WHAT ABOUT SOFTWARE TO TUTOR PHYSICS STUDENTS IN CANADA?

by Hans Laue

The article describes the use of software in the teaching of physics at post-secondary institutions in Canada. After a brief history of computer-assisted instruction that establishes why the current period is auspicious, the article presents a general survey of software used in Canadian physics departments with a focus on software that can be used for tutorial purposes. The article examines why tutorial software might be helpful in the teaching and learning of physics concepts and introduces the Canadian web-based computer tutorial system MAP (Modular Approach to Physics) as an example of such software. It is explained how MAP supports the best practice understandings of physics education research as listed in a recent draft document on Canadian first-year physics courses by the Division of Physics Education. The article concludes with the suggestion to share tutorial software country-wide and suggests ways in which this might be done.

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INTRODUCTION

The history of computer-based instruction in physics is almost as old as the electronic computer itself, and as computers have evolved so has educational software. The PLATO [1] learning environment using main-frame computers was initiated at the University of Illinois in 1961. The arrival of personal computers in 1977 brought about widespread development of computer-assisted instruction in physics. Alfred Bork wrote a paper in 1981 [2] in which he describes many of the unique possibilities for computer-assisted instruction opened up by personal computers and outlines a vision of which only parts have been realized so far. The themes in computer-assisted instruction are persistent and were addressed early [3]. From the late 1980's to the mid-1990's, several tutorial systems and courseware items were developed in Canada [4] on the early Macintosh platform, including the fairly comprehensive CALiPH (Computer Assisted Learning in Physics) tutorial system [5], in use for a while at several Canadian universities and colleges and a college in India. They became largely obsolete technologically with the development of the more powerful "multi-media machines" and world-wide web (WWW) beginning in the first half of the 1990's.

In the author's opinion, current technology allows creating instructional software that is "good enough". A future generation of software may incorporate a significant amount of artificial intelligence and thus be able to interact with individual users to a higher degree than present software. However, because of the quantum jump in technological advance that occurred in the 1990's, with its corresponding jump in potential for software, it may be time for another look at the tutorial software available. Moreover, there is reason to hope that current web-based software will not become technologically obsolete in the near future. The WWW is just too attractive a medium.

The article surveys what software is currently being used in the teaching of physics at Canadian post-secondary institutions. Although the focus is on software for tutoring physics students, I thought it would be helpful to include in the survey the use of all kinds of software in order to put the tutorial software into better perspective. There is no sharp line of demarcation anyway between software that can be used for tutorial purposes and other software. A Canadian software project with which the author has been intimately involved during the last seven years, MAP (Modular Approach to Physics), and MAP's relevance to curriculum goals, are described in some detail. The article concludes with a call for a country-wide collaboration on tutorial software development and exchange of such software.

SURVEY OF THE USE OF SOFTWARE IN THE TEACHING OF PHYSICS

In collecting information for this article, I wrote to 42 physics departments at institutions of post-secondary education in Canada, 40 universities and two four-year colleges. CEGEP colleges were not included in this survey. In the first instance, I wrote to members of the Division of Physics Education or Department Chairs. I received answers from 28 departments, in some cases from more than one person. I am very pleased about this level of response and wish to thank all people involved for taking the time to collect the information and to write to me.

In my survey of physics departments, I included six sets of questions. Not all of these questions may have been optimally articulated. Since the responses I received may have

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been conditioned by how the questions were formulated, the following exposition is organized under headings identical to the questions in the survey. In my summaries of responses to the questions, I use "department" for brevity's sake when I really mean "respondent from a department". The opinions reported are those of the respondents, and do not necessarily reflect a departmental consensus.

1. *Are there any courses in your department supported by tutorial computer software? If so, which course(s) and what kind of software is it? Is the software web-based or CD-based? Is it text with graphics or is it animations, possibly interactive animations? Is there a web address where I could access the software?*

The majority of departments (16) indicate that they are not using tutorial software while the remaining twelve departments list some use of tutorial software. A few of the departments not using tutorial software indicate that they prefer to use human tutors.

