An Open-Source Learning Content Management and Assessment System

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Abstract. In this paper, we describe the development and functionality of the LearningOnline Network with CAPA (LON-CAPA; http://www.lon-capa.org/) system. We summarize published findings obtained over the years regarding its content sharing and online assessment features, and present some new findings on gender differences in the usage of online homework.

Keywords: Course management, learning content management, online assessment.

1 First-Generation Online Homework Systems

In 1992, CAPA (a Computer-Assisted Personalized Approach) was started to provide randomized homework for an introductory physics course at Michigan State University [1,2]. The system provided a way to offer relevant practice problems and feedback to the students in spite of limited availability of teaching assistants. Different students were assigned different versions (for example, different numbers, graphs, formulas, images, and options) of the same problems, so that they could discuss problems with each other, but not simply exchange solutions. As an example, Fig. 1 shows two versions of the same homework problem, as it appears today on the web. When CAPA was first introduced, students received paper printouts of their problems, and had to enter their solutions through a Telnet terminal, where they received immediate correctness feedback. Students typically had a limited number of allowed attempts ("tries") to arrive at the correct solution. In later years, as the web became more widely available, a web interface for answer input was introduced.

A number of other homework systems were developed in the 90s, namely the UT Homework Service [3], WeBWorK [4], and WebAssign [5]. These systems offered very similar problem functionality with comparable randomization features. The systems however differed in their distribution mechanisms, their technology choices, and their problem-editing interfaces. For example, CAPA and the UT Homework Service initially were strongly driven by paper-based assignments and terminal input, and only later added web interfaces, while WeBWorK and WebAssign were web applications from the start. When it came to problem editing, CAPA, the UT Homework Service, and WeBWork offer highly flexible (but complex) programming

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languages, while WebAssign features easier-to-use but more restrictive web templates. CAPA, the UT Homework Service, and WeBWorK are free, while WebAssign is a commercial product.

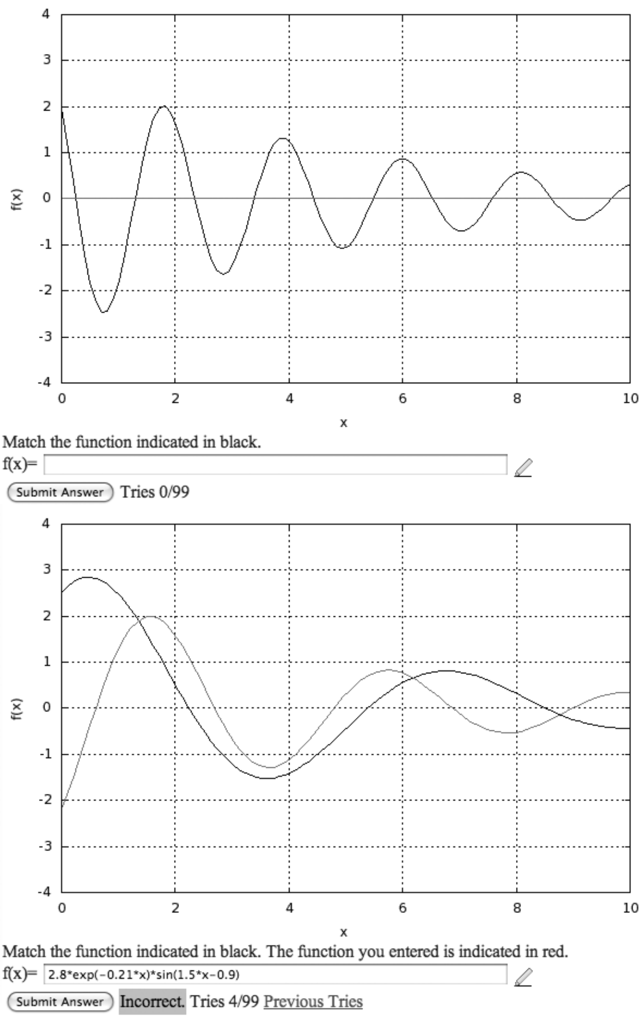

Fig. 1. Two versions of the same homework problem (LON-CAPA screenshots). Since the graphs are different, each student would have a different answer. In bottom graph, the student already entered a solution attempt ("try"), demonstrating some of the instant feedback features that the system can provide.

