Students Developing Concepts in Statics

Siegfried M. Holzer and Raul H. Andruet
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061-0105
holzer@vt.edu

We are developing a learning environment in the subject area of statics that includes physical models, interactive multimedia, traditional pencil-and-paper activities, and cooperative learning in the framework of experiential learning (Kolb, 1984). We are using Authorware Professional to construct the multimedia program. We taught a section of statics in this format, which now includes topics from mechanics of materials, for the third time in the fall of 97 to students in architecture.

In this paper we describe the learning environment and illustrate how students are guided to develop the concept of moment and the condition of moment equilibrium.

Learning Environment

> *Learning is the process whereby knowledge is created through the transformation of experience.* **David Kolb** (1984)

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 (Kolb, 1984). This is confirmed in a study by Stice (1987), 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.

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 or principle may be developed or applied in different contexts, at different times, and through different learning modes. This experience is shared by Wankat and Oreovicz (1993, 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." Moreover, it is not always desirable to start with concrete experiences. We use the inductive approach, starting with concrete experiences, to help students discover and develop concepts, principles, and methods of analysis; the deductive approach, starting with concepts, principles, and procedures, provides a quick review and guidance in the solution of problems. Research supports this approach. For example, Felder and Silverman (1988) state an effective way to reach learners is to use “first induction, then deduction.”

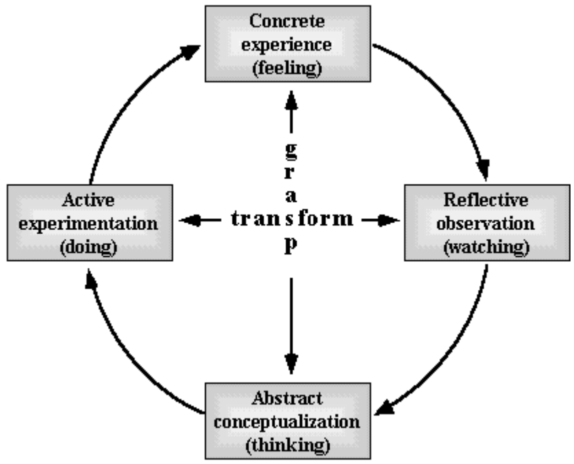

Figure 1. Experiential Learning Model (Kolb, 1984)

Our class meets in a computer lab where two students share one computer. Unfortunately the lab is not designed for group activities, which places some constraints on our movements and interactions. We would appreciate a physical environment similar to Workshop Physics (Laws, 1994), where two students share one computer and four students share one table (Fig. 2). This would facilitate one of our cooperative learning activities called **think-pair-share** (Lyman, 1987; Habel, 1996): Students **think** about a problem individually to organize their thoughts; they form **pairs** to share and discuss their solutions; they **share** and discuss their findings with another pair or a larger group. It is encouraging to receive positive minute paper (Cross, 1991) feedback from students: “I think our group works well together. I have learned a lot from working with them.” “I realized how much more I learn when I help people.” Encouragement is certainly needed because there always seem to be some students who tend to resist or struggle with cooperation.

A session is generally divided into three parts: (1) we start with short group activities, a warm-up problem to focus on problems or questions that surfaced in homework, weekly quizzes, or minute papers; (2) this is followed by mini lectures (10-15 minutes long) interspersed with cooperative activities; (3) at the end of a session, students are asked to reflect and answer questions about the day's lesson and activities (minute paper). Our learning resources include physical models of simple structures, a multimedia program that is used in lectures and group activities, pencil and paper for manual activities, and a board to aid discussions.

The biggest challenge is to achieve a good balance among various activities. 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 reduced as follows: (1) Give students the opportunity to master one topic before moving to the next (Terenzini and Pascarella, 1994); (2) frequently place topics in context of the course framework and objectives, the students' background, and real engineering problems; and (3) receive and provide frequent feedback. It is also important to communicate high expectations and to stress the students' responsibility for learning and the benefits of helping one another learn.

Clearly it takes time to provide students the opportunity to achieve mastery. However the alternative leads to frustration and dissatisfaction. This is reflected by the fourth attribute of good practice, **coherence in learning** (AAHE, 1996): Students succeed best in developing higher-order skills (e.g., critical thinking, effective written and oral communication, problem solving skills) when they have the opportunity to practice and reinforce those skills throughout their education (AAHE, 1996). In contrast, when there is too much pressure on covering material, "memorization quickly becomes the most efficient way to get through the course, leaving everyone dissatisfied in its wake" (Wagener, 1991).

