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Experiential Learning in Mechanics with Multimedia*

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Starting with multimedia learning modules for statics, and drawing on the rich literature on learning and teaching, we developed a learning environment that includes the following features: statics integrated with mechanics of materials, physical models, interactive multimedia, traditional pencil-and-paper activities, and cooperative learning in the framework of experiential learning. Our laboratory for evaluating and improving this learning environment is a course taught to students in architecture. In this paper we describe the learning environment and illustrate how students are guided to develop the concepts of moment and bending moment, the condition of moment equilibrium, and a procedure to construct shear and moment diagrams.

LEARNING ENVIRONMENT

> *I see more clearly than before that the path to motivating students is the joy of creation, exploration, and discovery. I see also that these processes are social in nature and that shared experiences in class and through teamwork projects are vital.* Shneiderman [1]

Experiential learning

> *Learning from experience is the process whereby human development occurs.* Vygotsky in Kolb [2]

LEARNING is the process whereby knowledge is created through the transformation of experience [2]. Experiential learning focuses on the two fundamental activities of learning: grasping and transforming experience (Fig. 1). Each activity involves two opposite but complementary modes of learning. One can grasp an experience directly through the senses (sensory, inductive mode) or indirectly in symbolic form (conceptual, deductive mode). Similarly, there are two distinct ways to transform experience, by reflection or action. At any moment in the learning process, one or a combination of the four fundamental learning modes may be involved. It is significant that their synthesis leads to higher levels of learning [2]. This is supported in a study by Stice [3], which shows that the students' retention of knowledge increases from 20% when only abstract conceptualization is involved to 90% when students are engaged in all four stages of learning.

Kolb's four-stage, experiential learning model (Fig. 1) guides our learning activities and the design of the multimedia program, which is divided into two parts: an inductive part, where concepts and procedures are developed; and a deductive part, where concepts and procedures are summarized, illustrated, and applied in the solution of problems. An effective way to reach learners is to use 'first induction, then deduction' [4].

We found it helpful to view the four-stage learning cycle as a spiral in time that extends beyond a session. For example, a concept may be developed or applied in different contexts, at different times, and through different learning modes. This finding is shared by Wankat and Oreovicz [5 (p. 292)]: 'For complex information the circle is traversed several times in a spiral cycle. The spiral may extend through several courses and on into professional practice as the individual learns the material in more and more depth.'

Cooperative learning

> . . . *early evidence suggests that students who work in small groups, even when interacting with high-tech equipment, learn significantly more than students who work primarily alone.* Light [6]

> *Team learning is vital because teams, not individuals, are the fundamental learning unit in modern organizations.* Senge [7 (p. 10)]

Cooperative learning is a structured learning strategy in which small groups of students work toward a common goal [8]. Benefits of cooperative learning include [9]:

- high-level reasoning;
- generation of new ideas and solutions;
- motivation for learning;
- personal responsibility;
- student retention.

Group activities are the key to engage students actively in learning in the classroom or laboratory.

We experimented with various group sizes and

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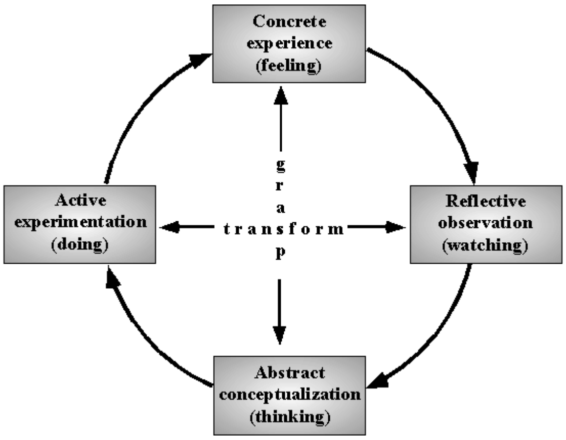

Fig. 1. Experiential Learning Model [1 (p. 42)].

cooperative learning structures and found that pair activities work well in class. In groups of three, for example, one student is easily left out. We also tried different cooperative structures and arrived, with the help of student feedback, at a combination of think-pair-share (TPS) [10] and think-aloud-pair-problem-solving (TAPPS) [11] as our base structure. For simplicity we call the combined structure think-pair-share (TPS).

- *Think*: think about the solution of the problem individually to organize your thoughts.
- *Pair*: form pairs, a think-aloud problem solver and a listener (TAPPS), to solve the problem; reverse roles after every problem.
- *Share*: share your findings with another pair or a larger group.

In TAPPS, each pair is divided into a think-aloud problem solver and a listener, each with specific instructions. Their roles are reversed after every problem but not during a problem. We found that TPS did not provide enough structure for some pairs; some students would work independently and ignore their partner. We tried TAPPS for a few weeks, and students indicated that it did not allow enough collaboration; so we introduced the best feature of TAPPS, a think-aloud problem solver and a listener, into TPS.

TPS can also be used to answer questions or to apply the 8–2 rule: For every eight minutes the teacher is in control (e.g., giving mini lectures), students should be given at least two minutes to summarize, reflect, discuss, and hence begin to process the material [12].

Sessions

Our course is taught in a computer lab. Two students share one computer to facilitate pair activities. Sessions generally consist of three parts:

(1) A warm-up problem to focus on problems or questions that surfaced in homework, weekly quizzes, or minute papers [13].
(2) Mini lectures (10–15 minutes long) interspersed with cooperative activities.
(3) A minute paper, where students are asked to reflect and answer questions about the day's lesson and activities.

Anonymous minute papers provide valuable insight into students' conceptions, achievements, and difficulties. This information allows one to evaluate and improve the learning environment in a continuous fashion. The Harvard Assessment Seminars revealed that small changes in the teaching format can lead to significant gains for students; best examples are minute papers and small-group activities [6].

It is a challenge to achieve a good balance among the various activities in our learning environment. This is crucial for students who are not highly motivated or skilled learners; a rich, active learning environment can become overwhelming. This potential problem can be alleviated as follows:

(1) Give students the opportunity to master one topic before moving to the next [14].
(2) Frequently place topics in context of the course framework and objectives, the students' background, and real engineering problems.
(3) Receive and provide frequent feedback.

It is also important to communicate high expectations, to stress the students' responsibility for learning, and to enable them to realize the benefits of helping one another learn [15].

Multimedia

The multimedia program is constructed with Authorware Professional [16]. We are using the program in various ways:

- to present mini-lectures;
- to guide student teams in the development of concepts, the solution of problems, and discussions;
- to provide connections to the students' background and engineering structures;
- to integrate traditional pencil-and-paper activities;
- to preview and review lessons (each student should have a personal copy of the program).

Navigation tools in the multimedia program (Fig. 2) include: pull-down menus, hotwords (in red), local buttons (e.g., Next), and global buttons (e.g., Previous menu in command bar).

