THE LEARNING*ONLINE* NETWORK WITH COMPUTER-ASSISTED PERSONALIZED APPROACH (LON-CAPA)

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ABSTRACT
LON-CAPA is a distributed open-source Learning Content Management and Assessment System that provides instructors with a common, scalable platform to assist in several aspects of teaching a course, from lecture preparation, communication among faculty and students, calendar keeping and announcements, to administration of homework assignments and exams. It also enables instructors to create educational materials and to share such learning resources with colleagues across institutions in a simple and efficient manner.

KEYWORDS
Open source learning content and course management system, online assessment

INTRODUCTION

As educational institutions establish an online presence, initial successes are often due to individual faculty members ("early adopters" of this new technology), working long hours to develop material more or less single-handedly. Frequently, they are leaving behind scattered projects, which are of intrinsic value, but of little use for the institution and far less for the larger academic community. “Late adopters” of technology in education might altogether refuse to venture into creating new online educational resources, since the task of creating comprehensive material appears overwhelming in isolation. To address these problems, a team of faculty and staff from Michigan State University (MSU) are creating an infrastructure to provide a course management system (CMS) and resource sharing: the Learning*Online* Network with Computer-Assisted Personalized Approach (LON-CAPA.)

The roots of this system go back ten years, when a group of faculty at Michigan State University started developing a sophisticated online homework and assessment system, with a strong focus on the sciences and mathematics. Soon other universities adopted the system, and it was not long before an informal culture of inter-institutional sharing of such resources developed. To formalize and thus further these efforts, the team added digital library and learning content management capabilities, and the ability for instructors to assemble these resources.

Today (Spring 2003), LON-CAPA has become a distributed Learning Content Management and Assessment System. LON-CAPA and its predecessor systems are serving a total of 12,000 students per semester at MSU alone, and well over 23,000 students per semester system-wide (middle schools: 300; high schools: 500; community colleges: 50; four-year colleges: 300; universities: >22,000). Its shared resource pool currently holds approximately 6,000 original homework and exam problems, 5,000 images, 150 movies, 180 java applets, and 3,000 content pages. Disciplines include astronomy, biology, business, chemistry, civil engineering, computer science, family and child ecology, geology, human food and nutrition, human medicine, mathematics, medical technology, physics, and psychology.

Grants from the Sloan Foundation and from the Mellon Foundation, as the well as the National Science Foundation, and strong support from Michigan State University have encouraged us to pursue the development of this enabling technology. The current leadership team is truly cross-disciplinary: Wolfgang Bauer and Edwin Kashy (physics), Cheryl Speier (business), Deborah Kashy (psychology), as well as educational psychology graduate student Helen Keefe as project manager, computer scientist Guy Albertelli as technical director, and Gerd Kortemeyer (science and mathematics education) as project director.

Over the coming three years, with continued support by the National Science Foundation Information Technology Research program (NSF-ITR #0085921), we plan to transform this system further beyond the boundaries of MSU's campus into a dynamic online collaborative community of faculty authors, commercial publishers, and learners. The LON-CAPA project currently has 18 pilot user institutions. Efforts to couple LON-CAPA with the NSF National Science Digital Library (NSDL) project are under way.

We believe that quickly scaling up this effort while accommodating a diverse user community is crucial to reach a critical mass of educational content, which could transform this network into a nationally used pool of online instructional resources. LON-CAPA provides the infrastructure so that researchers can collect data about online teaching and learning, as well as investigate market dynamics in an online educational economy. We plan to eventually develop this network into the independent "LON-CAPA Academic Alliance," which remains driven by faculty and is part of the academic community, yet at the same time involves commercial partners and contributors.

NETWORK INFRASTRUCTURE

The Learning*Online* Network with CAPA is a geographically distributed network of persistently connected servers at schools, colleges, and universities. Each participating institution needs to contribute at least one server to the network (Figure 1). An institution can set up any number of servers within their domain to scale with increasing workload. The network is set up to be redundant and load-balancing.

The network is logically divided into so-called domains, which usually correspond to one institution, such as Michigan State University, North Dakota State University, or Truckee Meadows Community College. Domains can be used to limit the flow of content and the extent of user privileges. Users can log into any server in the network. For example, an MSU user can log into a server at North Dakota State University using his MSU credentials, and find the exact same environment as on one of the on-campus servers.

To faculty users, the distributed content resource pool of LON-CAPA appears as one large virtual file system, and every resource has a system-wide unique and persistent URL path, under which it can be accessed from any server in the network. As users are browsing this filesystem, they are actually transparently accessing content from servers across the network (Figure 2). As resources are accessed, the network provides transparent resource replication to provide faster access to the resources.