Slow down, coverage is the enemy of learning.
Alfred North Whitehead

Moments and Equilibrium

I never discovered anything with my rational mind.
Albert Einstein (Senge, 1990, p. 169)

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 exercise in Fig. 3 illustrates the students' background when we begin with this learning activity. In this exercise, students apply the 3-step procedure to compute the forces in the strings supporting the 4 lb weight: (1) they draw a free-body diagram (FBD) of point 0; (2) they formulate and solve equations of equilibrium; and (3) they draw a final FBD to check equilibrium. Thus the students can apply Newton's laws (first and third) to analyze simple structures under concurrent forces. Most students can extend this approach to compute member forces in trusses by the method of joints. However, to compute reactions, we need to extend Newton's conditions of equilibrium to finite bodies by including moment equilibrium (Euler in Truesdell, 1968).

The experiential learning model (Fig. 1) is reduced to three steps in this development (Fig. 4): concrete experience and reflective observation are combined in **turning effect**; abstract conceptualization is conducted in **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 (Wankat and Oreovicz 1993, p. 287). The three stages are exploration, term introduction, and concept application.

Turning effect. The students work in teams through a series of questions using the think-pair-share structure. The key question about the cause of the clockwise rotation leads to a measure of the turning effect, which is defined as **moment** (Figs. 5 and 6). Defining concepts after some exploration corresponds to term introduction in the scientific learning cycle and is advocated by Arons (1990, p. 111) with the precept: “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 of all forces acting on the bar in equilibrium is zero about any point in the plane: (1) they draw a

FBD of the bar and compute the reaction (see **Manual** in Fig. 8); (2) they select moment centers and compute the net moments; for example, they select the moment center Q, draw moment arms, and receive feedback for incorrect answers (see **Note** in Fig. 9) -- generally we provide one clue before giving the solution; and (3) they are asked for the conditions of equilibrium of a body in a plane. The answer (Fig. 10) shows Euler's extension of Newton's conditions of equilibrium for mass points to finite bodies.

Testing. In the last stage of this learning cycle, the condition of moment equilibrium is used (Fig. 11) to test the balance of the seesaw (case 1) and to determine a state of balance (case 2).

Reflection

The inductive approach leading to the discovery and development of concepts requires time and patience. It may seem inefficient as compared to the traditional lecture approach, but it is not if efficiency is measured in terms student learning (Barr and Tagg, 1995; Flammer, 1987; Wankat and Oreovicz, 1993, p. 288). This is confirmed in a study led by the U.S. Department of Education which shows that U.S. 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." (Sanchez and O'Harrow, 1997)

> *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** (1996)

Acknowledgment

Funding for this work was provided by the NSF to SUCCEED (Cooperative Agreement No. EID-9109053). SUCCEED is a coalition of eight schools and colleges working to enhance engineering education.

References

AAHE, "What Research Says about Improving Undergraduate Education: Twelve Attributes of Good Practice," *AAHE Bulletin*, April (1996)

Arons, A. B., *A Guide to Introductory Physics Teaching*, John Wiley & Sons (1990)

Barr, R.B. and J. Tagg," From Teaching to Learning -- A New Paradigm for Undergraduate Education," *Chang*e, 27 (6), November/December (1995)

Cross, K. P., "Effective College Teaching," *Prism*, ASEE, October (1991)

Felder, R.M. and L. K. Silverman, "Learning and Teaching Styles in Engineering Education," *Engineering Education*, 78 (7), April (1988)

Flammer, G.H., “A Model of Learning and Learning Efficiency,” *Engineering Education*, 77 (5), February (1987)

Habel, Margaret, *CEUT Faculty Workshop*, Virginia Tech, February 10 (1996)

Halpern, D.F., “Using the Principles of Cognitive Psychology as a Pedagogy for Higher Education,” *AAHE Summer Academy*, Breckenridge, Colorado, July (1996)

Kolb, D., *Experiential Learning*, Prentice Hall, Englewood Cliffs, NJ (1984)

Laws, P., “Workshop Physics: Learning Introductory Physics by Doing It,” *Change*, 20 July/August (1991)

Lyman, F., “Think-Pair-Share: An Expanding Teaching Technique,” MAACIE, *Cooperative News*, 1, 1 (1987)

Sanchez, R. and R. O’Harrow, Jr., “U.S. Struggles to Solve its Math Problem: Time, Teaching Style Appear to Be Factors,” *The Washington Post*, January 23 (1997)

Senge, P. M., *The Fifth Discipline, The Art & Practice of The Learning Organization*, Currency Doubleday (1990)

Stice, J. E., “Using Kolb’s Learning Cycle to Improve Student Learning,” *Engineering Education*, 77 (5), February (1987)

Terenzini, P. T. and E. T. Pascarella, “Living with Myths, Undergraduate Education in America,” *Change*, January/February (1994)

Truesdell, C., *Essays in the History of Mechanics*, Springer-Verlag (1968)

Wagener, U. E., “Changing the Culture of Teaching,” *Change*, July/August (1991)

Wankat, P. C. and F. S. Oreovicz, *Teaching Engineering*, McGraw-Hill, (1993)

Biographical Information

Siegfried M. Holzer, Alumni Distinguished Professor of Civil Engineering, is involved in developing effective learning communities.

