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01 Nov 1994

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Recommended Citation

R. E. Flori, "Computer-Aided Instruction in Dynamics: Does It Improve Learning?," *Proceedings of the 24th Annual Frontiers in Education Conference (1994, San Jose, CA)*, pp. 77-81, Institute of Electrical and Electronics Engineers (IEEE), Nov 1994.

The definitive version is available at <https://doi.org/10.1109/FIE.1994.580473>

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Computer-Aided Instruction in Dynamics: Does it Improve Learning?

Ralph E. Flori, Jr.

INTRODUCTION

Since 1992 we have been developing and testing "BEST" Dynamics software (Basic Engineering Software for Teaching Dynamics) with the goal of transforming how engineering dynamics is taught here at the University of Missouri--Rolla. Four semesters of classroom use of the software in its various stages have taught us many lessons: The students like the software. It isn't easy to carve out class time for its use in class. It is a delicate feat to get the students to do what appears to them to be additional outside-of-class work. It isn't easy to get older faculty to use the software in their classes. But these issues relate mostly to how we *teach* with the software. The time has come, however, to address a much more important issue: What are the students *learning* from the software?

Students have noted in surveys that the software enhanced their visualization and problem solving skills, but to what degree? What cognitive skills are being cultivated? What specific features of the software or its classroom implementation affect cognitive development? These and related questions are important to address in order to bring some reason to bear on the hyperbole that often accompanies the development and use of educational software. This paper will introduce the reader to "BEST" Dynamics and its classroom implementation, it will raise questions concerning the cognitive impact of the software, it will attempt to classify the type of learning environment used in "BEST" Dynamics, and it will give some new directions that we are taking based on our observations and experiences.

ABOUT "BEST" DYNAMICS

At the University of Missouri--Rolla we have undertaken a project whose original goal was to transform how we teach our two credit hour engineering dynamics course. We are using Asymetrix Corporation's ToolBook authoring software which runs under Windows to develop teaching/learning modules that are visually attractive, easy-to-use, flexible, and comprehensive.

The project was initiated in July 1992 with one faculty member and two students. Through May 1993 we had developed 12 to 15 different problem simulations. As

modules were developed, they were tested in the classroom, to which student response was favorable. During the summer (1993) three faculty members and three students received campus support to enlarge and expand the project. The original simulations were completely revised and more than thirty additional problems were added. To date we have completed about 45 different simulations. These problems, together with some basic theory, span two dimensional kinematics and kinetics of both particles and rigid bodies. The software includes theory (equations, definitions, diagrams, and simple animations), simulations (with parameters that can be varied), and example problems (any of the simulations can be stopped at an arbitrary position and solutions investigated). Selected "BEST" Dynamics problems are pictured in Figures 1 through 6.

RESULTS FROM CLASSROOM USE OF "BEST" DYNAMICS

Our original goal in developing "BEST" Dynamics was to transform how we *teach* engineering dynamics. We use "BEST" Dynamics in the classroom to accompany lectures; the modules are also available for student out-of-class study, problem solving, and review. In the classroom, a projection system is set up in a corner adjacent to the blackboard, the room lights are low, and the blackboard is illuminated with track lights. In a typical class, we answer homework questions, develop new theory, and work example problems. At any time, but usually while discussing homework or working example problems, we can run a simulation on the screen to illustrate a concept, and turn to the blackboard to write the governing equations. This has worked effectively in the classroom and has been well received by students. They've noted that it helps them especially in visualization of the problems. In a class like dynamics, the study of motion and the forces associated with it, a visualization tool such as "BEST" Dynamics accomplishes what texts, blackboards, and words cannot.