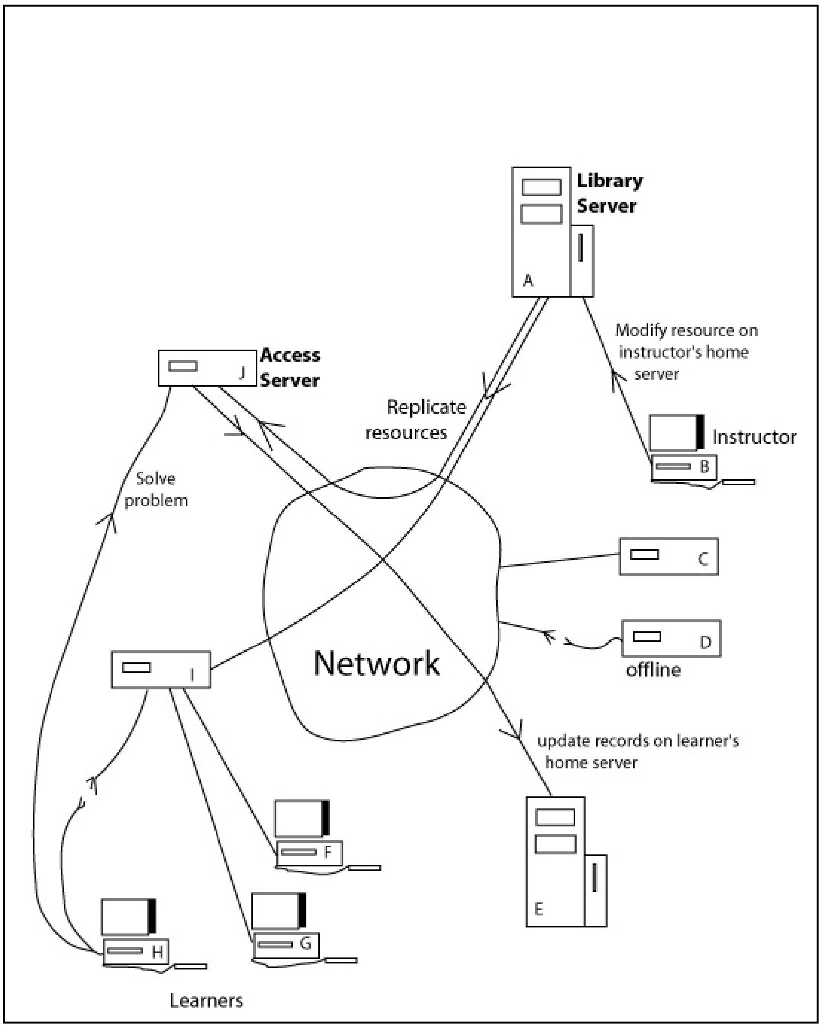


Figure 1. The distributed LON-CAPA network infrastructure

RESOURCE CREATION AND SHARING

Cross-institutional resource sharing has been one of the foremost design principles of the LON-CAPA architecture. Faculty can create learning objects and publish them into a cross-institutional and distributed resource pool (digital library). Such learning objects can be simple paragraphs of text, movies, applets, homework problems, etc.

In addition to providing the distributed digital library with mechanisms to store and catalog these resources, LON-CAPA enables faculty to combine and sequence these resources at several levels: each time a resources are assembled, a new learning object is created, which in itself is re-usable (Figure 3). For example, an instructor from Community College A can combine a text paragraph from University B with a movie from College C and an online homework problem from Publisher D, to form one page. Another instructor from High School E can take that page from Community College A and combine it with other pages into a module, unit or chapter. Those in turn can be combined into online course packs (Figure 3). Faculty can design their own curricula from existing and newly created resources instead of having to buy into a complete off-the-shelf product.