LEARNING ACTIVITIES

I never discovered anything with my rational mind. Einstein [7 (p. 169)]

In this section we illustrate some multimedia learning activities. The experiential learning model (Fig. 1) is used to learn about moments (Fig. 3) and internal forces in beams (Fig. 4): the inductive approach guides the **development** of concepts and procedures (from feeling to

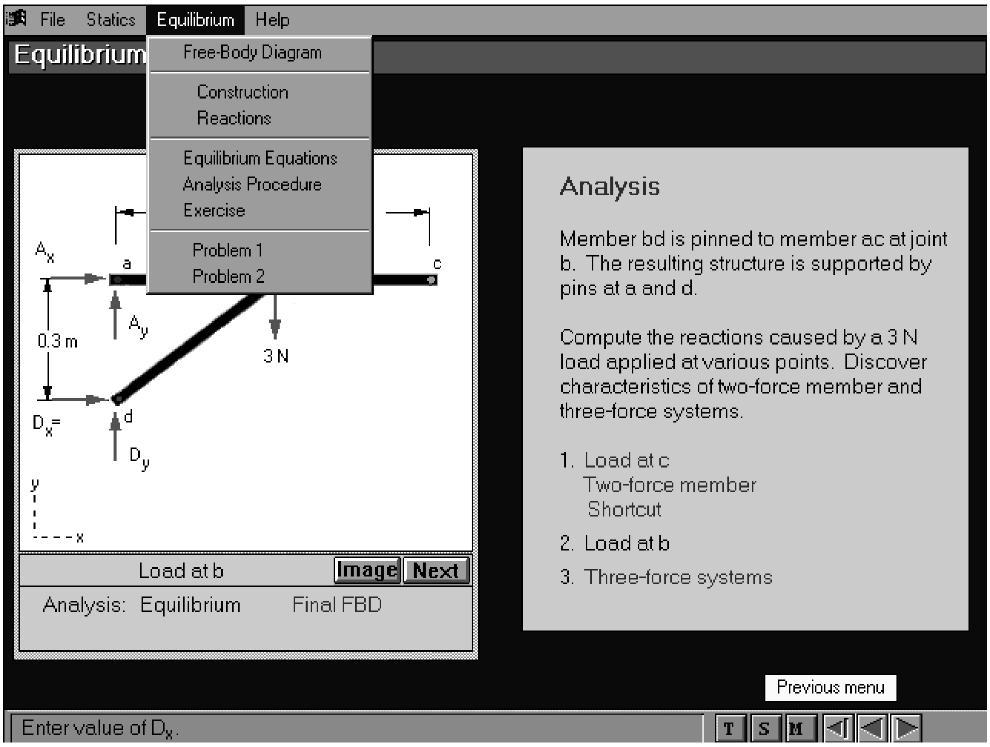

Fig. 2. Navigation tools.

thinking), and the deductive approach, starting with a **summary** of findings, guides the analysis of problems (from thinking to doing).

Moments and equilibrium

We are building on the students' intuitive notions of balance, acquired through their childhood experiences with seesaws, to help them develop the concept of moment and the condition of moment equilibrium. The experiential learning model (Fig. 1) is reduced to three steps in this development (Fig. 2): concrete experience and reflective observation are combined in turning effect; abstract conceptualization is conducted in

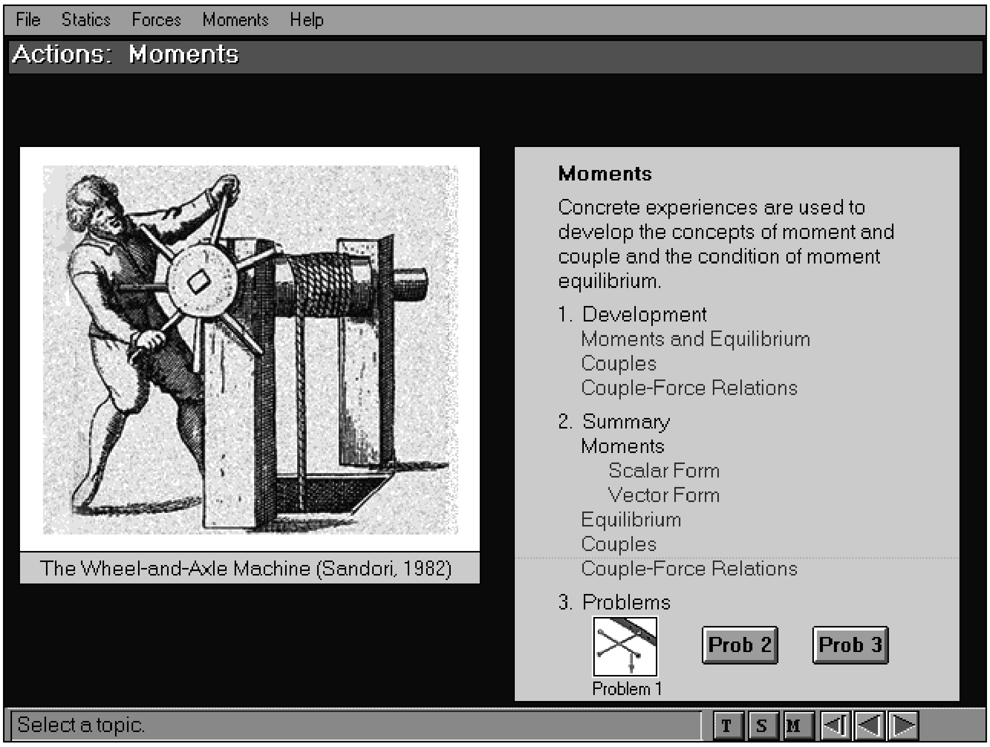

Fig. 3. Moments.

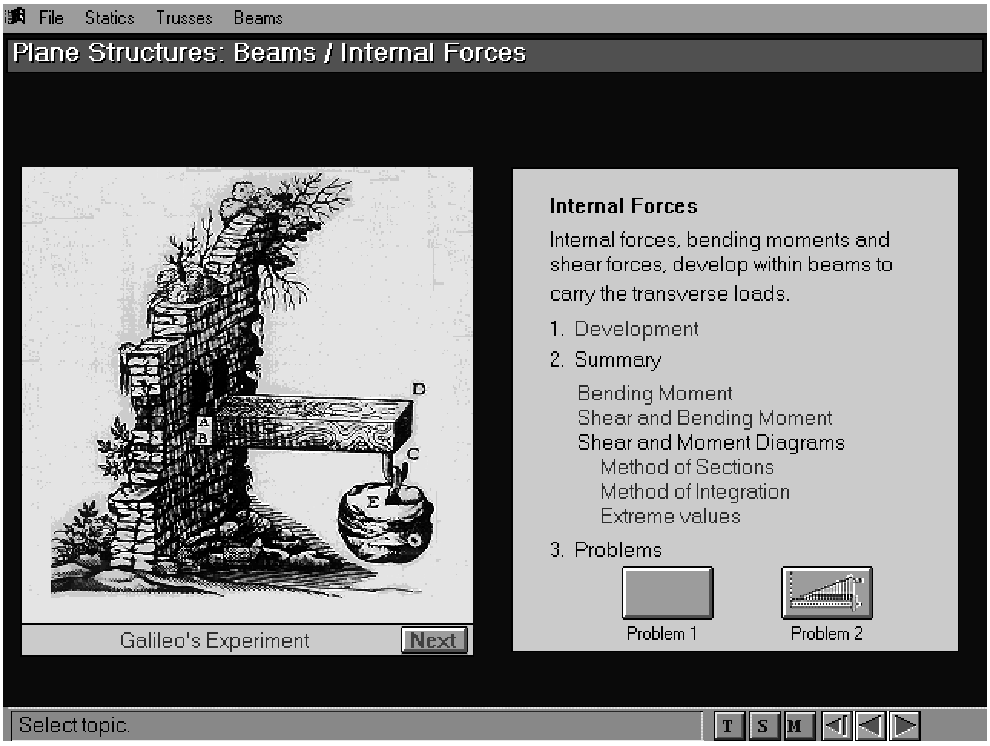

Fig. 4. Internal forces.