The twelve departments that do use software of tutorial character use a wide range of software, often more than one product in one department. Most widely used, by four departments, is CAPA (Computer Assisted Personalized Approach), an on-line student assessment system from Michigan State University started in 1992 that provides immediate responses to student answers. A Web student interface was established in 1995. The Overview on the CAPA homepage [6] states: "With CAPA, an instructor can create and/or assemble personalized assignments, quizzes, and examinations with a large variety of conceptual questions and quantitative problems." One department writes that "CAPA eliminates the use of TAs to manually grade assignments, so freeing them for human interaction with the students." However, another department indicates that "it is not at all obvious that the overall labour involved is lower for the CAPA problems unless the classes are very large - I estimate above 200." Two departments that were using CAPA became somewhat dissatisfied and either decided that the "computer-answered questions should always be supplemented with a few written problems to be handed in" or discontinued using it in some of their courses.

Starting in 1999, CAPA was extended to LON-CAPA, a LearningOnline Network of post-secondary institutions (including one Canadian university) and high schools that provides a full-fledged course management system with exchangeability of content among participating institutions via a shared content repository. LON-CAPA is open-source free software that can be modified under the terms of the GNU general public license. Detailed information about the LON-CAPA system is available from its website [7] The physics department at the participating Canadian university is currently experimenting with LON-CAPA "as Chemistry is moving to it." The department comments "It seems to have an unnecessarily complex interface and needs a heavy server compared to the older CAPA system. The main advantage I can see so far is that the instructor can generate a collection of problems to choose from by typing in keywords and assemble problems from a wide variety of sources, some of which provide more challenging problems than the older CAPA library. Most problems are still of the plug&chug variety though."

CAPA is not a true tutorial system, although, like any problem solving activity, it can be used for tutorial purposes. The same is true for some, but not all, of the other tutorial-like software that one or more of the twelve departments use, in lectures, sometimes in labs, or as a recommendation to the students to work with on their own. Among this software are the following products:

- Walter Fendt's applets [8] (two departments),
- Ron Greene's "Physics Illuminations" tutorials [9] (one department),
- David Harrison's FLASH animations [10] (one department),
- Wolfgang Christian's Physlet applets [11] (one department)
- Mastering Physics [12], Pearson's on-line physics homework and tutorial system, (one department),
- ActivPhysics [13], a collection of applets, animations, and inquiry-based tutorials available on-line with Knight, *Physics for Scientists and Engineers*, 1st ed., and Young and Freedman, *University Physics*, 11th ed. (one department),
- iLrn [14], Thomson's integrated testing, tutorial and class management system (one department),
- Just-in-Time-Teaching (JiTT) [15], a teaching and learning strategy based on the interaction between web-based study assignments and an active learner classroom (one department),
- Tutorials on CD accompanying a textbook (three departments),
- World-in-Motion [16], a physics video motion analysis program on CD (one department),
- On-line tutorials developed at the University of Guelph [17] (one department),
- Questions That Engage Students in a Socractic-dialogue Help Sequence from the University of Illinois [18] (one department),
- Socratic questions developed by Jim Hunt at the University of Guelph for the Guelph distance education course Phys 1020DE [19] (one department),
- David Sénéchal's mechanics applets [20] (one department),
- Physics demonstrations developed at St.Mary's University [21] (one department),
- Algebra review tutorial developed at the University of Manitoba [22] (one department,
- MAP (Modular Approach to Physics) [23,24,25] (three departments).

This certainly is quite a variety of products. Details on these products are available on their websites or, for the MAP software, in a section below.

Many instructors use web pages or course management software (see Item 4 below) to publish lecture notes, assignments, assignment solutions, etc. Easy access to lecture notes and assignment solutions, perhaps with embedded links to simulations and other web-based information, certainly has tutorial value.

2. *If there is tutorial software in use in your department, how is it integrated into the course(s)?*

There seems to be little integration of tutorial software into physics courses. Most instructors who use tutorial software in a course do not interweave it with the work required in the course, but leave it up to their students to work with the software.

Distance education courses tend to employ a tighter integration of software, e.g., Athabasca University's Physics 200 [26] or the Guelph distance education course Physics 1020DE, which is password protected. Brian Martin at the King's University College offers a physics course integrating parts of the MAP tutorial material. Dave Patton at Trent University is offering an astronomy course with WebCT-mediated integration of Astronomy Online, a set of interactive exercises and quizzes. The course requires exercises "which include tasks such as observing and commenting on a video clip or animation, … , and reading and commenting on additional content such as text, figures, tables, etc."