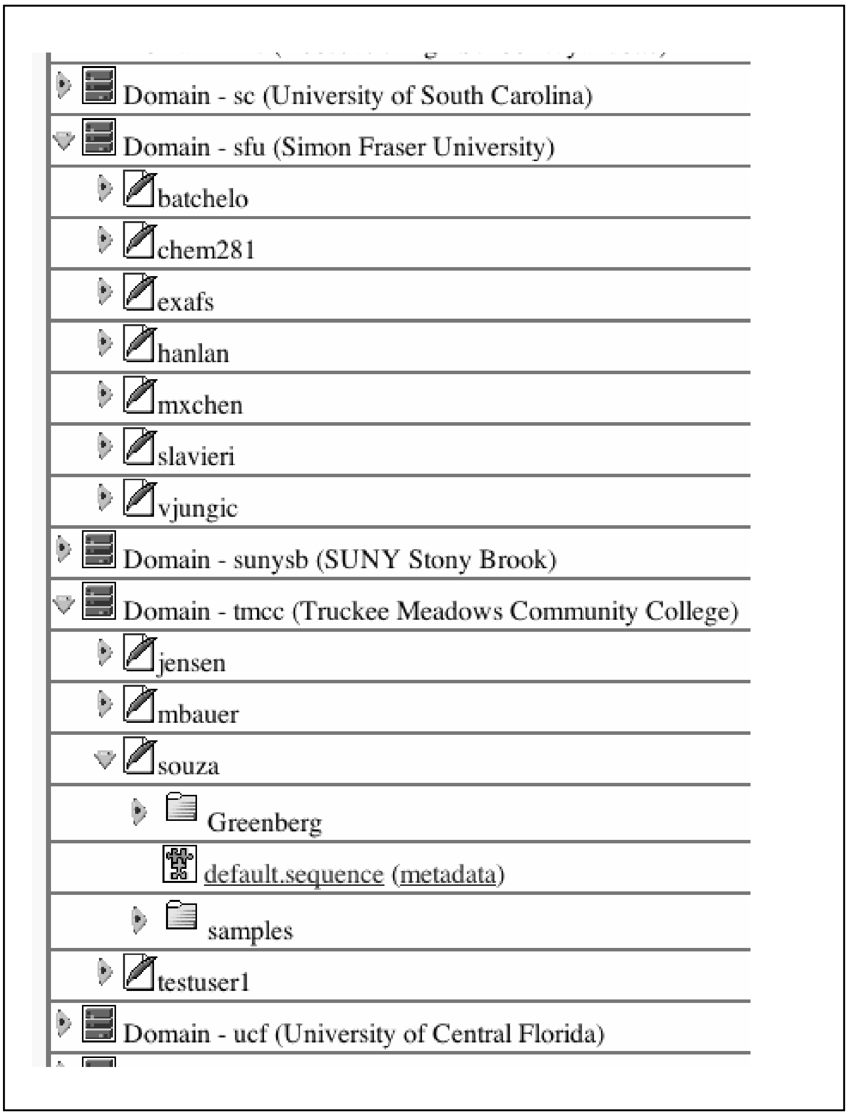


Figure 2. The distributed file system browser interface

Instructors can specify the actual path through the learning resources through combinations of learner choices and system-generated adaptations (for example, if the learner does not pass a test, additional resources may be included). Each learner can have an individualized curriculum according to preferences, capabilities and skills. Figure 4 shows a screen shot of the "Resource Assembly Tool" of LON-CAPA, which is used to combine learning resources (Figure 3). In this particular example, each box represents a resource – a single page, or a whole module or chapter. The arrows represent possible paths through the material, and the box labeled "COND" represents a condition under which the path is available.

LON-CAPA tracks resource usage: every time a resource gets incorporated into a learning object of larger granularity, every time it gets deployed in a course, and every time a learner accesses it, the transaction is recorded and added to the metadata for the resource. The former two events constitute a form of peer-review, with the approval being the adoption of a resource. In addition, data such as degree of discrimination, degree of difficulty, and average number of attempts until mastery of each resource are recorded. Instructors can use this data to make informed decisions when selecting resources for their courses and students.

