From evaluation to learning: Some aspects of designing a cyber-university

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June 27, 2014

Abstract

Research is described on a system for web-assisted education and how it is used to deliver on-line drill questions, automatically suited to individual students. The system can store and display all of the various pieces of information used in a class-room (slides, examples, handouts, drill items) and give individualized drills to participating students. The system is built on the basic theme that it is for learning rather than evaluation.

Experimental results shown here imply that both the item database and the item allocation methods are important and examples are given on how these need to be tuned for each course. Different item allocation methods are discussed and a method is proposed for comparing several such schemes. It is shown that students improve their knowledge while using the system. Classical statistical models which do not include learning, but are designed for mere evaluation, are therefore not applicable.

A corollary of the openness and emphasis on learning is that the student is permitted to continue requesting drill items until the system reports a grade which is satisfactory to the student. An obvious resulting challenge is how such a grade should be computed so as to reflect actual knowledge at the time of computation, entice the student to continue and simultaneously be a clear indication for the student. To name a few methods, a grade can in principle be computed based on all available answers on a topic, on the last few answers or on answers up to a given number of attempts, but all of these have obvious problems.
1 Background

1.1 This project

This R&D project in web-assisted education attempts to address the following issues:

- a shortage of experienced educators in mathematics and statistics
- a lack of implemented standards for education (baseline outputs) in mathematics and statistics
- a lack of applied statistics courses for researchers and students in other fields.

The approach taken in the project includes the following components:

- design freely available web-based material to degrees in mathematics and applied statistics
- allocate personalized drill items using an IAA (item allocation algorithm)
- invoke the student’s incentive for a high grade using a GS (grading scheme)

The primary research question addressed by the project is the search for the best item allocation algorithm or how one can best select the next drill item for the student, with the grading scheme a close second.

Many systems are available to instruct on specific topics and considerable research has been conducted on how to fine-tune presentation of material or drills on specific topics. The system to be designed is generic, however, uses mostly multiple-choice drill items, but delivered in a very specialized manner, and can be tuned to any field of interest.

1.2 Classical testing methods

The field of computerized testing has been around for a number of decades. Item response theory \[3\] has been used to design, analyse, and grade computerized tests of abilities. Data are binary responses to each item and such data are commonly analysed with logistic regression models. The three-parameter logistic model is often used to link the probability of a correct answer to the students ability

\[
P_{si} = P(Y_{si} = 1|\theta_s; a_i, b_i, c_i) = c_i + \frac{(1 - c_i)}{1 + \exp\{-a_i(\theta_s - b_i)\}} \quad (1)
\]
Figure 1: The three-parameter logistic model with varying $a$, $b = 0.3$ and $c = 0.2$

where $Y_{si}$ is the score of the $s$-th student to the $i$-th item, $\theta_s$ is the student ability parameter, $a_i$ is the item discriminant parameter, $b_i$ is the item difficulty parameter and $c_i$ is the item guessing parameter. Setting $a_i = 1$ and $c_i = 0$ results in the common Rasch model.

Common item-selectors include simple random selection and Point Fisher Information where the “most informative” item for this student is chosen. Information is measured by the Fisher Information

$$I(\theta) = E \left[ \left( \frac{\delta}{\delta \theta} \log L(\theta) \right)^2 \right]$$

where $L(\theta)$ is the likelihood (function of ability) for fixed values of item parameters. This results in the item information function

$$I_i(\theta) = \frac{P_i'(\theta)^2}{P_i(\theta)(1 - P_i(\theta))}.$$  

For the three-parameter model the item information function is

$$I_i(\theta) = a_i^2 \cdot \frac{1 - P_i(\theta)}{P_i(\theta)} \cdot \frac{(P_i(\theta) - c_i)^2}{(1 - c_i)^2}.$$  

The focus in CAT \cite{9} and IRT is to measure abilities and the item selection methods were developed for that purpose. Since the CAT methods do not account for learning in a dynamic environment, new models and item selectors needs to be developed for the purpose of increased learning. The need for this becomes apparent as models are fitted to actual data, as seen below.
2 The tutor-web

Figure 2: The tutor-web main page.

The tutor-web, used here, is a freely accessible web-based university which has been used for computer-assisted education in mathematics and statistics and research on education. Needless to say, the tutor-web is not the only such system. With the increasing number of web-based educational systems several types of educational systems have emerged. These include learning management system (LMS), learning content management system (LCMS), virtual learning environment (VLE), course management system (CMS) and Adaptive and intelligent Web-based educational systems (AIWBES). The LMS is designed for planning, delivering and managing learning events, usually adding little value to the learning process nor supporting internal content processes. A VLE provides similar service, adding interaction with users and access to a wider range of resources. The primary role of a LCMS is to provide a collaborative authoring environment for creating and maintaining learning content.