A major difference between CAPA and the other systems is that CAPA (and today LON-CAPA) relies on local installations at the user institutions, while the other systems are centralized with just one server farm at the institutions where the system originated. The distributed nature has some advantages: in terms of student data privacy, data relevant to grading never leaves campus, and in terms of scalability, the distributed setup is better suited to handle high workloads. As another benefit for regions of the world that have limited communication infrastructure, homework functionality can be delivered reliably at institutions that may have a stable intranet, but unstable or slow connections to the outside world.

None of the systems we have mentioned thus far offers full-featured course management functionality, and none of them can be seen as a replacement for a course management system such as BlackBoard [6], WebCT [7], or ANGEL [8]. Because the homework functionality in these commercial course management systems is insufficient and not well adapted for use in science and mathematics, we consider the above specialized physics homework systems as complementary rather than competing with mainstream course management applications.

2 Features of LON-CAPA

Because editing new problems is a time-consuming task, and because standard introductory physics problems are very similar, faculty at different institutions using CAPA soon started to exchange problem libraries with each other. Here, CAPA's distributed nature brought some challenges that the centralized services did not encounter: since CAPA had separate installations, exchanging materials meant sending the associated files via FTP or exchanging floppy disks. Overcoming this infrastructural shortcoming was one of the main design principles in the next generation of CAPA, the Learning*Online* Network with CAPA (LON-CAPA) [9-11]. The features of LON-CAPA include the following:

- Cross-institutional resource management. Although LON-CAPA is still deployed at separate installations, problems and content pages are copied on-demand between machines and automatically updated. Digital rights management protects sensitive content (for example, exam questions) and potential commercial interests (for example, back-of-the-chapter libraries of textbook publishers).
- Cross-institutional load balancing. Although all permanent data storage is at the instructor's home institution, any server in the network can host any session. Thus, sessions can be offloaded across the network in peak load situations.
- Completely web-based interface for all system functionality.
- Access to the full sophistication of the CAPA problem engine through an XML-based problem format with optional embedded scripting; this allows for the use of template-driven editors, while preserving the flexibility of programming languages when desired by authors.
- Multimedia content and problems are made available through an embedded course-management system with functionality similar to commercial systems, thus eliminating the need to use two separate systems for the same course.
- While being a distributed system, LON-CAPA is robust against connectivity dropouts and latency. For example, the system has content replication and subscription mechanisms, so internet connectivity to the site where the content originates does not need to available in order to make content available within the intranet of an institution.

3 Content Sharing

In Fall 2008 LON-CAPA had over 130 participating institutions (about half secondary and half postsecondary) with over 310,000 shared resources, over 120,000 of which are randomizing online problems, almost 100,000 are images, and almost 60,000 are web pages. The remaining 30,000 resources are other multimedia assets, for example, content assemblies (approximately 10,000 "learning paths"), sound and movie files (approximately 950), and animations and simulations (approximately 1700). Figure 2 shows the growth of the resource pool over the years.

The system is also used internationally, currently in Brazil, Canada, Germany, Israel, South Africa, South Korea, and Switzerland. The system had also been successfully deployed in Zimbabwe, where the redundant nature of its architecture overcame challenges posed by intermittent connectivity and latency problems (unfortunately, as of 2008, this installation is not active anymore). The system supports Unicode and has been translated into German, Japanese, and Portuguese; currently, efforts are under way for a Chinese translation (simplified script).

Faculty members have written most of the resources in the shared pool, originally mostly for use in their own courses. We found much willingness on the part of faculty to make their materials available to the pool, and the vast majority of the material in the system is published "system-wide," some of them even "open-source," thus allowing derivative works.

Initially, we believed that monetary incentives or bartering schemes would be needed to motivate faculty to share their materials. However, we found that faculty members are far less interested in earning usage fees than feeling a sense of accomplishment when they see the usage counters increasing or receive positive feedback from peers. The "e-commerce" schemes were also seen as too complicated, and we came to the realization that they might inhibit rather than foster the expansion of the network. From discussions with authors, it is apparent that the few authors who wish to restrict use of their materials are often hesitant to submit materials to public scrutiny, rather than generally unwilling to share.