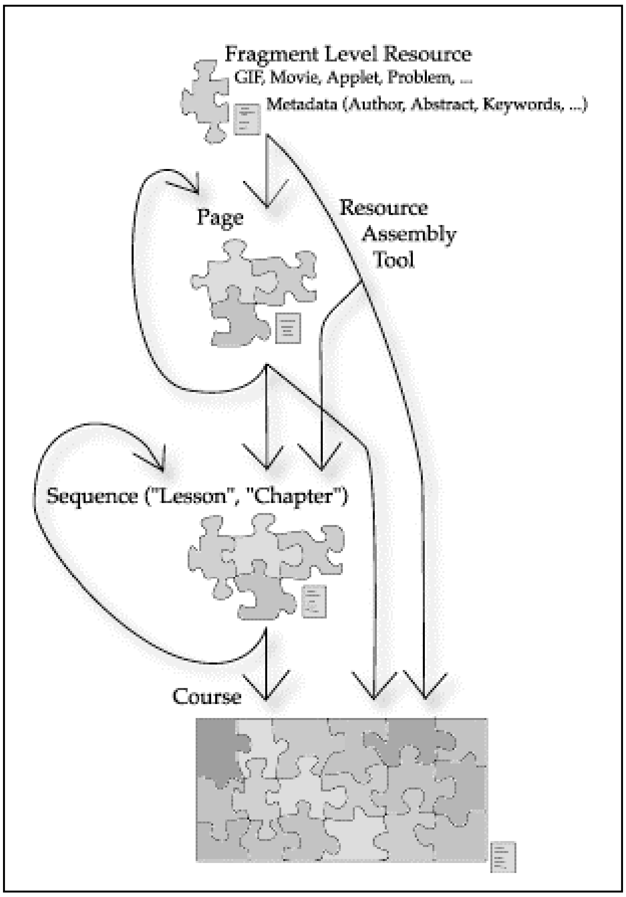


Figure 3. Resource assembly at different levels of content granularity

INDIVIDUALIZING PROBLEMS

With LON-CAPA, an instructor can create and/or assemble individualized assignments, quizzes, and examinations with a large variety of conceptual questions and quantitative problems. "Individualized" means that each student sees a slightly different computer-generated problem. This encourages collaboration between students on a conceptual level, but prevents blind copying of answers. Students are given instant feedback and relevant hints by LON-CAPA and may correct errors without penalty prior to an assignment's due date - this is formative assessment. Adaptive hints can be incorporated which can address particular wrong answers. Problems can include pictures, animations, graphics, tables, links, etc., and available assessment elements include standard components such as radio button and multiple choice, but also numerical, multicomponent numerical, complete support of physical units, symbolic math, image response, dynamic plotting, and random labeling. The writing and development is done through a web-based editor, and facilitated by templates. The generated files are XML-documents, which are processed server-side.