In the author's opinion, the manner in which tutorial software is integrated into a course is critical for the effectiveness of the software. In his experience, students will perceive software that is merely recommended to be extra material for which they don't have the time. (The same is true for recommended reading.) Some suggestions for effective integration of software into a course are made in the section on MAP.

Exempt from the danger of insufficient integration of software are tools like Maple, Mathematica, and Python when used in computational physics courses in which they are integral parts of the course.

3. *Are there individuals in your department who have developed tutorial software in the past or are currently doing so? If so, who are they?*

More than half (16) of the responding departments are not developing tutorial software and do not indicate that they ever have done so. Software has been developed in the past in most or all of the remaining twelve departments, but in only two or three something akin to tutorial software is currently being developed. A greater effort seems to be going into presenting course materials on-line, either via personal web pages or via course management systems, into developing data acquisition and presentation software, and developing programs and materials for computational physics courses.

Computational physics courses, both at the first-year and upper-year levels, are offered in several departments. Such courses use computer algebra software like Maple [27] and Mathematica [28] or a programming language like Python [29]. Normand Mousseau at the University of Montréal has written extensive notes [30] on Python. Richard Enns at Simon Fraser University and George McGuire at the University College of the Fraser Valley have written a book on nonlinear physics with Maple [31] Bill Baylis at the University of Windsor has written an introduction to problem solving with Maple.[32] In a general sense, these materials have tutorial character also.

4. *Is there any other kind of software support of courses in your department, e.g., course management software like WebCT or Blackboard or laboratory software for the evaluation of data?*

Software that is not specifically tutorial software is used more widely than strict tutorial software. One can distinguish several kinds of "non-tutorial" software: (a) course management systems and personal websites, (b) data acquisition and processing systems, (c) simulations and videos for motion analysis, (d) mathematical computation systems and programming languages, and (e) lecture presentation software. Their use will now be described in turn.

(a) The majority of departments uses course management systems to do one or several of the following: post lecture notes, quizzes, assignments and solutions, course calendar, web links, on-line chat, and individual grades and class grade distributions. One department uses a course management system (WebCT) for Just-in-Time Teaching [15] by Gregor Novak et al. in combination with Mazur-type "Peer instruction" [33] during the lectures. The most commonly used course management system, used by at least 14 departments, is WebCT [34]. Data obtained by the Carleton department show that a greater fraction of students was successful in a course (fewer failures and withdrawals) when the course was offered using a course management system (which was WebCT in this case) than otherwise. The reason may be that students pace themselves better when such a system is used. The department is currently experimenting with the Moodle course management system [35], which is free and open-source. One department is switching to the Desire2Learn system [36]. A few departments use course management systems provided by textbook publishers [12,14]. Still others create their own course management systems, either because of costs involved with commercially available systems or because they are dissatisfied with these systems. A comparison of a large number of course management systems is available on the Edutools site [37].

(b) For the laboratories, the use of software systems for the acquisition, analysis, and presentation of data is common. The following systems are being used, and in some departments more than one of these are employed:

- PASCO's DataStudio [38] in junior labs (three departments),
- National Instruments' LabVIEW [39] in senior labs (six departments),
- The MathWorks' Matlab [40] (two departments),
- Vernier's Logger Pro [41] (one department),
- In-house data analysis tools (several departments),
- Microsoft's Excel spreadsheet (several departments),
- Prentice-Hall's LogicWorks [42] for electric circuit simulations (one department).
- One department is thinking about replacing Matlab by Python [29]

(c) A few departments supplement laboratories with an analysis of simulations and videos:

- World-in-Motion [16] (one department),
- MSC.Software's Interactive Physics [43] (two departments),
- In-house digital videos of motions (one department).

(d) Mathematical computation systems are used in several departments, both for data analysis in the labs, and for assignment solutions and course work in general:

- Maple [27] (seven departments)
- Mathematica [28] (three departments),
- about Matlab and Python see Point 4(b) above.

(e) Several departments mentioned that they are using PowerPoint in their lectures. The use of this presentation tool may be more widespread than the survey indicates. Two departments are using a personal response system (PRS) [44]. Such a system makes it possible to collect student responses to in-class questions and thus facilitates an active-learning environment including Mazur-style peer instruction [33]. Some textbook publishers are also offering such systems.