It seems that sharing resources fits into the academic culture, just as for example research papers and findings are "shared." Arguably, this might be subject area specific: most participating faculty are from the natural sciences, and most resources are intended for introductory courses. Faculty members might take pride in writing a high quality homework problem regarding angular momentum conservation, but would hardly base their reputation on it, nor are they competing with peers teaching the same topic. Also, for example, introductory physics is far from controversial, so authors do not have to worry about scrutiny with regards to matters of opinion.

The most important aspect appears to be good stewardship of the material: the project needs to guarantee that materials, some of them exam or grading-relevant homework problems, do not "leak" out of the pool; students only have access to the material that faculty select for them, and only in rendered form. Particularly sensitive is the XML source code of the problems, because it allows for reverse engineering of the randomization and determination of the correct solution for any variation of the problem. Authors need good reasons to trust the system.

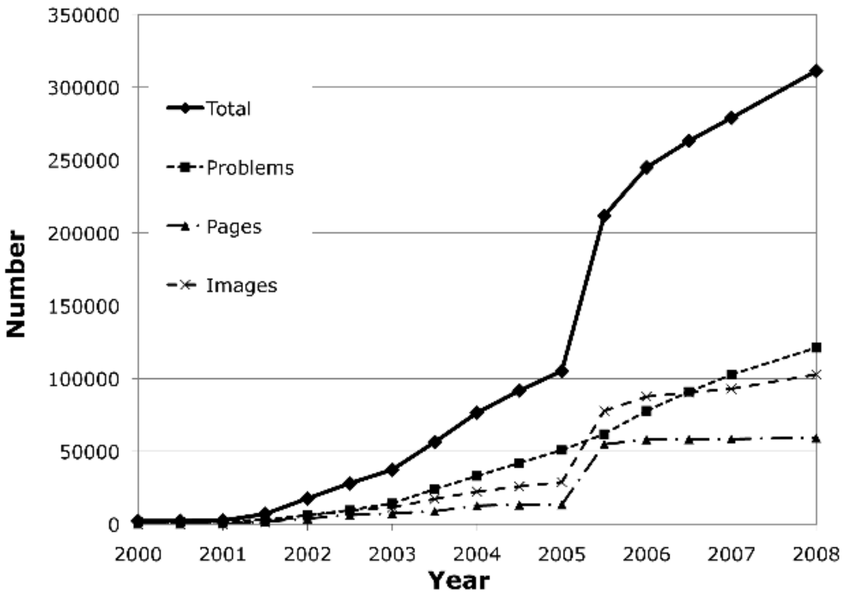

Fig. 2. Growth of the LON-CAPA resource pool over time

4 Measures of and Influences on Learning Outcomes

4.1 Course Grades

Although faculty acceptance in part depends on factors such as time-savings, convenience, ease-of-use, and philosophical considerations, both faculty and students care about learning outcomes: instructors care, because it is frustrating to see bad exam scores, and students care, because they want good grades.

A simple measure of learning outcomes is – hopefully – the course grade. Though in an individual year, many factors might play a role, Figure 3 shows grade distributions over several years in the standard introductory physics course for scientists and engineers (PHY 183) at Michigan State University [11,12]. A 4.0 is the highest grade, a grade lower than 2.0 results in failing the course. The solid graph shows the averaged distribution in the years 1992 to 1994 without online homework, and exhibits the classic bell shape with a maximum at around 2.5 (since this historical data was only available in semester-averaged form, no standard deviations are given in the graph). Unfortunately, we were unable to reconstruct which sections of the course correspond to the data, but we do know that at least six different instructors were involved over the years [11].

In 1996, online homework was introduced. We were able to obtain semester data from five different instructors who taught the course between 1999 and 2007 (gray graph in Fig. 3) [11]. Only one of these five instructors may have also been included in the data of the pre-CAPA time period. We indicate standard deviations, which reflect grading differences between the five post-CAPA instructors. The consistent observation in subsequent years with online homework is that the grade distribution is depleted around 2.0 in favor of higher grades, and overall becomes skewed.