Raul H. Andruet, an engineering graduate student, has been developing multimedia software for five years. He is completing his dissertation on “2-D and 3-D special finite elements for analysis of adhesively bonded joints.”

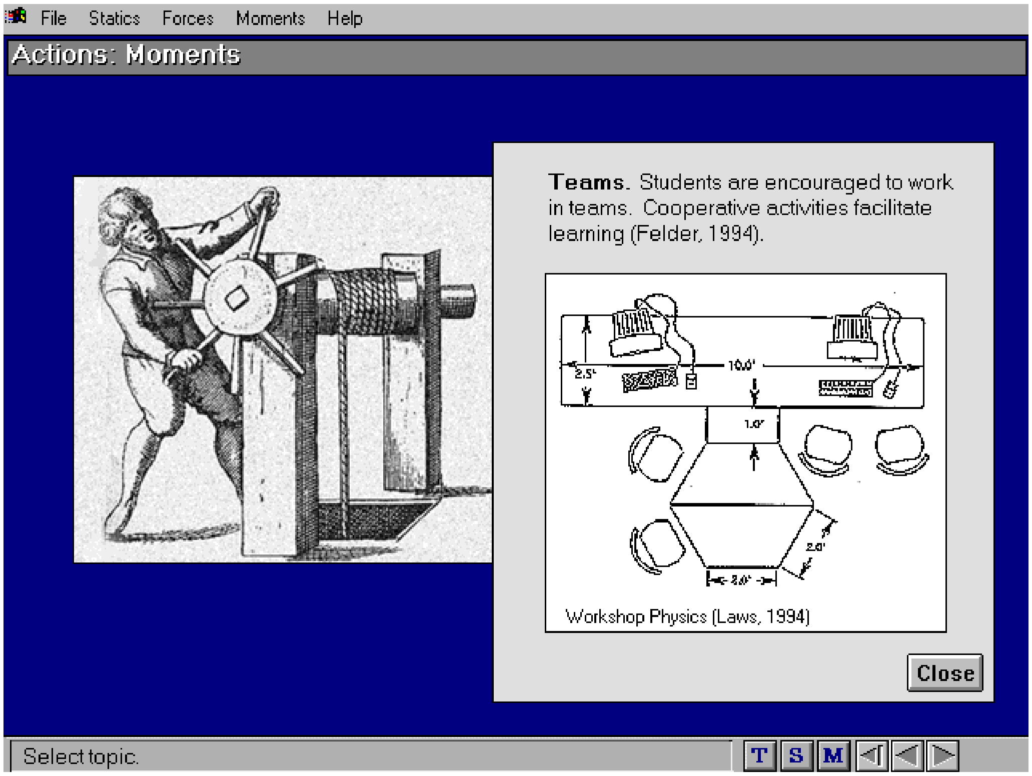

Figure 2. Workshop Physics (Laws, 1994)