While *in-class use* of "BEST" Dynamics seems to have been successful, it has been our observation that the students' *out-of-class use* of the software has not been as beneficial as we had hoped. We assign about twelve computer homework assignments per semester. Students are asked to make up and input their own numbers (or to



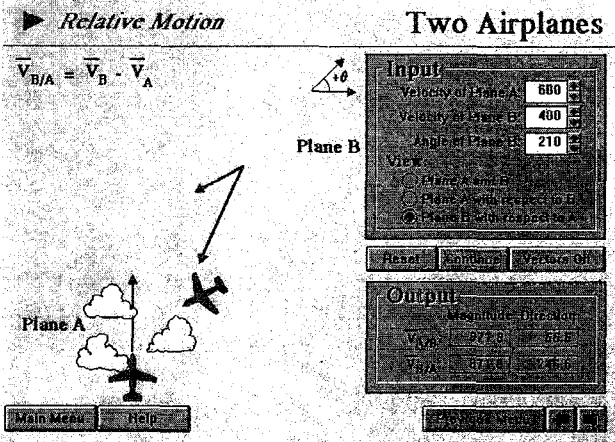


Figure 1: Relative Motion of Two Airplanes

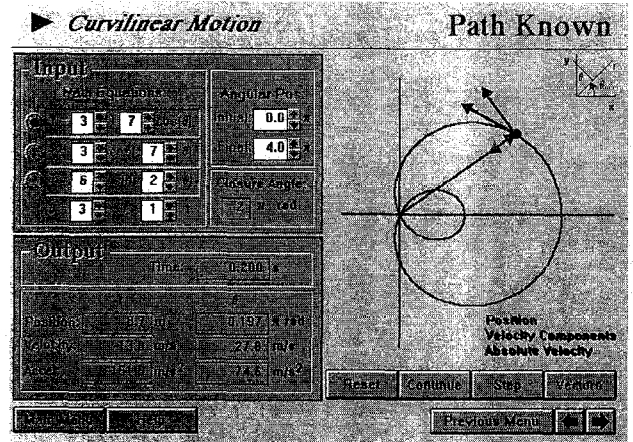


Figure 2: Particle Curvilinear Motion in Polar Coordinates

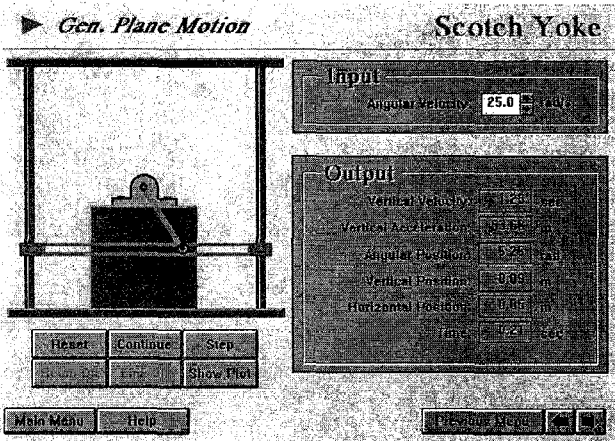


Figure 3: Scotch Yoke

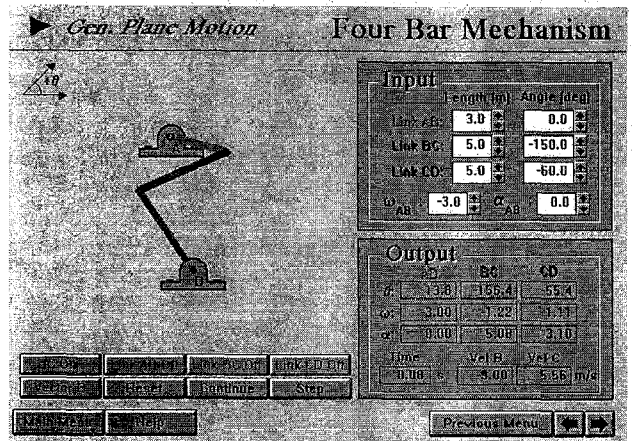


Figure 4: Four Bar Mechanism

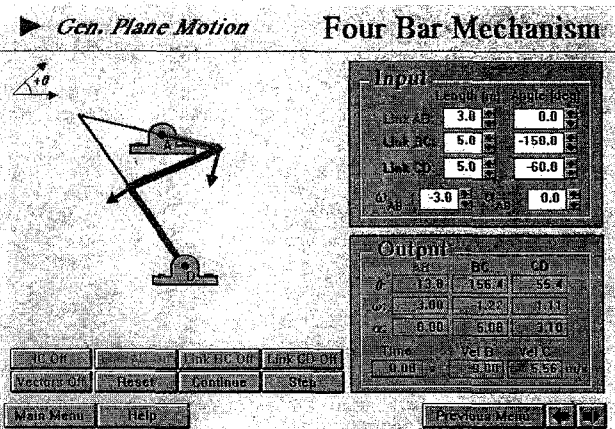


Figure 5: Four Bar Mechanism with Vectors and Instantaneous Center Options Activated