5. *Has there been a discussion in your department on software support of courses and, if so, what were the opinions expressed? Or is the use of software left up to the individual instructor?*

The typical scenario is that on a department-wide basis the use of software is discussed little or not at all and that, even if there is such discussion, any use of software is left up to the instructor. There are a few exceptions where departments as a whole have decided to use assignment systems, course management systems, and data acquisition systems. However, tutorial systems are rarely considered and never adopted on a department-wide basis. In a few departments the instructors of large first-year courses have made collective decisions about the use of software, but tutorial systems have not been adopted collectively. At a number of institutions, commercial software, e.g., a course management system, is made available institution-wide, but departments typically leave its use up to their instructors, who often decide not to use it.

6. *Personally, if you were teaching a first or second year course, would you want to have software support for such a course and, if so, what should this software be like and how would you integrate it into the course? How about upper-level courses?*

Different departments employ a range of teaching strategies and are prepared to use software to support these strategies. Among the 17 departments that responded to Question Set 6, there is some dissatisfaction with on-line software that presents plug&chug style questions and a preference for tutorials with human tutors and assignments with at least some long-answer questions. Other departments seem fairly comfortable with their teaching strategies and present use of software, as described in Points 1 and 4. As to computer-assisted tutorials, several departments indicate that they prefer to use human tutors because current tutorial software either does not work very well or does not give sufficient individualized feedback.

As to upper-level courses, several departments indicate that they like to use simulations, e.g, the CUPS (Consortium for Upper Level Physics Software) simulations [45] or in-house simulations. Of course, computer algebra systems and programming languages as mentioned in Point 3 are appropriate at this level. One department makes the suggestion to adopt, on a department-wide basis, "a single package that allows one to collect and analyze data as well as do computational work. Igor Pro [46] comes to mind. Using a single package across courses would allow students to become very proficient with it … By the time they got to their senior year they would be quite expert …"

In addition, I am quoting the following general statements:

- The use of such resources are to be added as a complement to existing and proven teaching strategies … not to replace them!
- Such software would be mostly for developing intuition about solutions of difficult equations.
- I think that really good, interactive problem-solving software that gives APPROPRIATE "hints" when requested could be extremely useful.
- … these packages [the tutorial computer packages] allow us to free graduate tutorial support for other positive uses like help centers and higher level tutorial support.
- It should have a very clean interface, a short learning curve for faculty and students, and support open-ended student inquiry as well as mastering concepts.

In the author's opinion, the MAP computer tutorial system meets all of the criteria laid out in the last bullet. Some details on MAP are presented after examining how computer tutorials can help in the teaching and learning of concepts.

WHY COMPUTER TUTORIALS?

I was stimulated to develop a computer tutorial system during a sabbatical in 1986 when F. Reif told me about his research into difficulties students had in applying basic concepts like acceleration [47] after successfully passing a first-year physics course. Such students could learn in a twenty-minute Socratic dialogue what they had failed to learn in their year-long physics course. From my own experiences in teaching large first-year classes I was aware of the difficulties learners had and I also knew that usually not enough skilled tutors were available to interact with students in Socratic fashion. I thought that a well-designed computer tutorial program could provide a first step in tutoring that would be accessible to large numbers of students and get them involved with the issues. Students may well have questions that a computer-tutorial does not answer, and it is at this point that human tutors become essential and can provide the "higher level tutorial support" mentioned in one of the bullets above.

This led to the development of the computer tutorial system CALiPH [5] by R.B. Hicks and myself. Before getting too far into the project, we tested the effectiveness of the kind of modules we were planning to create with a pilot module on acceleration and tension in Fletcher's Trolley, a subject that presents well-known pitfalls that, if not addressed carefully with individual students, will persist on final examinations. Pictures of a MAP applet on Fletcher's Trolley are shown in Figs. 1 and 2. The free-body diagrams in the two figures show that the tension in the string depends on whether the system is held at rest or is in motion.