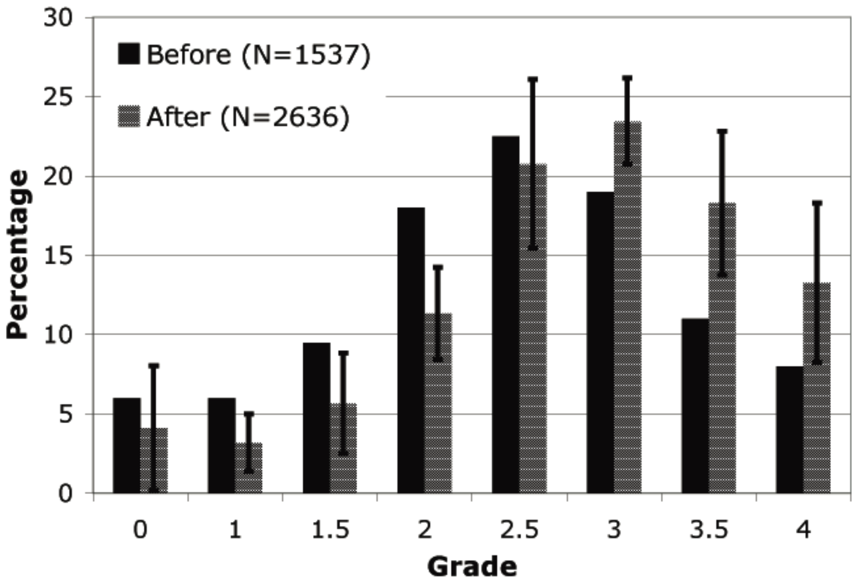

Fig. 3. Grade distributions across several sections and semesters of a physics course for scientists and engineers before using online homework *(solid)* and after its introduction *(gray)*. Data for the pre-CAPA period was only available in averaged form [12], but for the post-CAPA period, error bars reflecting the variation of grading between different instructors and semesters are given [11,12].

The average course grade was 2.4±1.0 before the introduction of online homework, and 2.7±1.2 afterward – the difference (0.3 grade points) is not statistically significant (or inflationary), but noticeable. It is important to note that the difference is not simply a result of an increased number of points for homework, because homework in all of these courses constituted only a small contribution of the grading criteria, but a result of higher exam grades [13].

4.2 Student Attitudes

One of the main reasons for the learning gains is most likely increased time-on-task: students are self-reporting that with the introduction of online homework, on the average, they are working one to two hours more per week on physics than without online homework [13]. Students who found online homework particularly helpful on the average worked 2.4 hours more per week after its introduction. Surprisingly, there were even a few students who worked ten hours more per week on physics, some of them still finding the system very helpful, but others (who failed the course), finding it useless. Another frequently quoted reason for the system's helpfulness is the immediate feedback and the ability to do the problem over and over (within a limited time and for a bounded number of attempts) until mastery is achieved. Although this feature is certainly perceived to be helpful by students and appreciated by faculty [14], there is some well-reasoned concern, confirmed by research results, that it can also "turn thinkers into guessers," where students adopt a trial-and-error approach to problem solving [15] – here, however, gender may play a role.

4.3 Gender Differences

Online homework consistently most strongly helps students who are on the brink of failing courses. Comparisons between grade distributions before and after introduction of online homework typically show that formerly strictly bell-shaped grade distributions get depleted around the 2.0-grade. As an example, in an earlier study we examined a two-semester course, where in a particular year the first semester was taught without, and the second semester with online homework [12]. Grades improved (compatible with Fig. 3), but surprisingly, it turned out that this was mostly due to female students. In the first semester, the average grade of male students was 2.8±0.8, versus 2.5±1.1 for female students. In the second semester (after introduction of CAPA), it was 2.8±1.1 for the male and 2.8±1.0 for the female students.