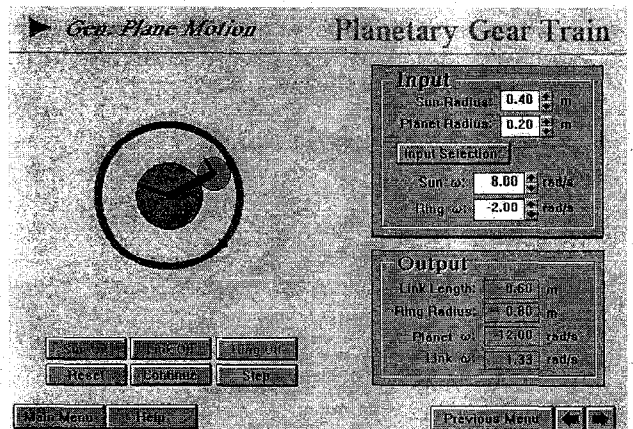


Figure 6: Planetary Gear Train

input numbers from a similar problem in the text) for a given computer problem, view the simulation, and verify the computer output at a particular position with their own calculations. We built considerable flexibility and generality in the "BEST" Dynamics package with the hope that, when given problems such as these, students will create and synthesize mechanisms, explore various configurations and, by so doing, learn more. Most of the students used the software in this way and gained some visualization ability, but they did not, we believe, gain a significantly greater (a) understanding of the conceptual elegance of dynamics, or (b) problem solving ability.

Students appear to approach problems without a well-formed mental model of the relevant fundamentals of dynamics. Their goal seems to be to "get the right answer" as quickly and with as little thought as possible. What they discover, however, is without careful thought, they are less likely to get the correct answer. Frustrated, they haphazardly change things, and some begin to resent the computer problems. Nearly all ultimately "get the answer", and they all appreciate seeing the mechanisms in motion, but they do not appear to extract all the (we believe, valuable) benefit that the software contains.

FOCUS ON LEARNING--NOT TEACHING

Educators often begin to develop and/or use educational software because they wish to improve how their subject is *taught*. It must be remembered, however, that the ultimate measure of a teacher, a class, a software package, or a text is the quality of *learning* that takes place. What cognitive skills are developed by the students? Are they able to retain, understand, and actively use the knowledge and skills set forth in the software or in the class? The focus must be on *learning*.

With modern computer technology, it is easy to put vastly more information in a software package than will ever be accessed by a student. Just having content in the software, even if the author thinks it is obvious, is no guarantee that the student will learn it. Software needs more than content. It needs an interface, a learning environment, that contains subject information, "phenomenaria" to aid in visualization, and creative opportunities and task management support for the learner. The interface is pivotal. Content is wasted, it remains unencountered and unappreciated without an interface that will help the learner to discover the content, to understand it, to appreciate it, to see it applied, and to apply it him/herself in meaningful contexts.

LEARNING ENVIRONMENT LESSONS

Our current development efforts are focused at building a learning-enhancing interface that will interact with the student and use our current "BEST" Dynamics modules as

a "kernel" or "engine". The details of the approach we are taking are given later in the paper. How we arrived at this approach follows from taking a careful look at what "BEST" Dynamics in its current form offers the student in the way of a learning environment. We have learned much from an article by David N. Perkins (1992a) giving the following five general facets of a learning environment:

(1) **Information Banks:** These are sources of information. In a conventional classroom the teacher, the text, and reference materials fulfill this role. Computer technology can make much more information available, for example through CD-ROM; hypertext links can be used to shorten the access paths to the information.