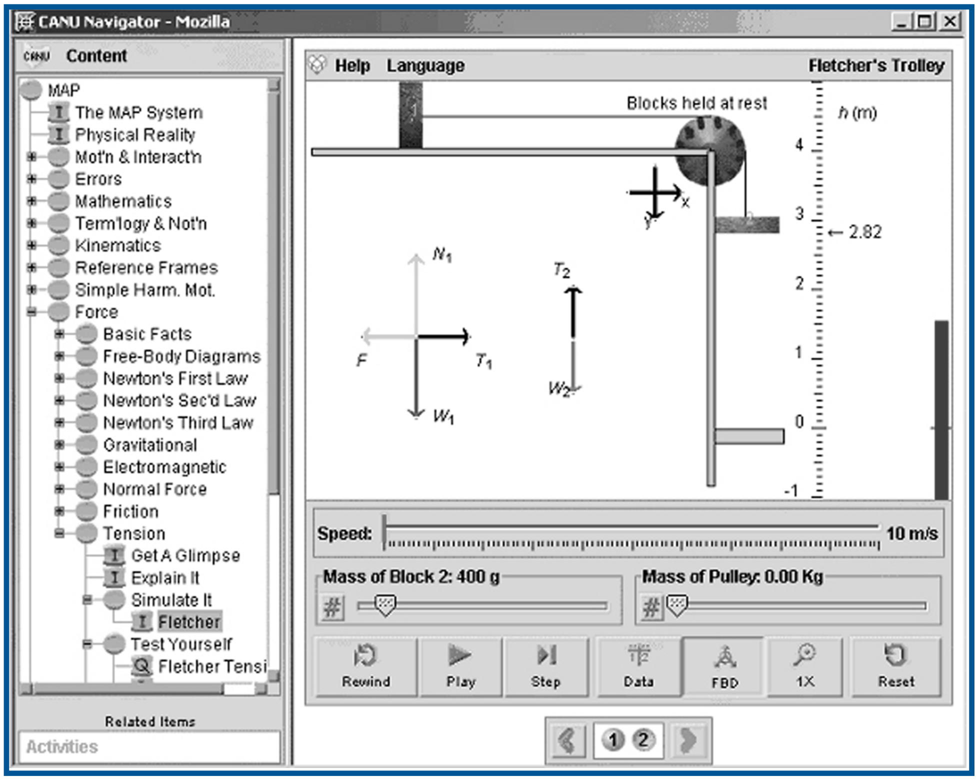

Fig. 1 CANU Navigator with Fletcher's Trolley Held at Rest

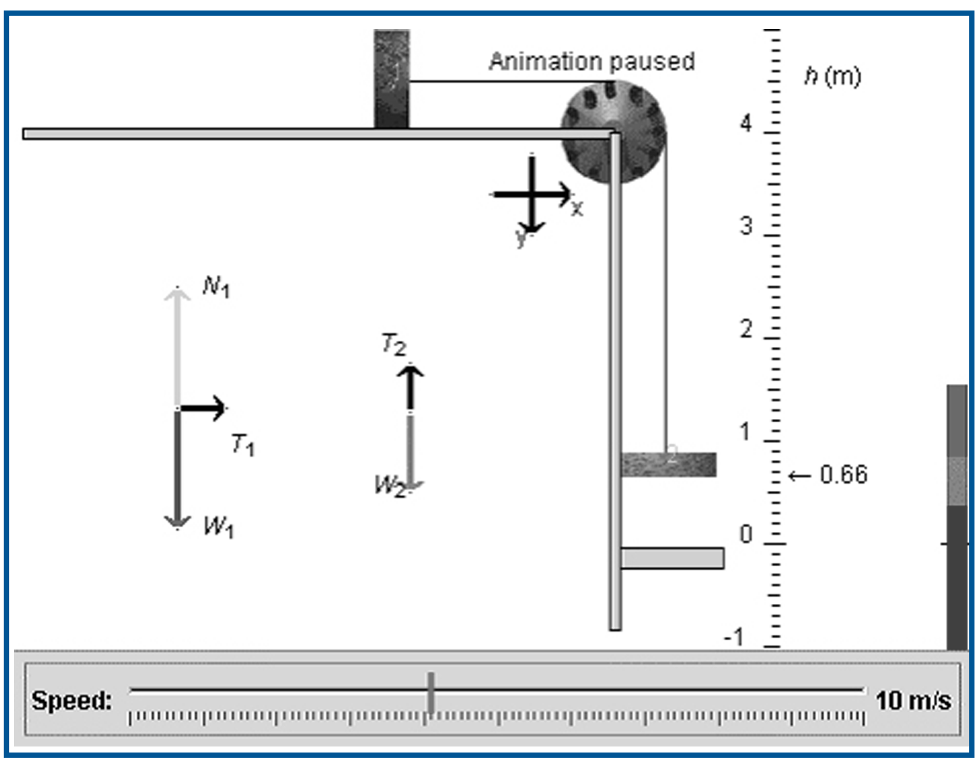

Fig. 2 Fletcher's Trolley in Motion

The test with the pilot module showed significant improvement in student performance as a result of working with the module without additional human tutorial help [48]. It convinced me that properly designed computer tutorials can be effective in helping students understand and apply basic physics concepts. I do not think that concepts can be derived inductively from laboratory experience. In contrast, interactive computer simulations can provide a constructivist approach to concept learning by allowing "experimentation with concepts", e.g., through free-body diagrams that change in response to actions by the learner as in Figures 1 and 2.

THE MAP COMPUTER TUTORIAL SYSTEM

The MAP project started in 1997 as a collaborative project between several Alberta universities and colleges, with funding by the Alberta Government's Learning Enhancement Envelope [49]. Since 2001, Alberta Learning [50] has supported the MAP project by funding both the creation of new and the enhancement of existing applets for use in the Physics 20-30 high school curriculum in Alberta. As a result, more than 60 applets were made available to Alberta Learning. These applets are available also as part of the MAP tutorial system. They can be set to either an English or a French user interface, as required by the Alberta curriculum. MAP currently includes basic concepts from error analysis, mathematics (notably vectors), kinematics and dynamics including rotational motion, fields and potentials, electric circuits, oscillations, and optics.

MAP (Modular Approach to Physics) is modular in two respects: (a) the content focuses on concepts, which are the building blocks of any introductory physics course and (b) it uses a content management system (to be distinguished from course management systems like those mentioned above) that lets instructors organize the material so that it fits their course.