equilibrium and active experimentation in testing. In this condensed form, the experiential learning model is akin to the 3-stage scientific learning cycle, which is based on Piaget's theory of constructivism [5 (p. 287)]: (1) exploration, (2) term introduction, and (3) concept application.

- *Turning effect.* The students work in teams through a series of questions using **TPS**. The key question about the cause of the clockwise rotation leads to a measure of the turning effect, which is defined as moment (Fig. 6). Defining concepts after some exploration

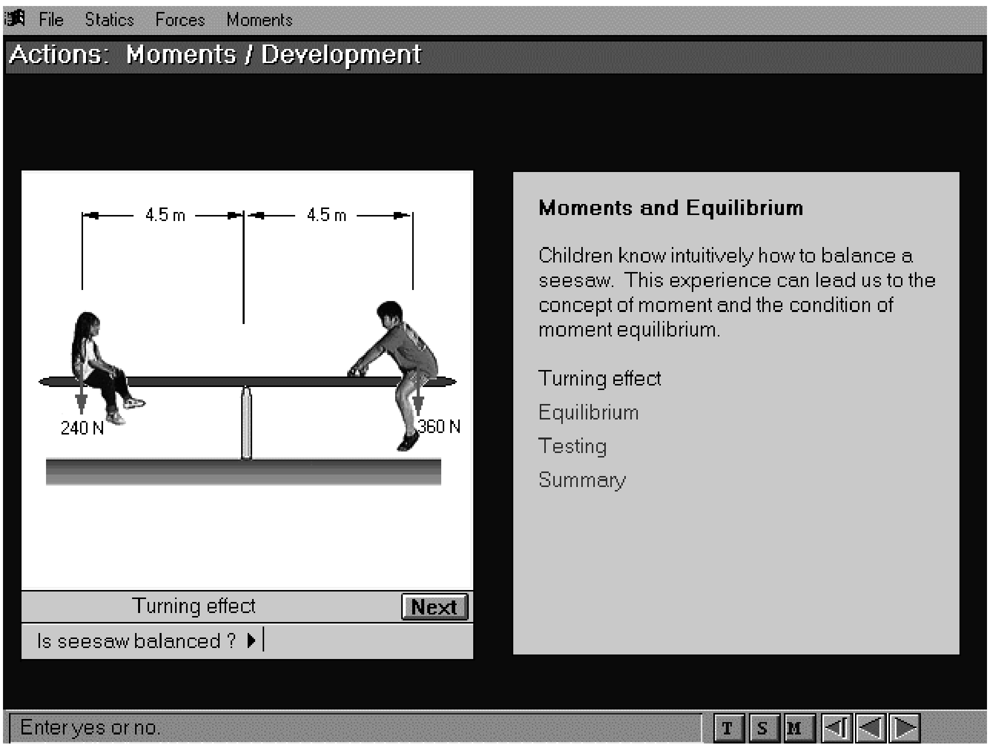

Fig. 5. Moments and equilibrium.

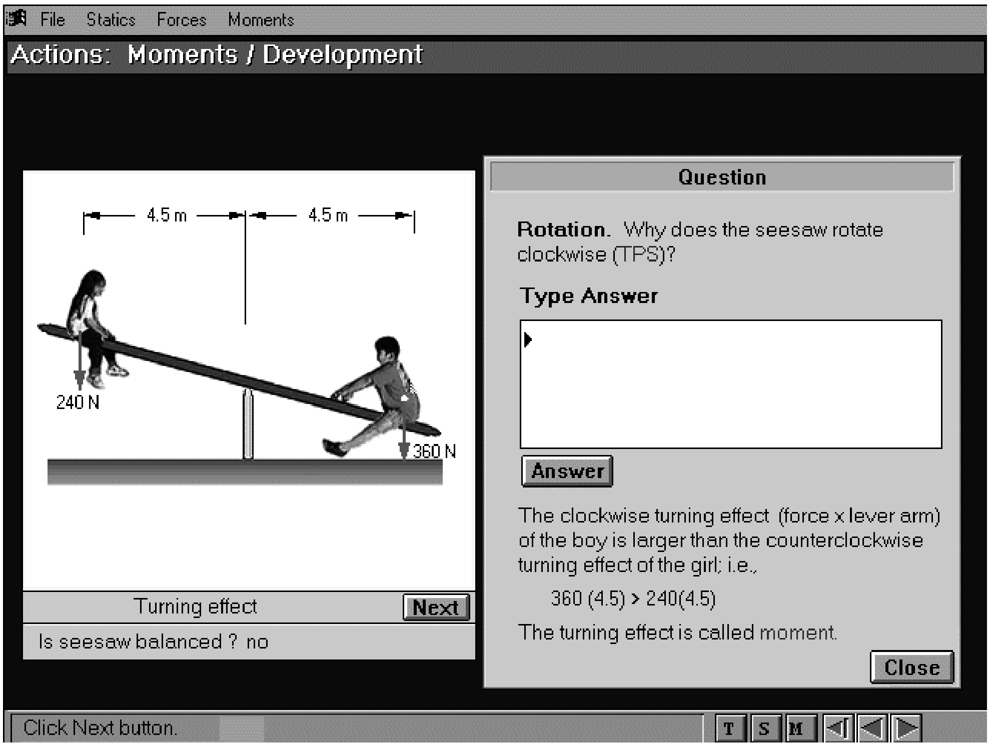

Fig. 6. Turning effect.

facilitates learning [17]: 'idea first and name afterwards.'

- *Equilibrium.* The balance condition is generalized to the condition $\Sigma M_0 = 0$ and a moment sign convention is introduced (Fig. 7). Next, the students are guided to discover that the net moment about any point in the plane is zero; they are asked to state the conditions of equilibrium of a body in a plane. The answer (Fig. 8) contains Euler's extension of Newton's conditions of equilibrium to finite bodies.
- *Testing.* The condition of equilibrium is applied in Fig. 9 to verify that the seesaw is not balanced.