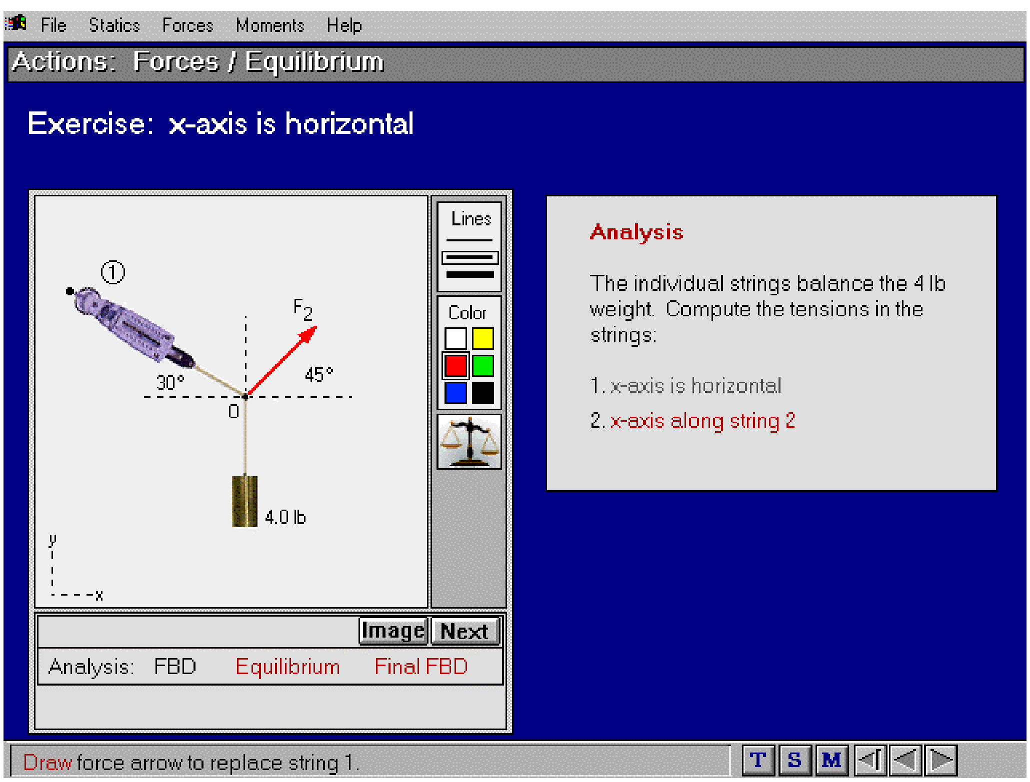

Figure 3. String Support

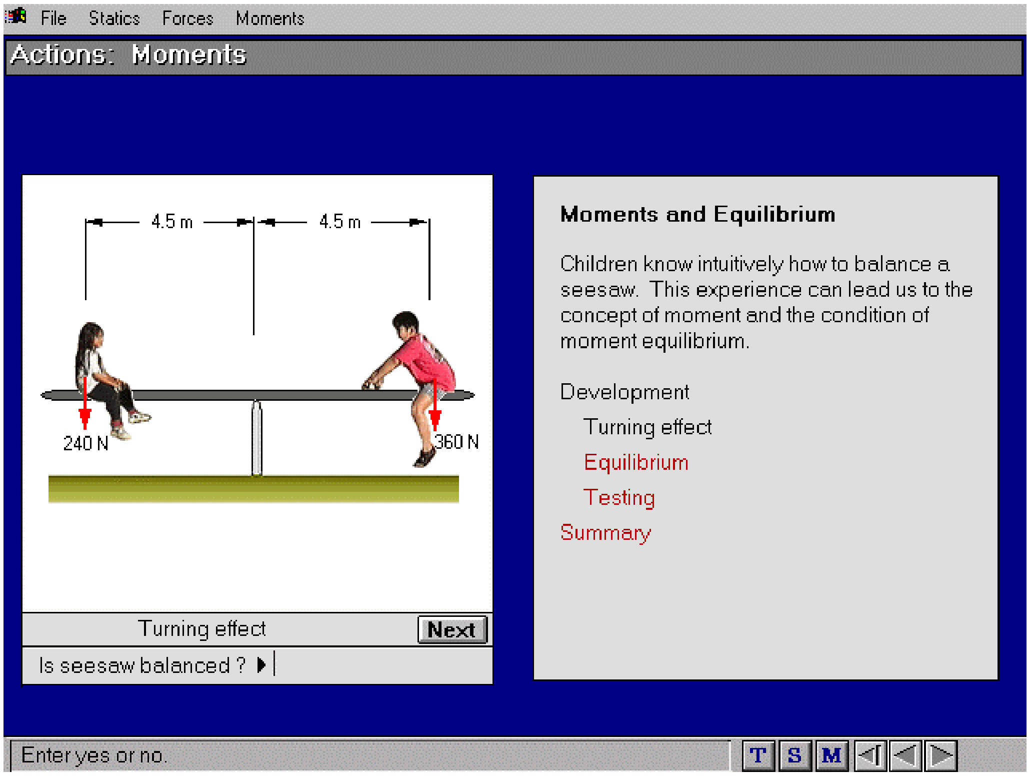

Figure 4. Concept Development