With respect to requirement (a), research [33,47] has shown that students often emerge from introductory physics courses with a deficient understanding of basic concepts and their correct application to realistic situations, in spite of good grades. Requirement (b) is important because software that is cast in stone tends to collect dust on the shelves. For software to get used by students it must be an integral part of the course, and this can happen only if it fits the course. Thus, MAP uses its own content management system (CANU) that (i) allows instructors to assemble their own software package and (ii) allows students to navigate through the content arranged by their instructor.

At this point you may want to have a look at some MAP content as delivered by the CANU Navigator. Go to the MAP site [23], and open the course MAP. (Note that MAP is both the name of a course and the name of the entire project.) The hardware and software requirements are described under System Requirements on the Start page of MAP. Note that two navigation modes are available, the Tree navigation mode pictured in Figure 1 and an Item Path navigation mode. The mode can be selected by choosing Navigation on the Content menu. A User's Guide is available from the Content menu as well.

After the initial joint planning stage for MAP, the groups in Edmonton (MAP North) and Calgary (MAP South) worked largely independently. MAP South developed CANU and almost all of the content in the present course MAP. MAP North developed applets, Flash animations, video labs, lessons, and questions. MAP North materials still need to be included in CANU. The MAP South applets and Flash animations can be accessed directly, i.e., outside of the CANU Navigator, from the Calgary Applets site [51]. The MAP North applets are available in Brian Martin's PowerPoint presentation at the 2003 Gordon Conference at Oxford [52]. Another MAP North site [25] contains links to actual student tutorials in Brian Martin's physics course at King's University College.

Integration of a tutorial system like MAP into a course is essential for its effectiveness. Possibilities include (a) using MAP-simulations as lecture aids (e.g., a lesson on vector addition could be taught with the applet at MAP/Mathematics/Vectors/Addition/Simulate It/Add Two Vectors), (b) linking assignment and exam questions to MAP (students could be asked to provide calculations, with explanations in terms of physical principles, of the numerical values generated by simulations), (c) linking problems in tutorial sessions run by a human tutor to MAP (with optional access to MAP during such sessions), (d) requiring students to submit, possibly on-line, written comments or explanations related to MAP simulations.