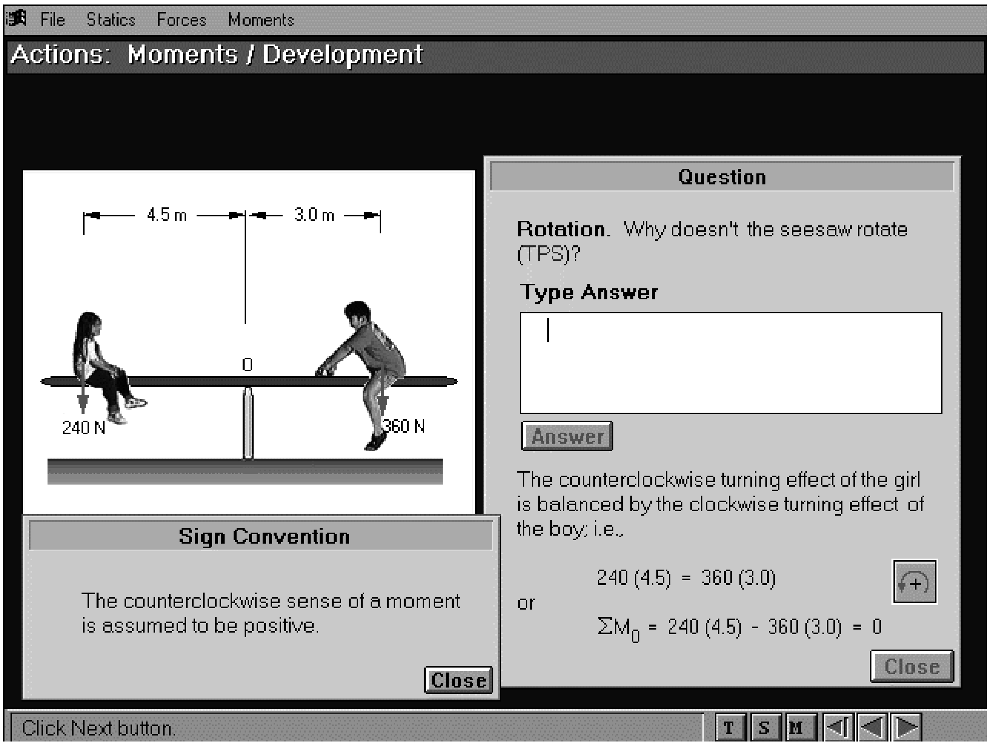

Fig. 7. Balance condition.

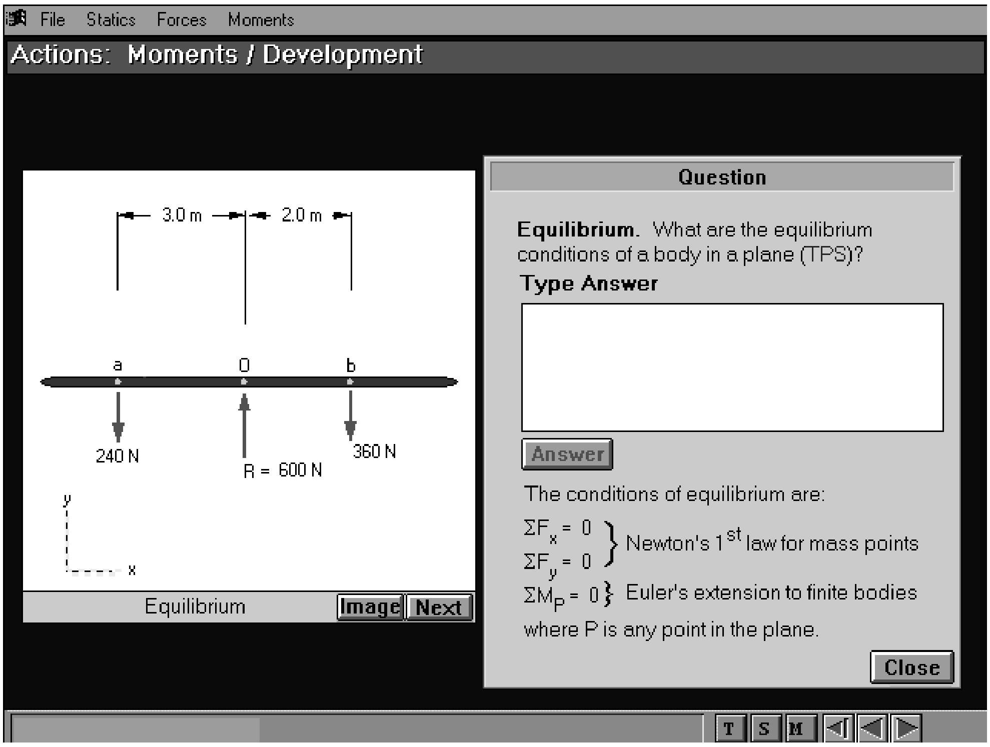

Fig. 8. Conditions of equilibrium.

Bending moment
After exploring bending deformation and the resulting compression and tension faces of beams, students are asked to graph the normal stress, representing experimental data, over the cross section of a beam (Manual in Fig. 10). Two- and three-dimensional graphs (Fig. 11) are provided for comparison. The final task is to compute the couple corresponding to the stress blocks. Figure 12 illustrates one step in this process; the second incorrect value for the compressive force, F, results in the Note in

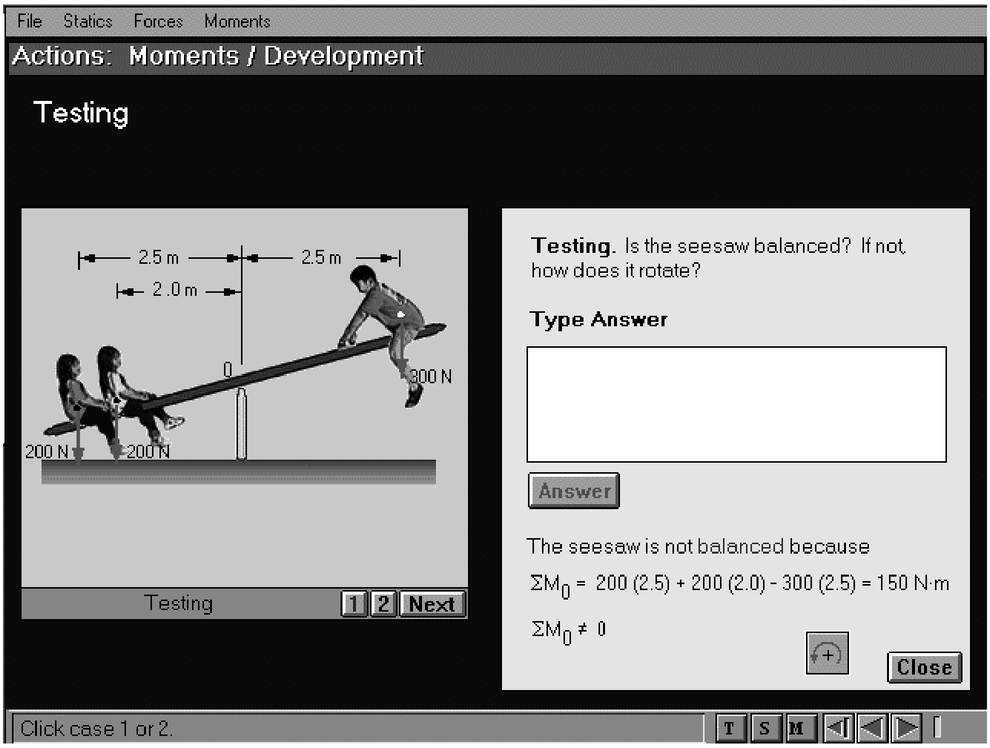

Fig. 9. Testing.