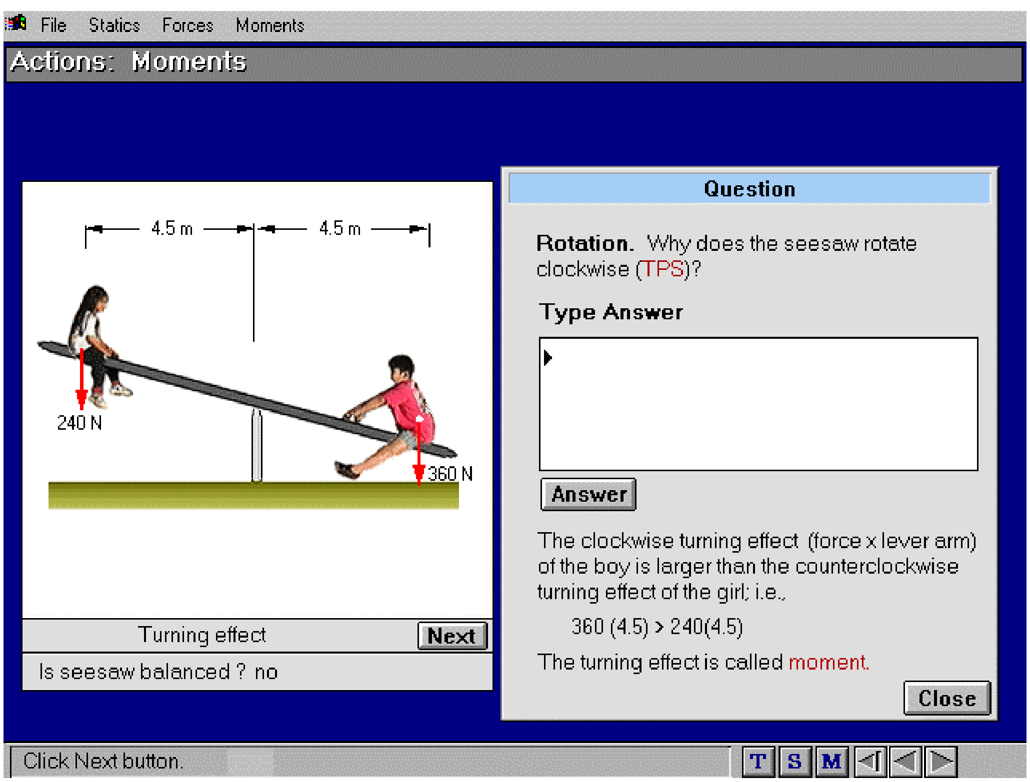

Figure 5. Turning Effect

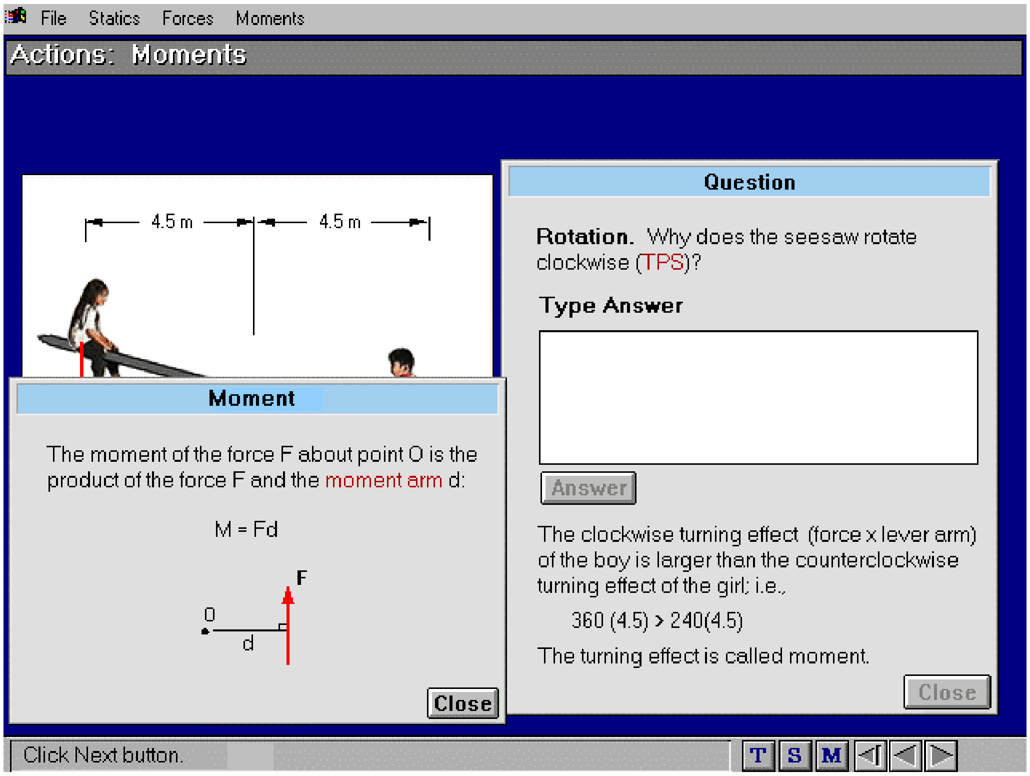

