element in this training was the introduction of the newly developed CAI module on polymers in order to increase their awareness of the program and encourage them to apply it in their schools.

The assessment of both the training and the program was done using two tools. One was the Card Traversal Graph, CTG,[15] and the other one was a questionnaire to evaluate the content, structure, and design of the software, as well as teachers' attitudes toward the use of computers for science teaching.

4.1. Card Traversal Graph (CTG). The CTG is a "quiet" companion, transparent to the user, that operates in the background and automatically tracks the order and duration of use of the "cards" (screens) in the program.

Thus, it serves as a means to record from each student both the sequence of cards viewed and the time spent with each card. At the end of each session, the collected data is used to draw the CTG. Such a plot may help a teacher analyze a student's learning strategy and use the analysis to provide advice and corrective measures.

Examining the CTGs of the teachers who took part in the CAI training, we found that only two (out of the possible four) learning strategies were used: structured (shown in Figure 8) and bookstyle (shown in Figure 9). The "Structure and Characteristics" section was studied the longest time, in accordance with our assumption that this topic is the most problematic for frontal teaching.

Table I. Statistics for Four Significant Items in Questionnaire

item	group	difference	SD	$p \leq$
1	experiment	0.52	1.12	0.045[a]
	control	0.17	0.65	0.213
2	experiment	0.24	0.44	0.020[a]
	control	−0.16	0.47	0.100
3	experiment	0.53	1.02	0.037[a]
	control	0.00	0.59	1.000
4	experiment	0.33	0.66	0.030[a]
	control	0.15	0.59	0.267

[a] $p < 0.05$.

4.2. Pre- and Post-Attitude Questionnaire. An attitude questionnaire, consisting of 26 items, was passed to the CAI training group ($N = 22$) and a control group ($N = 27$) that received enrichment in chemistry without any use of computers. The questionnaire was found to have Alpha–Kronbach = 0.81.

We computed the difference in scores between post-test and pre-test and found several items that showed a significant difference for the experiment group and was nonsignificant for the control group. These items were the following:

(1) "In teaching chemistry, the use of computers is required for demonstration and/or laboratory instrumentation."

(2) "I feel comfortable when I am around computers."

(3) "Programming the computer on my own will give a sense of self-confidence to use computers in the future."

(4) "Students are interested in experiments and process descriptions through computers."

Examining Table I, we see that training had a positive effect on teachers' attitudes toward using computers for demon-