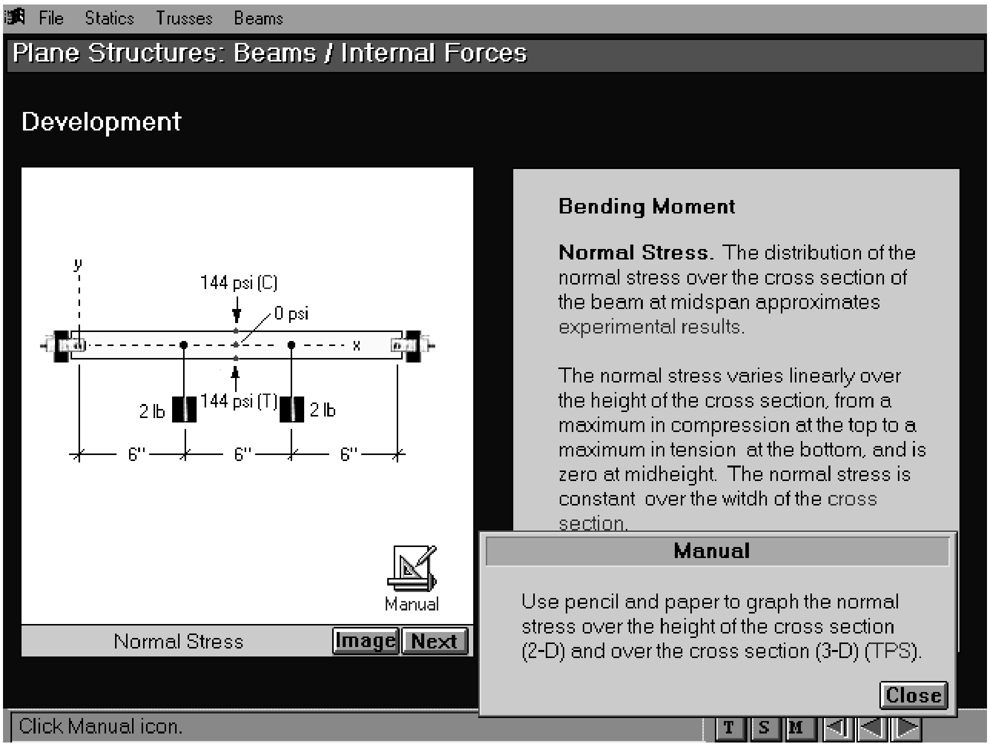

Fig. 10. Normal stress.

Fig. 12. Generally, the program responds with a clue to the first error and the solution to the second error. The bending moment is defined in Fig. 13.

Shear and moment diagrams

Figures 14–17 illustrate an inductive approach to develop methods for drawing shear and moment diagrams. The method of sections (Fig. 14) is defined after some exploration and linked with truss analysis; making connections facilitates learning. The objective, reflected in Figs. 14 and 15, is to write the functions V(x) and M(x) for the domains between concentrated forces and to graph them.

The method of integration is first developed for

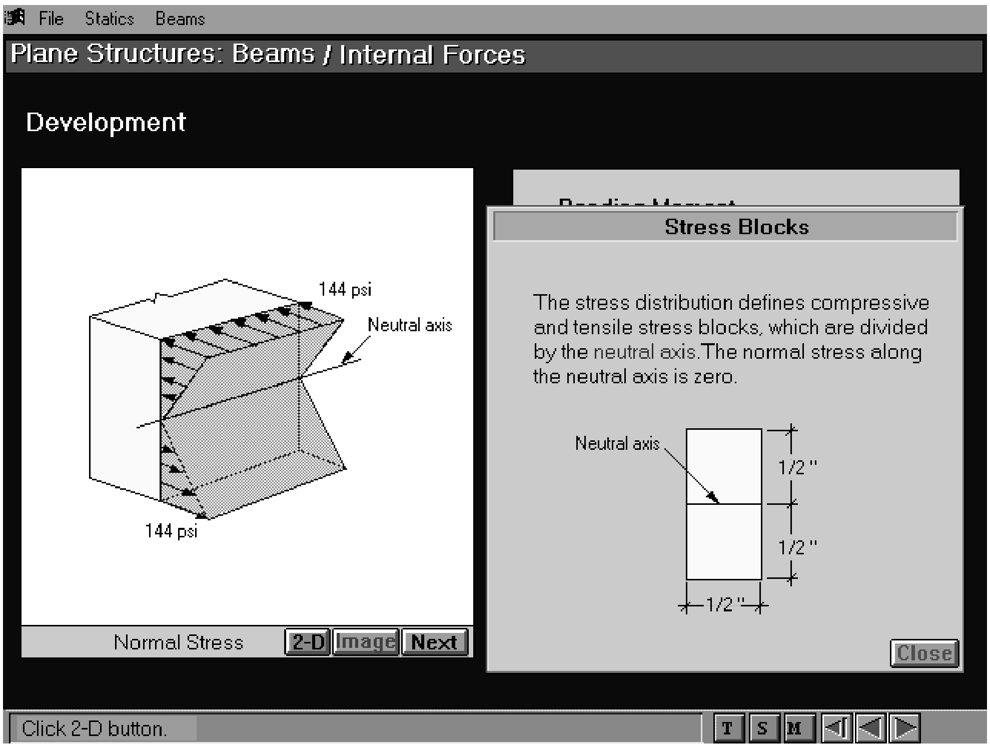

Fig. 11. Stress distribution.