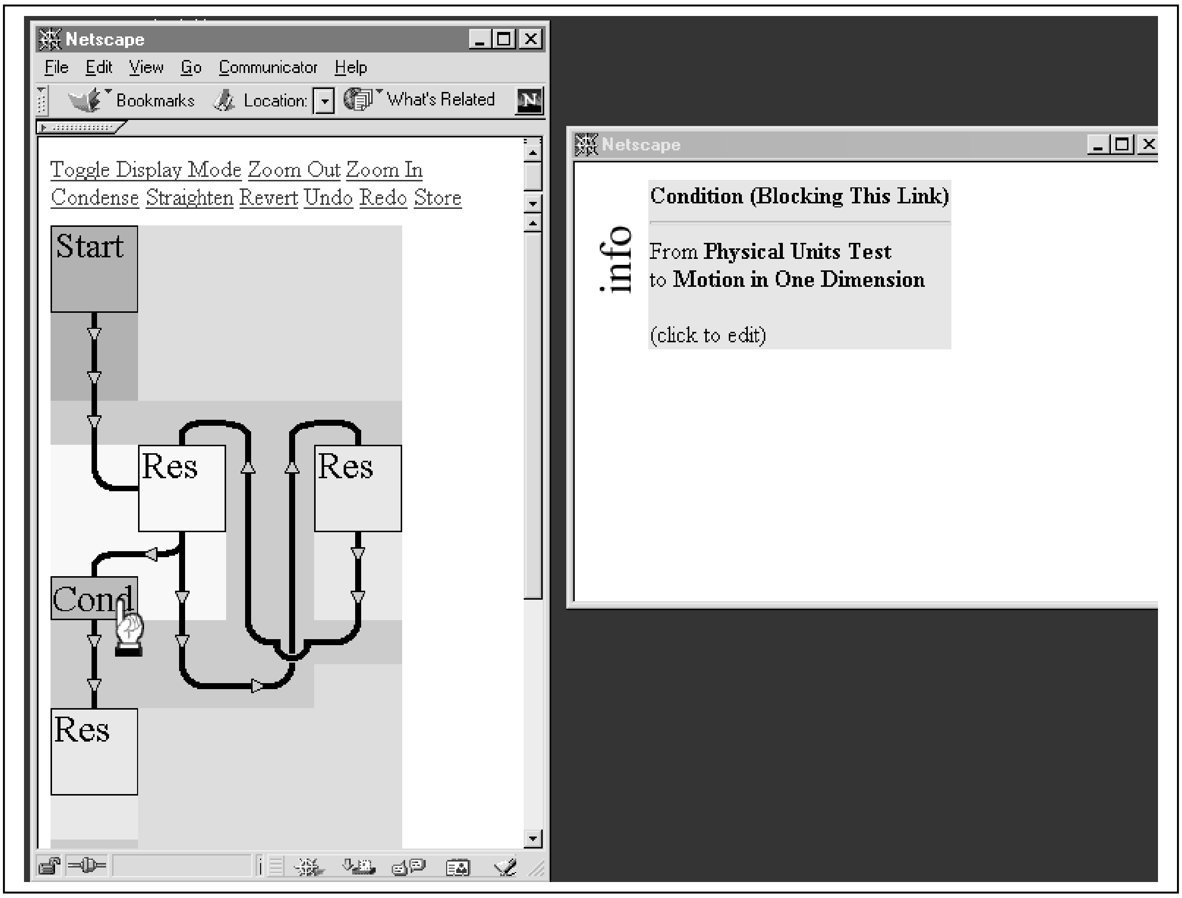


Figure 4. Screenshot of the Resource Assembly Tool

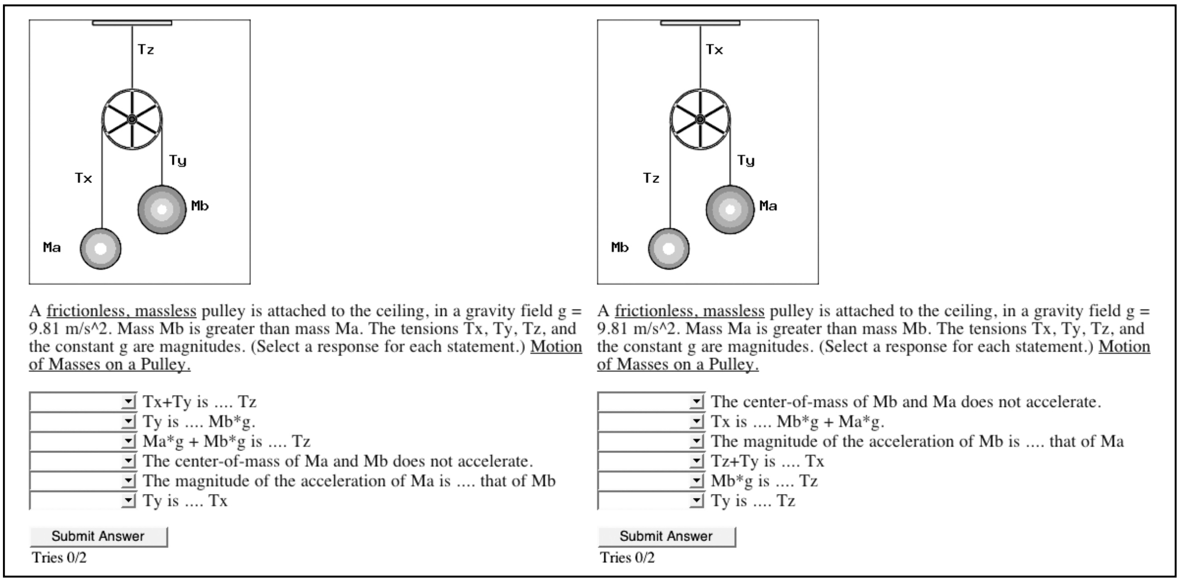
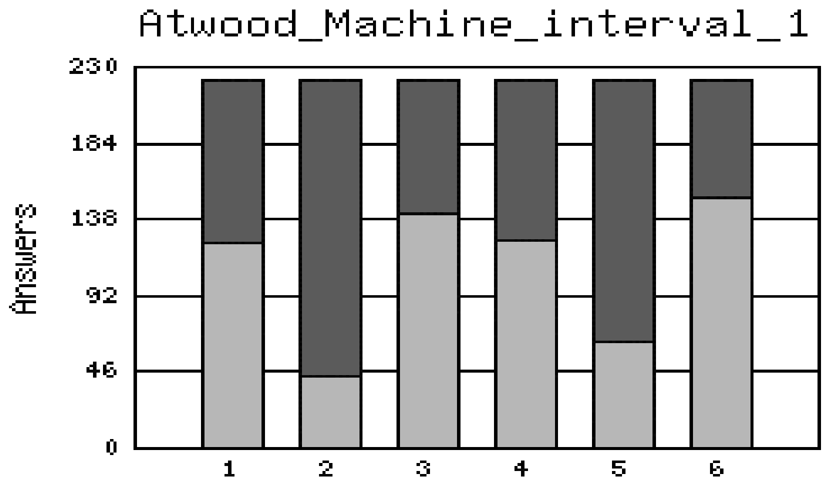


Figure 5. Web-rendering of the same homework problem for two different students

In Figure 5, one and the same homework problem is rendered for two different students: the labels in the image (Ma, Mb, Tx, Ty, and Tz) are denoting different masses and tensions in the Atwood machine, and learners have different choices - not only are the labels inserted according to their respective function, but also the choices themselves and their order are varied – a total of more than 10,000 variations on this problem. For example, in the left rendering, the learner has the choice "Ma*g+Mb*g is ____ Tx," while in the rendering on the right, a corresponding choice is "Tx is ____ Mb*g+Ma*g." Obviously, the correct answer could be "less than" in the one case, and "more than" in the other – if that is true (and in which order), or if the answer is "equal" in both cases is left as an exercise to the reader. Internal to the homework problem, both of these choices are members of the same so-called concept group, and the homework engine insures that one and only one choice from each concept group appears.