Figure 6. Definition of Moment

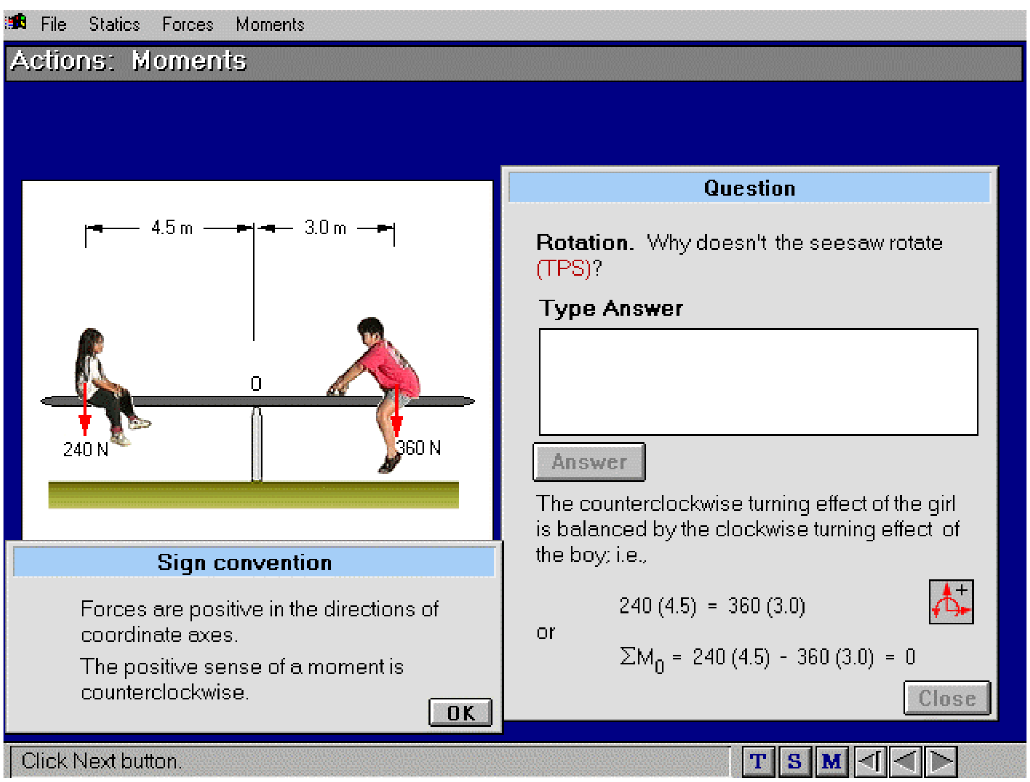

Figure 7. Balance Condition

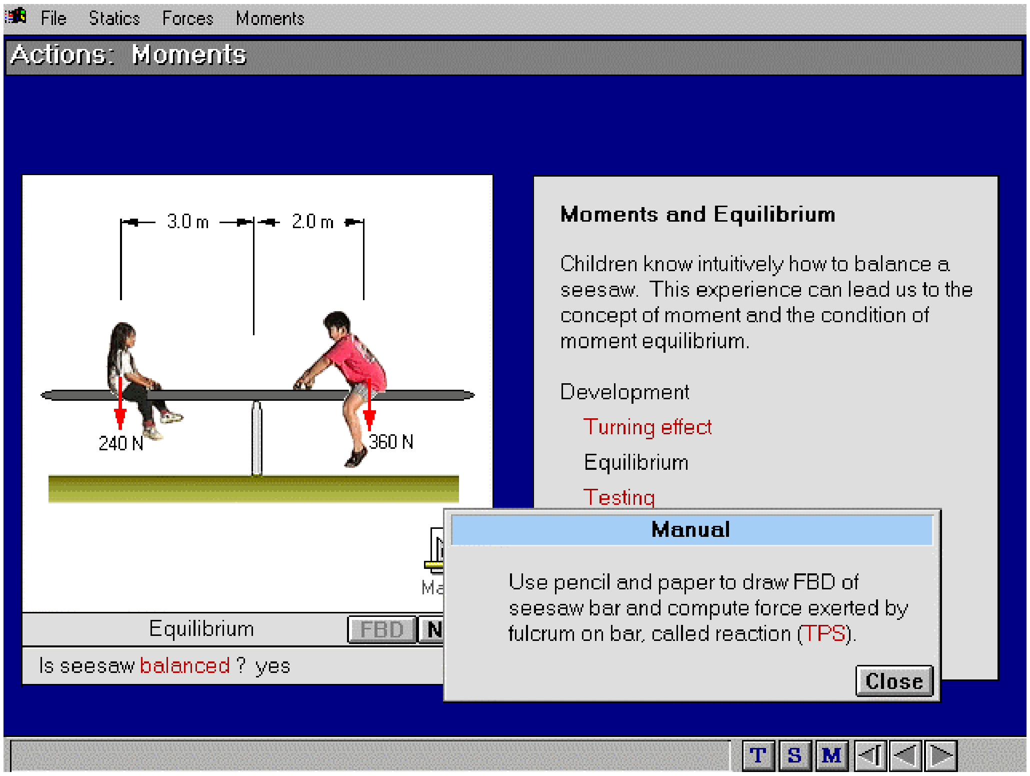