Figure 4 shows the grade distributions for female and male students in the first and the second semester [11,12]. It can be observed that for female students, the grade distributions in the first semester (black, without online homework) and the second semester (gray, with online homework) are very different, while for male students, there is hardly any difference between the semesters with and without CAPA. The grade distribution for female students was significantly different from the male distribution in the first semester (χ^2=3500; p<0.0001), indicating a significant gender gap, but this difference almost vanished in the second semester (χ^2=14; p=0.05).

A similar effect was observed at Central Michigan University [16]. In that study, only one gender difference in student interaction with online homework was discovered, namely, it was also found that females in semesters where they outperformed the male students usually did their online homework earlier, i.e., not as close to the due date.

We were able to exclude simple population, instructor, or attrition effects. Also, in a study of one particular course, we found no significant differences in the online usage data, such as average number of attempts used, and both male and female students reported the same average amount of time-on-task, i.e., 5.1±3.6 and 5.6±3.3 hours per week, respectively. Both male and female students also solved the same number of online problems, i.e., 381±40 and 389±30 problems over the course of the semester.

However, in an open-ended survey, we found indicators that male and female students make different use of being allowed multiple tries to solve online homework problems: male students frequently, before anything else, attempt to immediately solve the problem, while female students are more likely to first interact with peers and teaching assistants before entering answers. Particularly, the online discussions, which are part of LON-CAPA's course management features, appear to be used more by female than by male students, both in posting and reading. More male than female students state that they use the multiple allowed attempts to enter "random stuff," while more female than male students state that having multiple attempts allows them to explore their own problem solving approaches without "worrying" or "being stressed out" about grades.

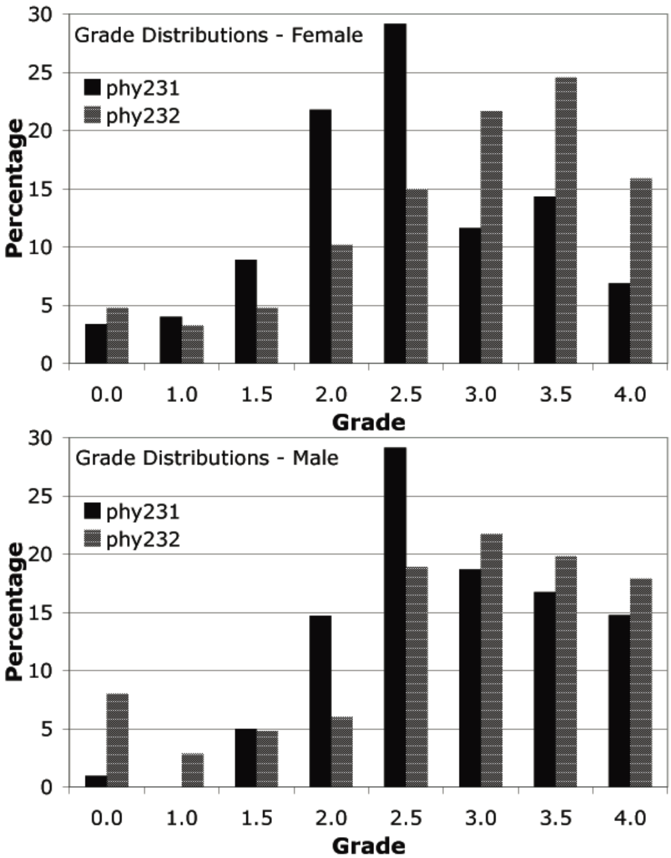

Fig. 4. Grade distributions in the first semester *(solid)* and the second semester *(gray)* of a non-majors introductory physics course. The top panel shows the grade distribution of female students, the bottom panel of male students. Online homework was used in the second, but not the first semester [12].

5 Conclusions

We have introduced LON-CAPA as an open-source tool to develop, use, and share online teaching and learning resources. We find that individualized online homework can be an effective learning aid, particularly in the sciences, and particularly for students who are at risk of failing the course. There is evidence that online homework helps to close the gender gap usually present in science courses. The sharing of such resources across institutional boundaries is a reality, as shown by international collaborations around online teaching and learning, which have continually grown since LON-CAPA was first introduced in 2000.

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