1. Two M's have same size acceleration (string does not stretch)
2. Weight of the two M's > tension in top string (cm accelerates)
3. Top tension equals the two bottom tensions. (pulley mass = 0)
4. Tension acting on the two M's are equal (pulley mass, frict, = 0)
5. Accelerations: small M up (T>Mg), large M down (T<Mg)
6. Center of mass accelerates downward

Figure 6. Distribution of initial correct (lower, light gray) and incorrect (upper, dark gray) answers to concepts in problem Fig. 5

These concept groups can be used to identify student misconceptions even though the problems that the students see are randomized (Albertelli, 2002); LON-CAPA provides analysis tools for this purpose. Figure 6 shows the correctness of the initial 12% of entries for the problem Figure 5 for each concept group (since students have multiple attempts to get each problem correct, it is important to capture the initial response rather than the final answers). The lower bar is the number of correct response, the upper bar the number of incorrect responses for each of the six concepts. Clearly, the students have the biggest problem with the concept that the weight of the two masses is greater than the tension in the top string.

Such diagnostic tools allow faculty members to have immediate feedback on the progress of their students, and detect misconception early on, thus enabling just-in-time teaching.

Time saved in routine grading of student work, as well as better insights into the learning progress, both foster communication between learners and educators – delegating work that a computer does best to a computer allows humans to interact on a higher level, even in rather unexpected ways: it was frequently observed that the addition of LON-CAPA to the instructor-student relationship removes the adversarial relationship between educators and learners with regard to turning in late homework, partial credit and immediate feedback. Rather, the learner and the educator are on the same side, struggling valiantly with the “immovable LON-CAPA beast” that seemingly comes up with these tough homework problems out of nowhere.

Problems are stored in an XML format, and as with all other LON-CAPA documents, problems are one-source-multiple-target. Depending on external parameters, problems can render themselves in online mode, print mode, online exam mode, and bubble-sheet mode, as well as edit mode for online problem creation.

```
<problem>
<script type="loncapa/perl">
$initial_velocity=&random(70,130,5);
$acceleration=&random(-5,-1.2,0.2);
$time=&random(0.5,4.5,0.1);
$distance=($initial_velocity/3.6+$acceleration*$time/2)*$time;
$forgotinitial=-$acceleration*$time*$time/2;
</script>
<startouttext />You are driving with a velocity of $initial_velocity <m>$km/h$</m> and
step on the brake. The resulting acceleration is $acceleration <m>$m/s^{2}$</m>.
Starting from when you hit the brake, how far will you have traveled after
$time <m>$s$</m>?<endouttext />
<numericalresponse format="1f" unit="m" id="11" answer="$distance">
        <responseparam description="Numerical Tolerance" type="tolerance" default="5%"
name="tol" />
        <responseparam description="Significant Figures" type="int_range,0-16"
default="0,15" name="sig" />
        <textline />
        <hintgroup>
<numericalhint unit="m" id="12" answer="$forgotinitial" name="forgot_initial_velocity">
    <responseparam default="5%" type="tolerance" name="tol" />
</numericalhint>
<hintpart on="forgot_initial_velocity">
    <startouttext /> You have forgotten to take into account the initial velocity of
your car. And, by the way,
braking does not make you go backwards.<endouttext />
</hintpart>

        </hintgroup>
</numericalresponse>
<postanswerdate><startouttext />The correct formula to solve this problem is
<m>\[x(t)=vt+\frac{1}{2}at^{2}\]</m>
<endouttext />
</postanswerdate>
</problem>
```

Figure 7. XML source code of a problem

Figure 7 shows the XML data structure of a numerical homework problem. Note that the XML incorporates Perl code for the numerical calculations, and LaTeX for the mathematical typesetting. The problem code has several elements. The <script>-block sets all variables, where the &random-call produces a random number in the range from the first to the second parameter, in step sizes of the third parameter. The script then continues to computer the correct answer, $distance, as well as a wrong answer, $forgotinitial. In the following text, the variables can simply be referred to by their names. LaTeX formulas are embedded into <m>-tags. The XML document goes on to define the correct solution for the problem ($distance), as well as parameters such as numerical tolerance, significant digits, and – most importantly – the physical unit for the answer $distance, i.e., “m”. Next, the script defines a conditional hint for the wrong answer $forgotinitial, and finally, it includes a block which is shown after the answer date is past (a date set by the instructor).