(2) **Symbol Pads:** A symbol pad is a "blank sheet of paper", or more generally, a "surface for the construction and manipulation of symbols." The purpose for these is to support the students' short term memories as they record ideas, develop outlines, formulate and manipulate equations, and so on. In the traditional classroom, these are the student's notebook. In the modern classroom, this could be a word processor and/or drawing program on a laptop computer.

(3) **"Phenomenaria" (or "microworlds"):** A simple example of a "Phenomenarium" in a primary school classroom is the aquarium or terrarium, "microcosms of the aquatic and terrestrial biological worlds." The purpose of a phenomenarium is for "presenting phenomena and making them accessible to scrutiny and manipulation." Other examples of these are assembled scientific apparatus illustrating concepts of physics or chemistry, simulation games modeling war or negotiations between nations. SimCity, an imaginary municipality, is another example. Our software, "BEST" Dynamics, is an example of a phenomenarium. The examples that come with Knowledge Revolution's "Interactive Physics" or "Working Model" are also phenomenaria.

(4) **Construction Kits:** These are collections of components that a learner can assemble in some way in order to promote learning. In primary school, these may be Legos, Lincoln Logs, Tinker Toys or Erector Sets. In advanced schooling, these may be apparatus for a chemistry, physics or engineering laboratory. These could also be commands in a programming language, or equations in a symbolic math environment. Knowledge Revolution's "Interactive Physics" or "Working Model" are construction kits. "BEST" Dynamics possesses some of the qualities of a construction kit in that it gives the user considerable flexibility in specifying parameters on most of its simulations.

(5) **Task Managers:** "These are elements of the environment that set tasks to be undertaken in the course of learning, guide and sometimes help with the execution of those tasks, and provide feedback...." The teacher, the text and the learner share the role of task managers in varying proportions. The degree to which the learner



participates as a task manager is highly dependent upon the style of instruction. In computer-aided instruction, the software can function as a task manager.

EXAMPLE LEARNING ENVIRONMENTS

Having given above the five facets of learning environments, it should be noted that all five are not always present. For example, the typical classroom...

"...features principally information banks (the teacher, the text), symbol pads (notebooks, scratch paper, worksheets), and task managers (the teacher, written instructions).... Learning occurs through telling students about things (information banks rather than [students learning through observing] phenomenaria); that students cannot manage much of their own learning (little task management left to them); that working out problems rather than constructing entities is primary (symbol pads rather than construction kits)." (Perkins, 1992a)

"In contrast, many more progressive learning environments give center stage to phenomenaria and construction kits." Our "BEST" Dynamics is an example of a phenomenarium which simulates many types of particle and rigid body motion while allowing the student to vary input parameters. Knowledge Revolution's Working Model and Interactive Physics are examples of construction kits which give the teacher or the student open-ended tools for constructing a wide range of mechanisms. "In both cases, learners bear much more responsibility for their own task management than in more conventional settings, and the role of the teacher shifts to something more like that of a coach"(Perkins, 1992a). A particularly valuable aspect of such software to engineering education is that "learning [is] 'situated' [or 'anchored'] in authentically complex and meaningful contexts." (Brown et al., 1989)

CONSTRUCTIVISM, MENTAL MODELS AND COGNITIVE LOAD

Constructivism, a currently popular view of how students learn, holds that the learner is a "constructor" of his or her own knowledge.

"Central to the vision of constructivism is the notion of the organism as 'active'--not just responding to stimuli, as in the behavioristic...[tradition], but engaging, grappling, and seeking to make sense of things."

"In particular, learners do not just take in and store up given information. They make

tentative interpretations of experience and go on to elaborate and test those interpretations...until a satisfactory structure emerges.

"If learning has this constructive character inherently, it follows that teaching practices need to be supportive of the construction that must occur. The constructivist critique of much conventional educational practice is that it is not especially supportive of the work of construction that needs to be done in the minds of the learners." (Perkins, 1992a)

We believe that the general ideas (not every idea, however) of constructivism form a valuable model for engineering educators. The name itself appeals to engineers as it suggests that the learner is actively involved in a building process. The learner should build a mental model (or "schema") of the phenomena in question which, in our case, is dynamics. At the outset of a class, students will have a prior mental model of dynamics that likely is naive, flawed, and fragmented. The aim of any instruction is to challenge the resident model and to facilitate the learner in forming, testing, modifying, retesting, and cementing a new mental model so that the learner becomes competent and skilled.