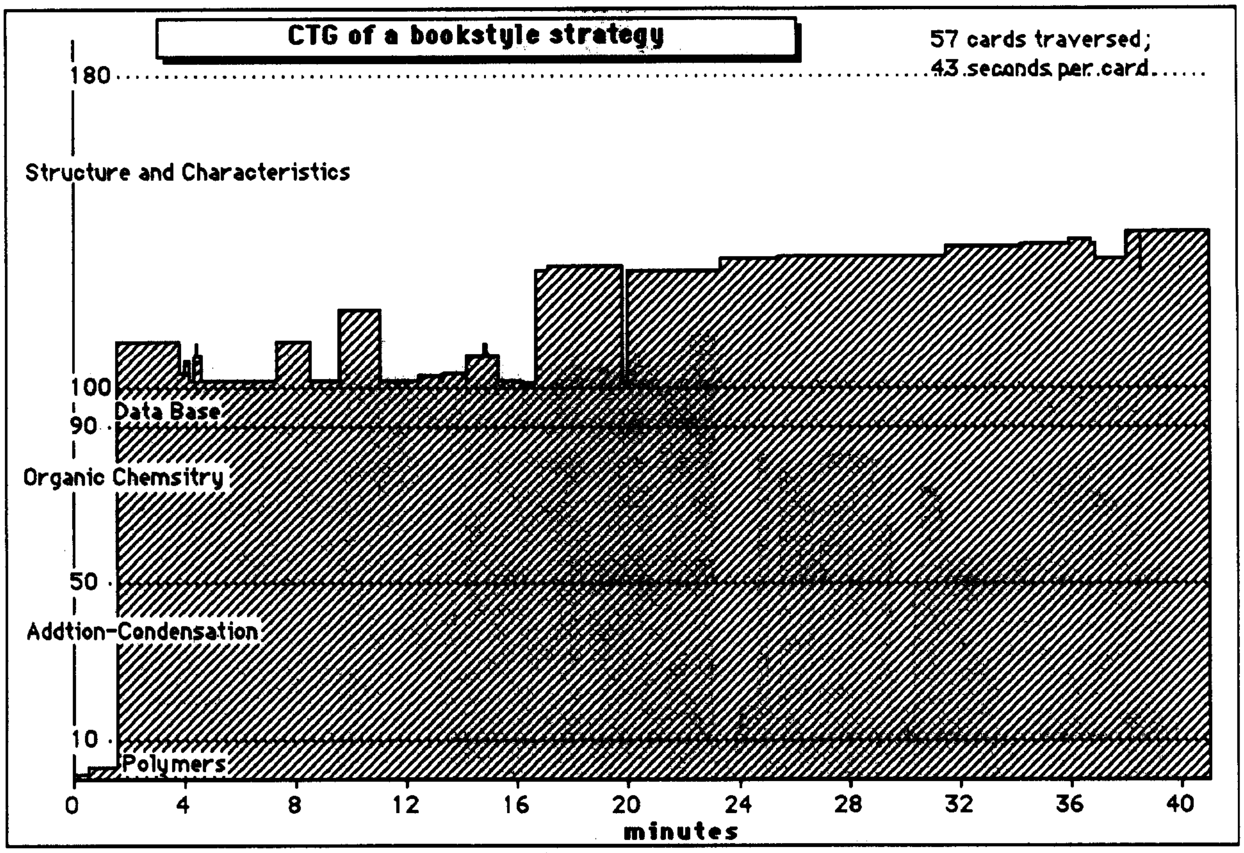

Figure 9. Bookstyle learning strategy exemplified in a session with the polymer module.

strations, as well as for participating in developing a CAI unit.

Through factor analysis on the questionnaire, we have found several factors, one of which showed a significant difference in attitudes of the teachers before and after the CAI training. One factor, consisting of the three items listed below, was found to have a difference of 0.25 with SD = 0.54 (on the scale of 1–4). It is significant ($p < 0.04$) for the CAI training group and nonsignificant (0.16 with SD = 0.59; $p < 0.16$) for the control group. The three items in the factor were:

Using computers in science teaching enables students to advance at their own pace.

Teaching chemistry with computers yields higher achievements.

Teaching chemistry with computers does not slow down the pace of students' advancement.

In the questionnaire, we also asked the teachers to comment on the polymer module they practiced. Below are some of the most frequent responses.

The courseware is very friendly and easy to work with.

The operation of the courseware is easy, and the directions are clear; no problems in navigation.

The animation and other visual effects are nice and enlightening; they clarify polymerization and stretching processes that are hard to understand through books or a drawing board.

The courseware is instrumental in teaching the subject through practicing and organizing the material.

Most of the teachers who took part in this training expressed their desire that we invite them with their students to the microcomputer laboratory to experience first-hand the use of this module.

5. SUMMARY AND FUTURE WORK

We have developed a CAI module on polymers that enables the student to select topics without imposing any predetermined learning path. It enables students with a variety of knowledge levels to engage in effective learning at their own pace. It consists of three topics—organic chemistry, addition and condensation polymerization, and structure and characteristics. The module is self-contained and, therefore, can serve as a stand-alone enrichment unit even in those schools where this unit is not studied in frontal lessons.

An in-service chemistry teachers training that we conducted was aimed at introducing the teachers to the use of microcomputer technology as a teaching aid and to the newly developed CAI module on polymers. This was done both to obtain feedback on the module for improving it and to increase the teachers' awareness of the program so that they will be willing to apply it in their schools.

Based on teachers' comments, as well as things that we found ourselves, we plan to improve the module by extending the database and by adding environmental and recycling aspects of polymers.

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