THE CANU CONTENT MANAGEMENT SYSTEM

The content management system CANU (Content Arranging and Navigating Utility) is a Java-applet with three modes: Arranger, Navigator, and Administrator. With the Arranger, an instructor can make up content packages called "courses" which are hierarchically-organized packages of web-based material. If you followed the suggestion in the last section, you already used the Navigator in looking at the course MAP. The Administrator allows assigning passwords and editing privileges to a course. It also allows "exporting" a course in xml format so that another institution can install the course on its copy of CANU by "import-

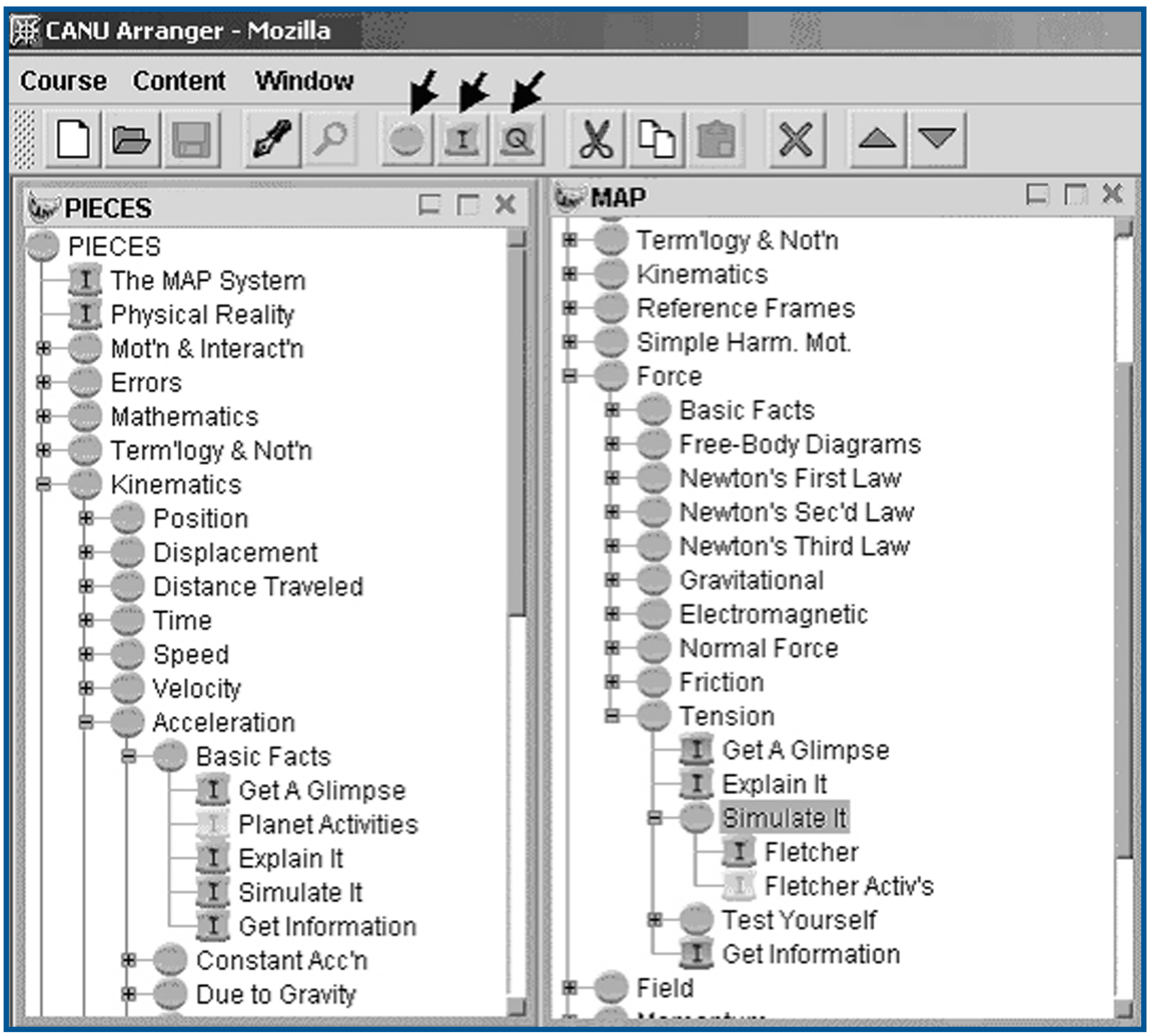

Fig. 3 Building the Course MAP with the Arranger.

ing" the xml file. Note that CANU stores a "course" as a collection of metadata. The actual content files could reside anywhere on the WWW.