While it is an option, authors usually will not write their problems in raw XML. Instead, each XML element can also be rendered for the “edit” target, which produces fill-in-the-blank forms as shown in Figure 8.

Figure 8. Editor rendering of XML code, Fig. 7

Finally, Figure 9 shows the problem as it is rendered for the student, in the particular state where the student entered an answer covered by the adaptive hint.

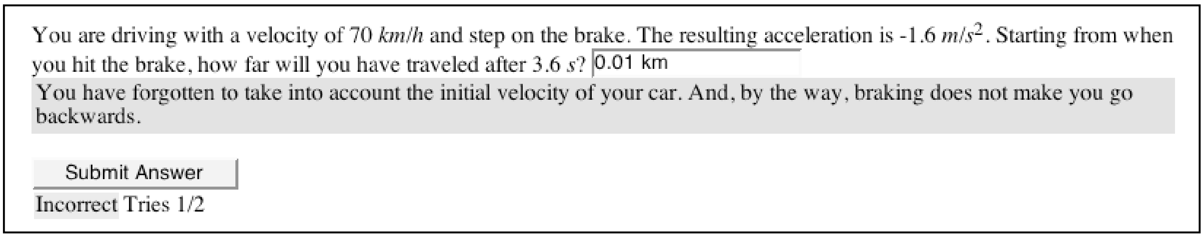


Figure 9: Web rendering of XML code, Fig. 7

COURSE MANAGEMENT

In addition to the learning content creation and management capabilities, LON-CAPA provides the course management features needed to run a course using this material. This includes: appropriately enrolling all students and instructors, assigning the dates and times at which resources are available and homework due, invoking the necessary marking/grading schemes, as well as managing course communication, feedback, bulletin boards, calendar, and chat rooms. Templates are available to on-the-fly generate discussion board, syllabi, simple content pages, and upload non-HTML content such as PowerPoint presentation or PDF files.

LEARNING OUTCOMES

The ultimate measure of success for our system is whether it indeed proves to be an effective tool in increasing educational outcomes for students. A number of systematic studies, conducted primarily within undergraduate physics courses, suggest that LON- CAPA can have a pronounced impact on student learning. One study (Kashy, 2001) followed an introductory calculus-based physics course from the years before system implementation until late into its deployment. In the years before using LON-CAPA, the final grade distribution exhibited the traditional bell shape around a grade of 2.5, with relatively few students receiving grades of 3.5 or 4.0. After the move to LON-CAPA, the proportion of students earning a grade higher than 3.0 increased dramatically. Notably, independent evaluators judged that the examinations used in the course after deployment were more challenging than those used in earlier years, and so the positive change in educational outcomes cannot be attributed to a lowering of standards for the class.

Two other studies suggest that LON-CAPA may increase the participation and success of women in the sciences. One study (Thoennessen, 1996) focused on a yearlong physics course for non-science-majors, in which the system was used only during the second semester. Final grades from the second semester indicated that women were especially likely to benefit from the system. The second study indicated that women, who began the course significantly less well prepared than men, improved their performance relative to men across the semester until there were no gender differences by the final exam. These preliminary findings are currently being studied in more detail.

A majority of students, typically 80%, consider that LON-CAPA helps them learn and understand the course material. This is surprising, since the time students spend working on assignments and other course requirements has increased by nearly a factor of two.

UNANTICIPATED CHALLENGES

LON-CAPA has a proven track record of using technology to challenge the learners. A recent development has been that the learners use technology to challenge the educators. While the personalization feature of LON-CAPA still curbs rote copying of answers more than any other system, students have established interactive web sites (financed by banner adds and donations) to network with each other in an attempt to defeat the system. Whole Excel spreadsheets are going up in an attempt to reverse-engineer the individualization mechanisms – one problem at a time, and featuring "52,359 homework forum messages." These efforts in turn have moved educators to write even more sophisticated problems, using for example random labeling on individualized graphs. The final word on this "technology war" has not been spoken yet, however, a survey in which students after the end of a course were asked how often they used the cheat site has shown that the final grade was significantly negatively correlated to site usage.

SUSTAINABILITY AND POSITIONING

LON-CAPA is unique amongst course and learning content management systems in that it is developed under the open-source GNU General Public License. We do not expect that the Michigan State University team of developers alone will be able to sustain the code-base of LON-CAPA (currently around 60,000 lines of code) without input from a broader development community. In contrast to proprietary commercial software, the cooperative open-source community has a fast turn-around on debugging and adaptation to new technologies (as demonstrated by the success of the Linux operating system). We are investigating if this model is successful for a system that operates in the academic community, where the main stakeholders usually are not themselves programmers. However, already today, the LON-CAPA system has a code base comprised of contributions from four universities, and incorporates a vast number of available open-source tools and libraries.