Many systems are merely a network of static hypertext pages but adaptive and intelligent Web-based educational systems (AIWBES) use a model of the goals, preferences and knowledge of each student and use this to adapt to the needs of that student. These systems tend to be subject-specific because of their structural complexity and therefore do not provide

1 The terms VLE and CMS are often used interchangeably, CMS being more common in the United States and VLE in Europe.
a broad range of content.

The tutor-web (at [http://tutor-web.net](http://tutor-web.net)) is an open and freely accessible AIWBES system, available to students and instructors at no cost. The system has been a research project since 1999 and is completely based on open source computer code with material under the Creative Commons Attribution-ShareAlike License. The material and programs have been mainly developed in Iceland but also used in low-income areas (e.g. Kenya). Software is written in the Plone\(^2\) CMS (content management system), on top of a Zope\(^3\) Application Server.

In terms of internal structure, the material is modular, consisting of departments (e.g. math/stats), each of which contains courses (e.g. introductory calculus/regression). A course can be split into tutorials (e.g. differentiation/integration), which again consist of lectures (e.g. basics of differentiation/chain rule). Slides reside within lectures and may include attached material (examples, more detail, complete handouts etc). Also within the lectures are drills, which consist of multiple-choice items. These drills/quizzes are designed for learning, not just simple testing. The system

\(^2\)http://plone.org
\(^3\)http://zodb.org
Figure 4: Grade development based on averages across 162 students in an introductory statistics course.

has been used for introductory statistics[8], mathematical statistics, earth sciences, fishery science, linear algebra and calculus[4] in Iceland and Kenya[4], with some 2000 users to date.

The whole system is based on open source software and the teaching material is licensed under the Creative Commons Attribution-ShareAlike License[5]. The system offers a unique way to structure and link together teaching material. The structure of the tutor-web can be seen in Fig. 3.

An important part of the system are the interactive drills where the emphasis is on learning rather than evaluation. A student can continue requesting drill items until a satisfactory grade is obtained. The grade is currently calculated as the average of the last 8 questions per lecture in the current version of the system, but alternatives are considered below.

3 Analyses and results

3.1 Some experimental results

The most important part of the tutor-web is a drilling system, the whole point of which is to induce learning, rather than evaluation. It is seen in Fig. 4 that the mean grade to a question increases as the students see more

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4 http://tutor-web.tumblr.com/post/59494811247/web-assisted-education-in-kenya
5 http://creativecommons.org/
questions, as is to be expected. Although this does not automatically imply understanding, it does imply that student knowledge changes during the use of the system. From this it follows that the usual IRT models do not apply to the present setup, nor do any conceptual models or frameworks designed only for testing purposes.

3.2 Model results

The final fitted model, based on retaining statistically significant variables becomes:

\[
\log \left( \frac{p}{1-p} \right) = \beta_1 \cdot \text{rankdiff} + \beta_2 \cdot \text{numseen} + \beta_3 \cdot \text{numseen}^2 + \beta_4 \cdot \text{numseen}^3 + \beta_5 \cdot \text{natt} + \beta_6 \cdot \text{natt}^2 + \text{sid},
\]

where \text{rankdiff} is the ranked difficulty of the question (at the time of analysis), \text{numseen} is the number of times the particular question has been answered (seen) by the student, \text{natt} is the total number of attempts the student has made at questions in the lecture, and \text{sid} is the student id.

It should be noted that the fitted equation 2 is quite different from the usual IRT equation since the fitted equation needs to take learning into account. This is done by explicitly stating the number of times an item has been seen as well as the number of questions requested.

The two-parameter Rach model only incorporates the first and last terms in equation 2 but the remaining parameters are also statistically significant and therefore also needed to explain the data at hand.

4 Discussion

It is seen that the specific question is not a significant contributor to explaining the data once question difficulty has been inserted as a parameter.

If the student answers a great many times, then the model predicts a lower grade, consistent with assuming this corresponds to guessing. This result will almost certainly depend on the range of attempts made available to the model. Thus, since the current data include up to 60 attempts within a single lecture, the upper end will almost certainly correspond to guessers. Within this particular course a minimal return rate of 20 correct answers per lecture was required, and each such on-line lecture contained items corresponding to 1-2 weeks of material in the actual course. This is quite different from a system with smaller on-line lectures and lower return
Figure 5: Top panels: Model predictions of average grade as a function of (a) the number of times a question is seen and (b) the total number of answers given. Bottom panels: (c) Expected grade as a function of ability and (d) Expected grade as a function of ability, for different numbers of attempts at the question. The density shown in the lower panels indicates the distributions of estimated student ability.
requirements from each lecture. In such a course one would expect to see a true quadratic effect with a maximum grade at an intermediate number of attempts, given enough data.