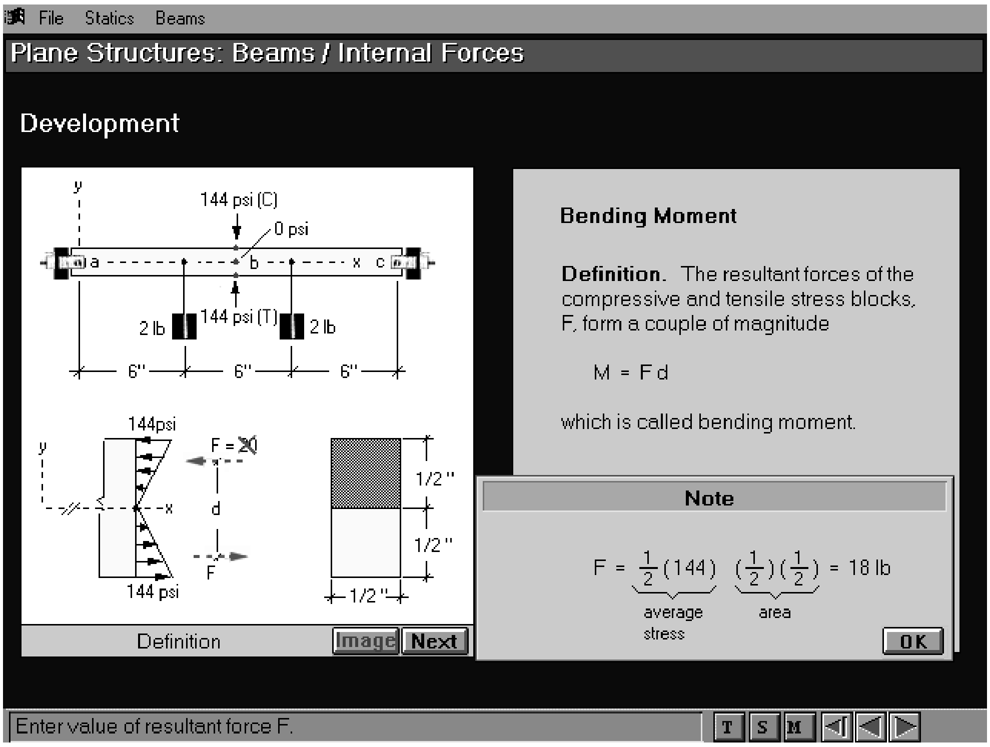

Fig. 12. Computing bending moment.

a specific beam segment. Specifically, the shear-load and moment-shear relations are obtained from conditions of equilibrium in Figs. 16 and 17, and relations for the slopes of shear and moment diagrams are inferred from specific examples.

Only after students have developed the method of integration and applied it to simple problems are the general differential equilibrium equations derived and integrated (Figs. 18 and 19) to verify the procedure.

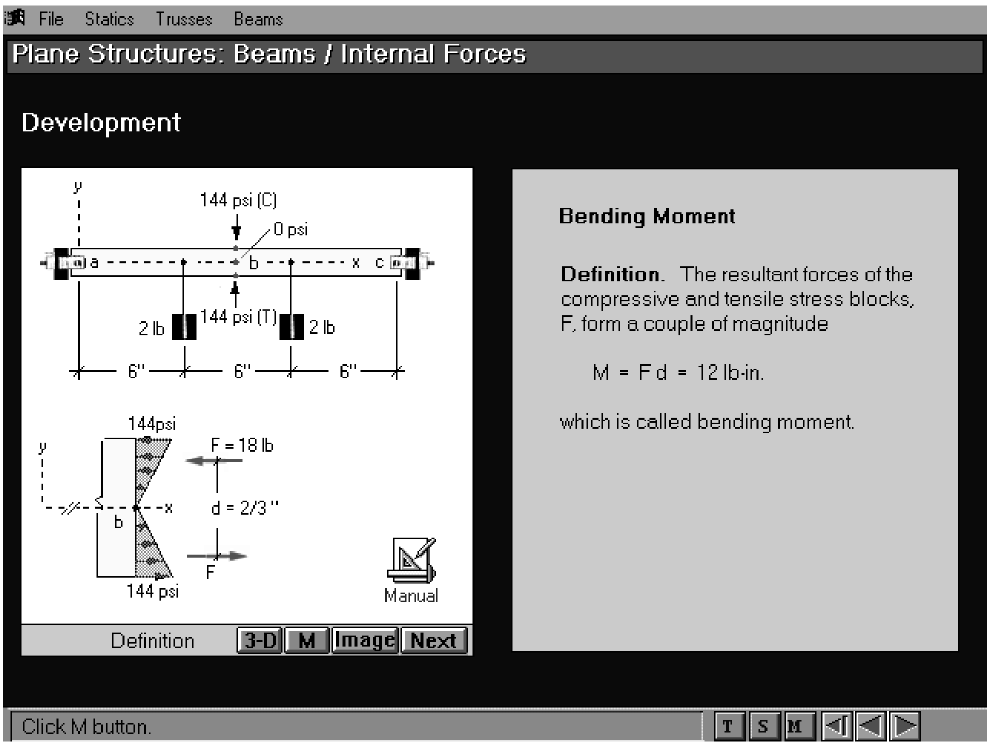

Fig. 13. Bending moment.

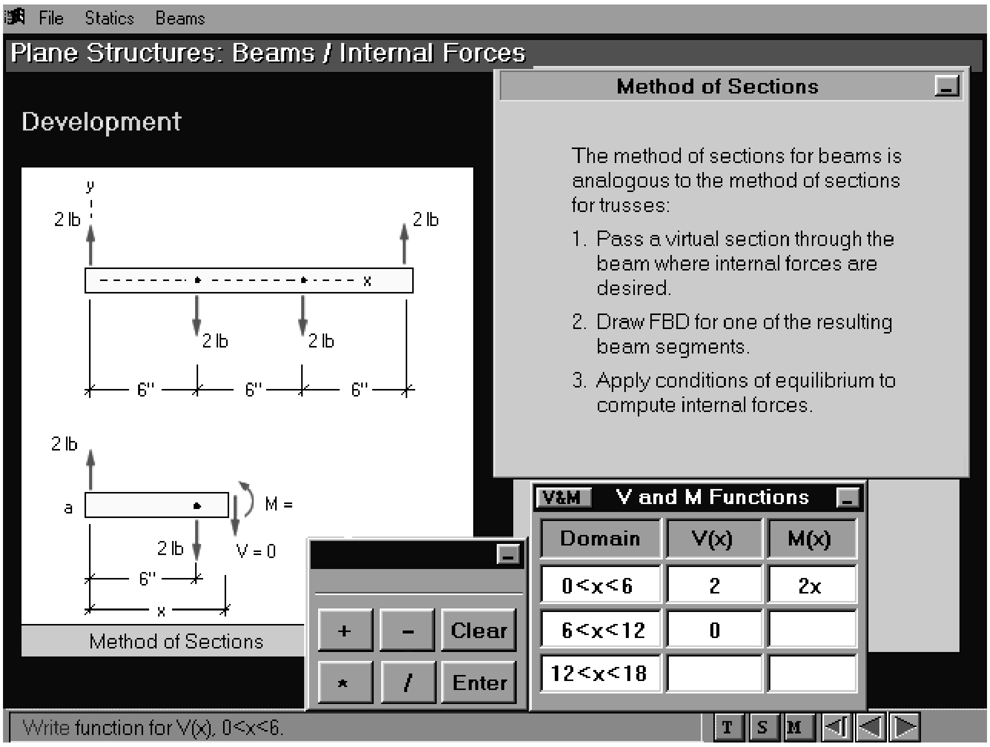

Fig. 14. Method of sections.