LON-CAPA was never intended as a competitor to commercial course management systems, and instead offers an inherently academic approach to online teaching and learning. Its sharing of resources is formed around the principle of peer-review (through peer-adoption of resources and giving credit to the author), and will soon further formalize this concept for explicitly peer-reviewed subsets of the resource pool. Through its ability to be molded and modified, as well as its extensive logging of learner interaction, it allows instructors to conduct educational experiments on a large scale, and to track the educational impact of targeted interventions. The project was recognized by IEEE and ASEE with three best papers awards at the annual Frontiers in Education Conference (1997, 1998, 2000), the Ben Dasher Award (1998), the Wickenden Award (1999), and a ComputerWorld Honors Award (2003).

Over the years, the project has sponsored annual conferences and workshops, with a growing number of participants. At the 2002 LON-CAPA user conference, hosted by Florida State University, 56 faculty members - mostly science researchers – from 22 institutions attended. The 2003 conference at Truckee Meadows Community College in Reno, NV, had 72 participants from 28 institutions. LON-CAPA provides a catalyst for them to discuss educational issues, for which they would not usually have a forum.

Increasing LON-CAPA's user community is crucial to both the immediate success as well as the long-term sustainability of the project. Started as a purely academic effort, eventually the system will need to exhibit financial sustainability without grant support. Making this transition without loosing the unique characteristics of the system and without turning an academic department with research faculty into a purely financial interest-driven service entity is a challenge.

CONCLUSIONS

In the broad and varied use of IT in education, a common thread appears to be the large increase in the interactive component of the teaching and learning process (Brown, 2000). Our own work with LON-CAPA and its antecedent systems has demonstrated that such technology can be used so that students achieve higher success rates with higher standards for achievement.

The improvement in student performance is not ascribable to technology per se (Russell, 1999), but rather to the broad use of IT in implementing learning opportunities technology has made possible. Examples include individualized homework, examinations and quizzes with timely feedback to students, transformation of mid-term examinations into formative assessment tools, development of content that stimulates interaction and discussion while inhibiting mindless copying. Technology allows us to use these intensive learning exercises with students in a cost-effective manner when such exercises would not be possible otherwise (especially in large-enrollment classes) because of the large resources required.

One important result has been the significant increase in time that students devote to the assigned work. This increase in time-on-task is undoubtedly a major factor contributing to the improvements in learning that we have noted. Students seem to spend more time working because they are motivated by the prompt feedback they receive as they carry out the work, and by the opportunity to correct that work and get rewarded.

The students are not the only ones who benefit from the immediate feedback technology provides – instructors are also the beneficiaries of such feedback. Specifically, instructors get detailed information concerning the material and concepts which student find difficult and are then able to promptly address these areas. In addition, Research indicates that discussion among students and between students and staff are greatly enhanced when LON-CAPA is implemented in a course. Another interesting effect has been the level of discussion dealing with student learning which now takes place among faculty using the technology. This has led to considerable sharing of methods and applications among the faculty. This is a great step forward considering that faculty collaboration in teaching activities is often an essentially non-existent aspect in many departments.

We have found the concept of educational content sharing to be highly effective in fostering the creation and maintenance of high quality online resources. The potential of having an impact beyond the boundaries of one's own classroom appears to be a major incentive for the creation of such resources for many educators. The peer-review provided by the resource selection mechanisms, as well as the continuing evaluation by thousands of students across courses, semesters, and institutions increases resource accuracy, reliability, and relevance. We have also found important cross-fertilization among disciplines. For example, an individualized problem type originally designed for a botany class has been extensively used in teaching Astronomy. The majority of current LON-CAPA material is in the introductory-level natural sciences, and at least for this group of faculty authors, we found an almost surprising willingness to share content, and very little concern regarding intellectual property and possible royalties beyond recognition of authorship.

Two aspects of content creation and sharing where LON-CAPA especially excels are in the simplicity of the process and the reliability of the material. The latter is simply the consequence of having the authoritative version of any resource residing exclusively in the author’s domain, thus insuring that other users have access to the latest corrections and most up-to-date version. The advantage should be especially clear to those who have had experience with the problems of transferring content by sending source files across the network.

Finally, we note one area where our expectations have not been met. It is the open-source code development of the LON-CAPA platform by users external to the initial development team. A small number of such contributors have indeed made significant contributions to the software, but we had hoped for a greater involvement from the external community. Our expectations were probably unrealistic because educators, the system's main stakeholders, are typically not programmers at the level where they could productively contribute to the code in a reasonable amount of time.

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