If the student sees the same question more than once then there is clear evidence of learning.

4.1 General experience

The tutor-web has been used for teaching mathematics and statistics to students of mathematics, biology, geography and tourism with considerable student satisfaction [8]. In a recent survey of 60 students using the tutor-web, 53 of the students indicated that they had less difficulty answering the last questions in a drill session than the first and all of the students answered “yes” to the question “I learn by taking quizzes in the tutor-web,” in accordance with the numerical results from this study.

4.2 Current work

It is reasonably clear that an item allocation method which simply hands out items with equal probability is not optimal. In particular this does not guarantee that a beginner first sees “easy” items nor that a student who completes the lecture or course has had to answer the most difficult items as a part of the way towards a high grade.

![Image of probability distribution functions for different grades]

Figure 6: Possible development of pmf for questions as grade develops.
Current development is therefore focused on implementing the following item allocation rules within the system:

- select easy questions in the beginning
- increase item difficulty as the grade increases
- select, with some probability, questions the student has done incorrectly in the past
- select, with some probability, questions from old material to refresh memory.

Fig. 6 gives one implemented development of the probability mass function (pmf), as a function of item difficulty. The panels indicate how the pmf varies as a function of the student’s grade. This simple approach alone implements a personalized approach to the drills and it satisfies several important criteria, first by starting with easy items and second by ensuring that a student does not leave with a high grade without answering difficult items.

4.3 Item database design

Consider for the moment the 3PL in Fig. 1. One aspect of item design is to design items which classify students. Each should therefore have a steep slope and they should have different midpoints. For the data considered here, however, Fig. 5 indicate that the student ability distribution lies quite far to the right on the scale, when compared to the difficulty of easy items, but matches the mid-point of the most difficult items considered here. If the ability was static and the items were drawn at random one would only conclude that a batch of more difficult items is needed, but the dynamic nature of the on-line study is more complex.

The last panel of Fig. 5 demonstrates how the distribution of ability is too far to the right compared to the mean difficulty of items received in the first attempt within a lecture. However, as the number of attempts increase, the student’s ability increases (panel a) and this leads to an upwards shift in the expected grade as seen in panel d.

What is needed is a combination of several approaches: The item allocation algorithm needs to take into account both the item difficulty level and link this to the student’s dynamic ability. The simples such approach is merely to increase the mean difficulty as the grade increases, as is done in Fig. 6 but this is not enough as is seen in panel d of Fig. 5: (i) First, the
item design needs to ensure that even the best students will, at the peak of their learning, still receive difficult items, as measured on their personalized scale. These items are much more difficult than could possibly be administered randomly to a random group of students. (ii) Second, the link between the mean and ability is not quite trivial, also as seen in the same panel: In this IAA the mean item difficulty is linearly linked to the student’s grade and this lifts the mean grade too much compared to the ability distribution. A different link could be chosen to ensure that students get items which, at every ability and learning level always have a probability of a correct answer closer to 0.5.

Next, the grading scheme itself can be modified in many ways. In the present setup the average grade for the previous 8 answers is used as a “lecture grade”. Again, many alternate approaches could be designed in order to entice the student to continue. These include a longer or expanding tail (i.e. more than 8, e.g. \(\max(8, n/2)\) where \(n\) is the number of attempts) and/or tapering, where the most recent answers get more weight in the average.

Finally, timeout options do not exist within the tutor-web. It would be an interesting experiment to investigate how different timeout functions affect behavior.

Overall, it is seen that student behavior and corresponding model results are quite different for the on-line student in a learning environment, as compared to a student in a testing environment. This leads to new considerations and research on how these dynamic environments can be designed so as to maximize student learning as opposed to just estimating student knowledge with a high degree of precision.

5 Acknowledgements

The tutor-web project has been supported by the University of Iceland, the United Nations University the Icelandic Ministry of Education and the Marine Research Institute in Reykjavik. Numerous authors have contributed educational material to the system. The system is based on Plone and educational material is mainly written in \LaTeX. Examples and plots are mostly driven by R. The current Plone version of the tutor-web has been implemented by Audbjorg Jakobsdottir but numerous computer programmers have contributed pieces of code during the lifetime of the project.

Preliminary analyses in this work were first presented at EduLearn11.

\footnote{http://www.plone.org}
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