EFFICIENT LEARNING

Rapid changes in the nature of knowledge and in the workforce have created a need for knowledge workers, who can learn efficiently and think critically. Diane Halpern [18]

The inductive approach leading to the discovery and development of concepts requires time and patience. It may seem inefficient in comparison to the traditional lecture approach, but it is not if efficiency is measured in terms of student learning [5 (p. 288), 19, 20]. This is confirmed in

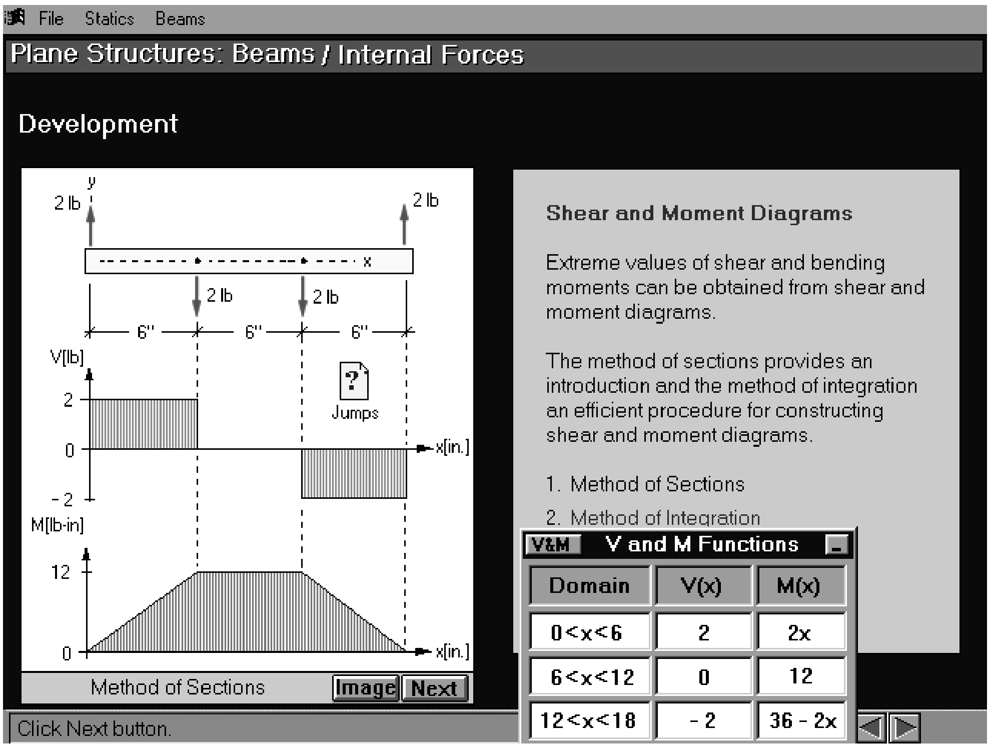

Fig. 15. Shear and moment diagrams.

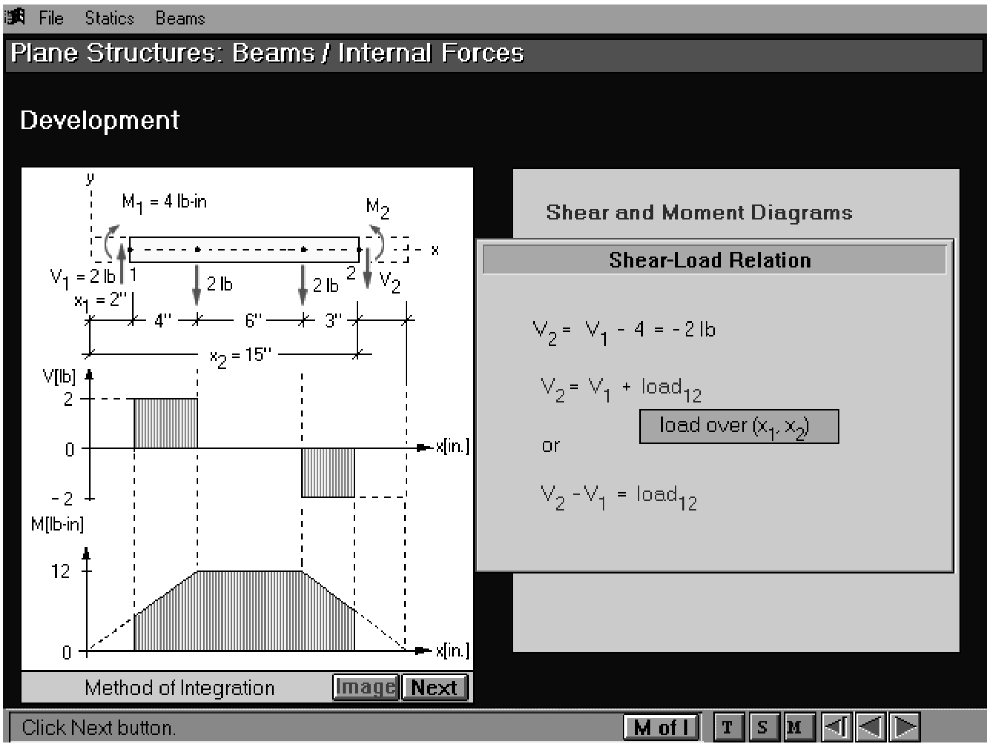

Fig. 16. Method if integration: shear-load relation.

a study led by the US Department of Education which shows that US math scores lag behind because most teachers only state concepts without fully developing them: 'Students in Germany and Japan learn 10 to 20 math subjects in depth, our students are asked to cover 35 math subjects and, therefore, don't learn any of them in depth' [21].

SUMMARY AND ASSESSMENT

A workshop style learning environment is described that combines topics of statics and mechanics of materials. It includes physical models, interactive multimedia, traditional pencil-and-paper activities, and cooperative learning in

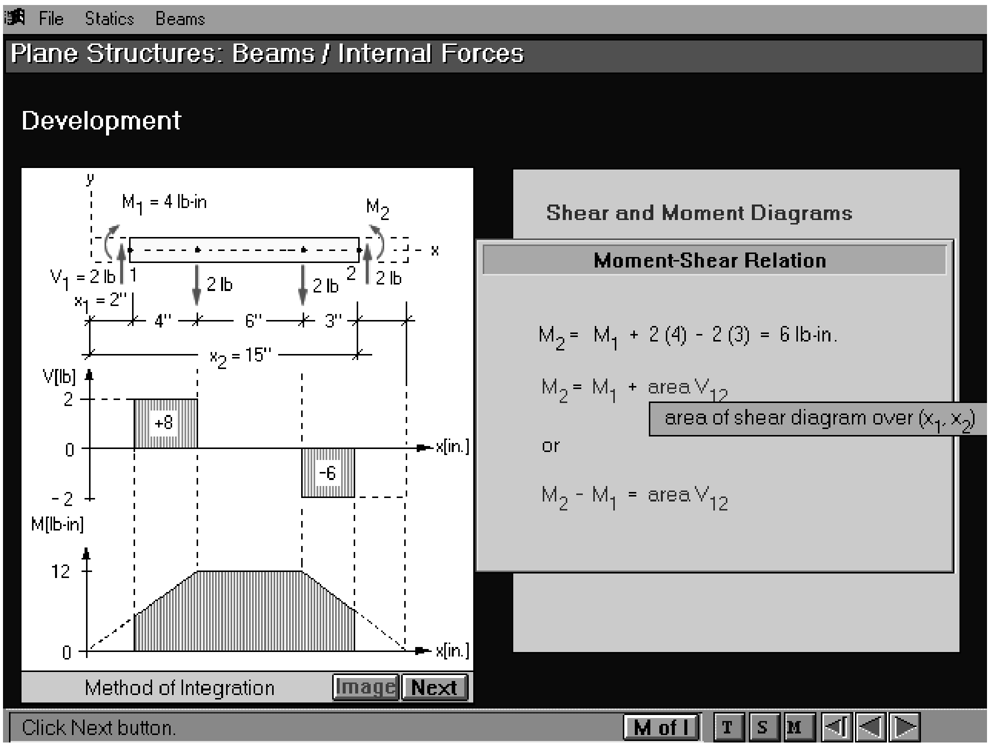

Fig. 17. Method of integration: moment-shear relation.