Figure 8. Manual Activity

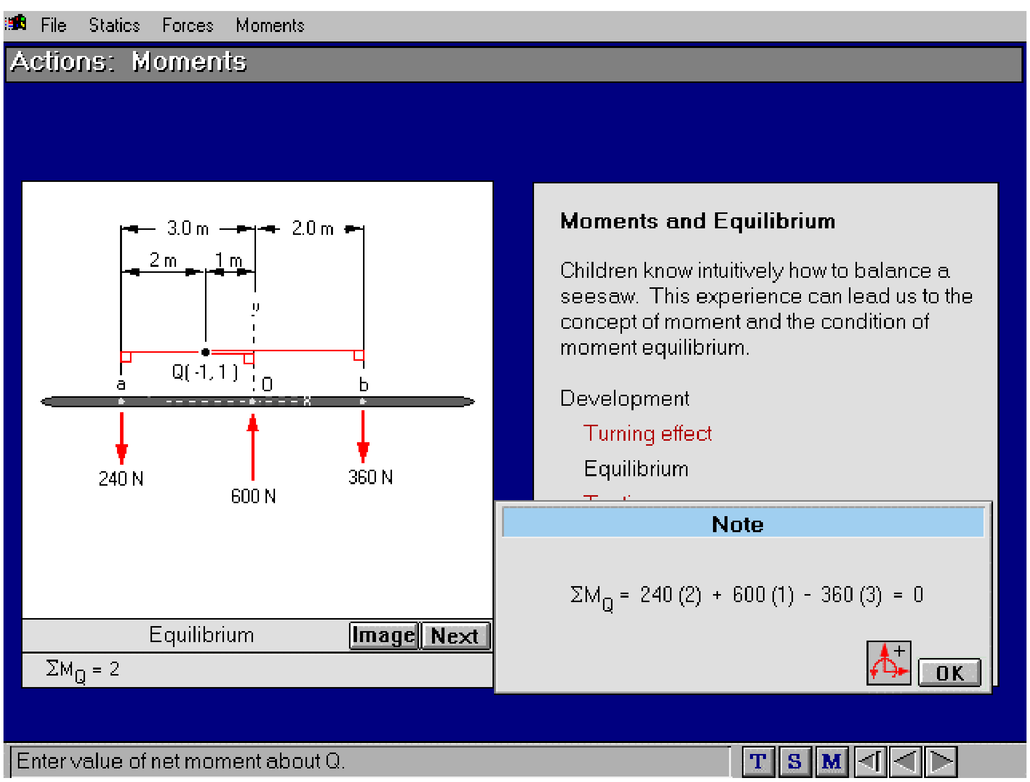

Figure 9. Moment Center Q

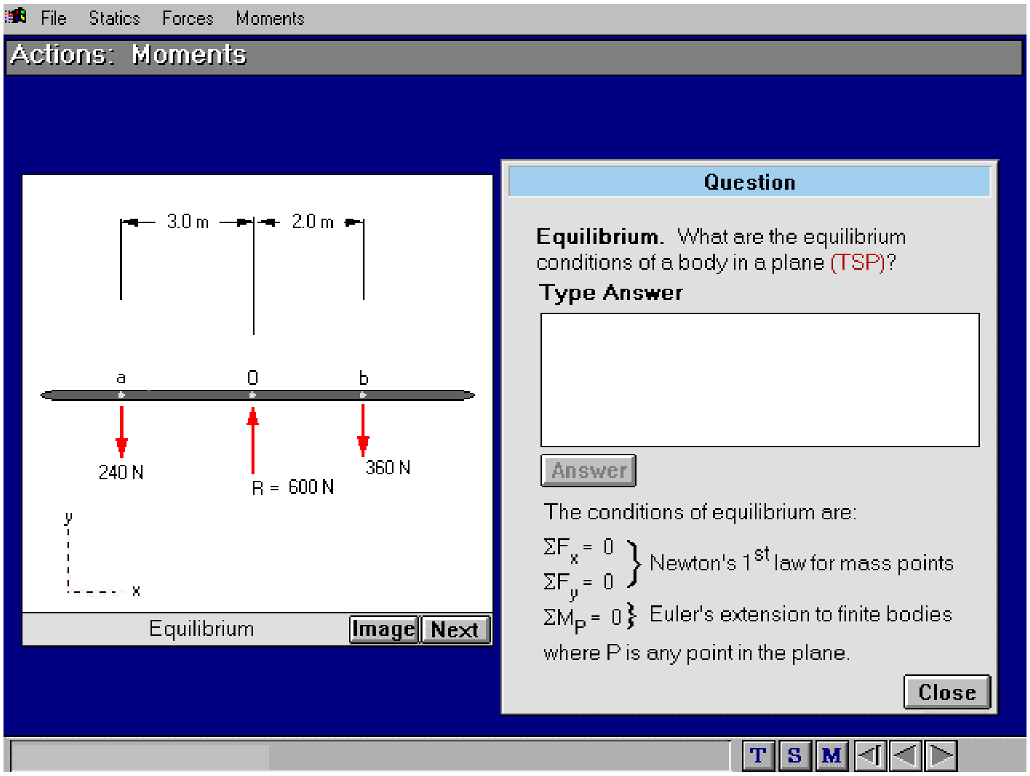