How is this done? The learner should be exposed to a (preferably, rich) learning environment consisting of the five facets given previously. Especially valuable are phenomenaria (like "BEST" Dynamics) and construction kits (like Knowledge Revolution's Working Model), because these place the learner directly in the position of having to make sense of the subject. These also expose the learner to real-life examples, so that learning is "situated" or "anchored" in authentic, complex, and meaningful contexts. These also challenge the learner to engage in "understanding performances", which are tasks such as explanation, extrapolation, and evidence giving, cognitively more complex activities than simple recall of fact or smoothly executing a simple "drill-and-practice" exercise.

Phenomenaria and construction kits, as valuable as they are, can impose a rather steep "cognitive load" on students. This is partly by design because quality instruction aims at exposing inconsistencies in the learner's naive models to "challenge the student to form better models or at least to ponder the merits of alternative models presented by the teacher." But how do students respond to such conflict? One response is the learner may simply "ignore or hardly note the conflict...; ...they learn to play 'the school game' for tests and assignments." Another common response is the learner will face the conflict but will founder because he or she is ill-equipped to handle it. What is needed here is "scaffolding" or "coaching", as for instance in the "cognitive apprenticeship" model." "It is the job of the...teacher (or interactive technology) to hold learners in



their "zone of proximal development" by providing just enough help and guidance, but not too much." The "scaffolding" can be provided through timely availability of information (from an "information bank") and through carefully-designed task management which helps the learner to manage their interaction with the content of the software.

A LEARNING-ENHANCING INTERFACE FOR "BEST" DYNAMICS

We plan to design and build a learning-enhancing interface onto "BEST" Dynamics that will incorporate our current simulations and theory as an "engine" or "kernel". This interface will interact extensively with the student, it will query the student on key principles and evaluate the student's response. It will lead the student through special cases, stop the simulation at certain points, and ask the student questions about what is shown.

We plan to select several topics spread throughout the course including both particles and rigid bodies, kinematics and kinetics. For these topics we will create a multifaceted environment which will include:

- (a) Basic theory (an information bank), linked via hypertext to problems and other locations where students may need it.
- (b) Exercises and interactive problems (generally, more basic than our present simulations) requiring application of elemental theory. Feedback will be provided for the student in response to their answers/inputs. As much as possible, these exercises will be formulated as "games" giving the student opportunities to score points, with incentives for insightful solutions and/or speed of solution.
- (c) "About" information for each of the present simulation problems explaining the significance of the problem and a sketch of the solution approach.
- (d) Questions and exercises reviewing the "About" information.
- (e) The computer will be able to hyperjump to these simulation problems and show special cases demonstrating particular aspects of theory. Students will have opportunity to make observations of these special cases, to manipulate the underlying equations, and to record their observations on paper (or on the computer).
- (f) The student will be given a symbolic pad (a computer-based notepad) that can be solely for his/her own use, or at times we will ask him/her to answer certain questions, or to recast theory or principles in his/her own words, and print it out to hand in with a problem (or save it to a file to which the teacher has access). We are particularly interested in students being able to articulate the theory underlying a problem; this is important evidence as to whether they understand a given problem, and of course the exercise itself is a valuable learning device.

We mention above several examples where the student will answer questions, participate in scored games, and work various exercises. All of these may be cast into either a practice or a quiz mode. The questions/exercises in either mode will be of comparable difficulty, but the quiz mode will write their score to a master file to be accessed by the teacher. These scores will become part of the students' overall quiz grade in the class.

The overarching goal will be to reinforce the fundamental principles of dynamics in as many ways as possible. The basic equations and principles of dynamics are few in number. We want to create an interface that will be carefully and intelligently constructed so as to engage the student in activities that support his/her personal development of mental models of the material being learned. Sufficient exercises and creative opportunities will be provided so that students will retain, understand, and be able to apply this knowledge and skill to meaningful problems.

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