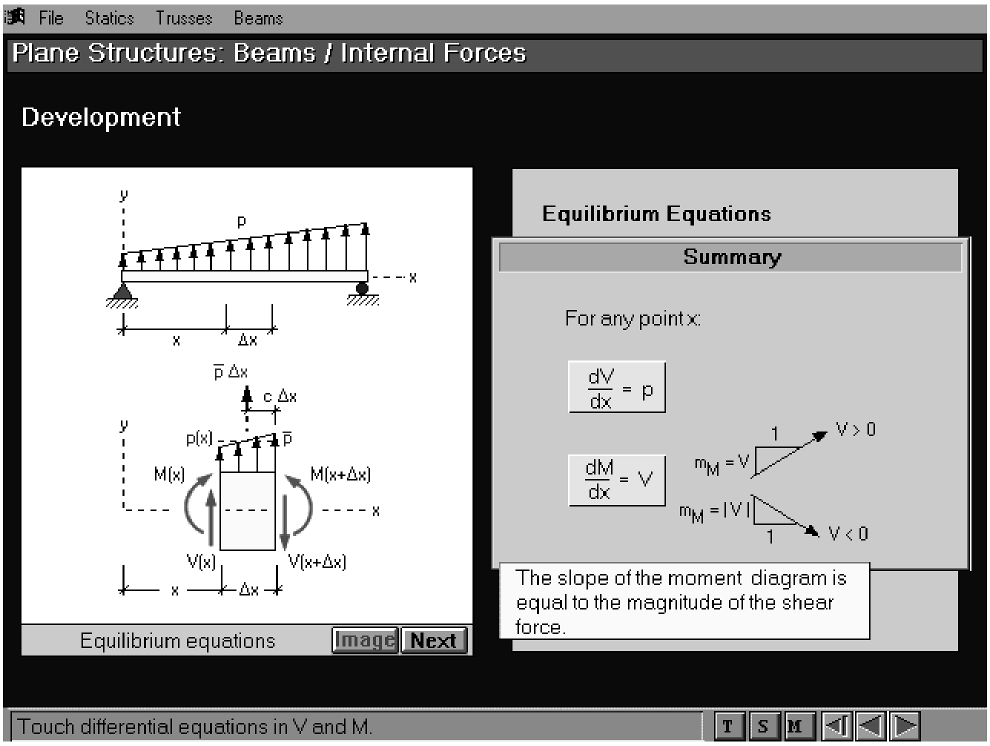

Fig. 18. Equilibrium equations: for any point x.

the framework of experiential learning [2]. Learning activities are illustrated that show how students are guided to develop the concepts of moment and bending moment, the condition of moment equilibrium, and a procedure to construct shear and moment diagrams. A section of statics-mechanics of materials in this format is taught to students in architecture.

Student feedback provides the information to improve the learning environment and to develop more effective multimedia learning modules. Although occasionally a student doesn't like the

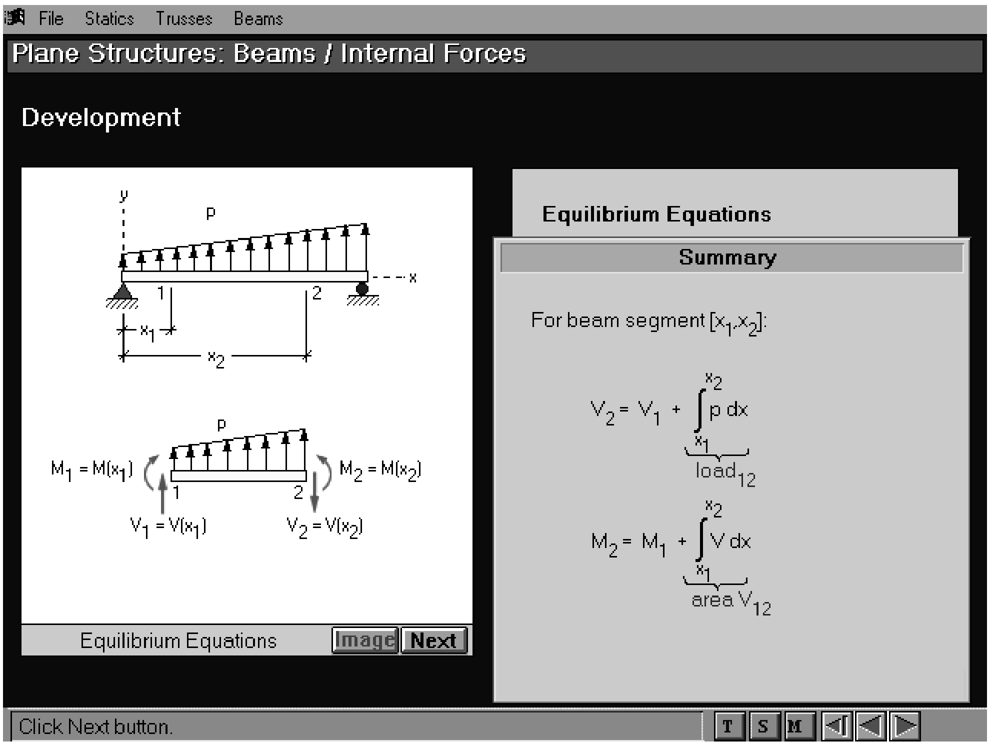

Fig. 19. Equilibrium equations: for beam segment.

computer as a learning tool, on the whole the students are actively engaged in learning, and teaching is rewarding. The following excerpts from student evaluations provide some insight into their learning experiences:

- *I never realized how much I can learn by helping others.*
- *Yes, the* [multimedia program] *did facilitate learning by providing an interactive learning procedure where principles were developed and expanded upon active involvement with concrete and abstract example problems.*
- *Yes* [the multimedia program] *helped me a lot. It was really good to see examples and how they worked.*
- *I used it* [the multimedia program] *a lot out of class and found it very helpful.*
- *Yes* [the multimedia program facilitated learning]. *It worked very well in class time and with a partner.*
- *He created a strong learning environment and his method was exceptionally strong for learning; I feel I took a lot from this course and professor.*
- [He] *taught us to think intelligently and learn.*
- *His system with the computer, 'think-pair-share' learning teams, and in-class problem solving is the most effective way to learn such subject matter that I have encountered in 16 years of schooling.*

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