Figure 10. Conditions of Equilibrium

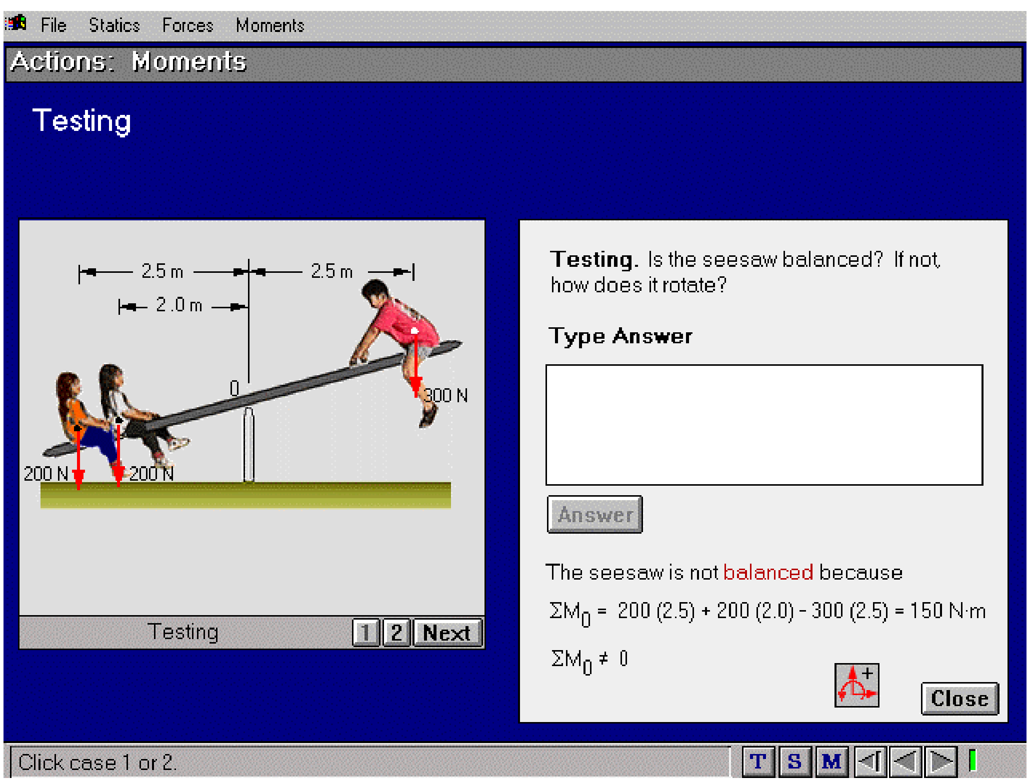

Figure 11. Testing Balance Condition