In many cases, instructors when building a new course with the CANU Arranger may want to borrow content from the course MAP. The Arranger can display the content trees of two (or more) courses side-by-side as in Figure 3, and items can be moved from one course to the other by drag-and-drop. Instructors can also use the Arranger to add their own or other web-based material to a course or set up questions in the text-matching, multiple-choice, and numerical question formats. To experiment with the Arranger, please get in touch with the author[53] who will sign you on as an instructor. For details on the Arranger, please see the item CANU / CANU Arranger in the course DEMO [23].

CURRICULUM GOALS AND MAP

MAP presents learning materials in a variety of ways, using both instructivist and constructivist approaches. Some of the latter have been pointed out in a conference paper [54]. The item "MAP System" at the beginning of the course MAP describes the ways in which content is presented. Examples of all of these are at MAP / Electric Circuits / Basic Facts [23].

A draft document of August 2004 prepared by the Division of Physics Education lists a number of approaches to physics teaching that "seem well established" from physics education research as reported in the Resource letter by McDermott and Reddish [55]. These include (1) active student learning, (2) a curriculum that concentrates on mastery of a more limited set of important concepts, (3) demonstrations, applications, and experimental work with an early application of concepts, (4) collaborative learning, (5) spiral based approaches, and (6) an enthusiastic classroom atmosphere. MAP supports all of these approaches.

(1) A student working with MAP materials is very much in the driver's seat and in a position to construct his/her knowledge, e.g., by working with interactive simulations and carrying out related activities as in the item on tension in Fletcher's Trolley at MAP / Force / Tension / Simulate It / Fletcher [23].

(2) MAP is designed to help with the understanding and application of concepts. Working with MAP does require a significant amount of time, leading to a more-in-depth understanding in return. Thus, including fewer concepts is advisable.

(3) MAP deals with applications of concepts via simulations and questions.

(4) MAP lends itself to both individual and collaborative learning.

(5) The navigation capabilities of CANU make it easy to follow a spiral approach.

(6) MAP supports instructor enthusiasm in the classroom with well-designed simulations.

OUTLOOK

I would be delighted to see MAP used as widely as possible. MAP is well suited to support courses taught in all kinds of formats: lecture, studio, or distance. MAP would also be very well suited for teacher preparation and professional development. CANU and the course MAP or individual items [56] in this course are available to any Canadian physics department for free except for any expenses incurred in making CANU and MAP or parts of MAP work for a given instructor or department. (This might involve installing a copy of CANU on a local server and transferring content to that server.)

Moreover, both CANU and MAP content could be developed further and such developments shared among the physics community in Canada. I would like to suggest a country-wide collaboration on tutorial software development and exchange of such software. It is too time-consuming and expensive to carry on independent projects of this kind. More importantly, it is an advantage to be able to use the good ideas and work of others.

CANU and MAP content can be modified because they were created in-house from the ground up. A desirable extension of CANU would be inclusion of a testing system with question bank. Specifications have been worked out and, because of the existing structure of CANU, the cost of implementation would not be that great. Another extension of CANU would be a change in the format of its metadata to the SCORM (Sharable Courseware Object Reference Model) format proposed for the storage of learning objects in repositories like CAREO (Campus Alberta Repository of Educational Objects) [57]. A system for "marking up" objects in this format is available in the form of ALOHA (Advanced Learning Object Hub Application) [58]. The link between ALOHA and a repository is under construction.

Eventually, repositories like CAREO or MERLOT (Multimedia Educational Resource for Learning and Online Teaching) [59] in the United States and mark-up software like ALOHA will be available for efficient storage of and access to learning objects. In the meantime, the CANU system together with the MAP content directory on the University of Calgary server could serve as a kind of repository to which everybody has access. CANU's search engine can find items tagged to belong to a certain topic. However, eventually a separate directory on a different server may be desirable along with a copy of CANU on that server. The Division of Physics Education could perhaps take a steering role in all of this.

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Many people have worked on MAP or made constructive suggestions. See Contributors on the MAP Start page [23]. Graeme Irwin and Arend Meetsma programmed CANU and made many essential contributions to its design. Arend Meetsma as leader of the MAP South content applet design team made invaluable contributions to the design of the applets. Jim Hunt incorporated parts of MAP into the Guelph distance physics course and commissioned several applets.

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