e-status: An Automatic Web-Based Problem Generator—Applications to Statistics

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ABSTRACT: The article presents a web-based tool designed to support a learning project led by a team of teachers to assist students in learning statistics. The goal is to build a tool that is able to display statistical or mathematical problems and to correct the students' answers. The problems may include random data, so the solution cannot be previously known (if solved beforehand), and the student can reconsider the problem if necessary. The methodology proposed could be useful in many other courses with a mathematical basis, particularly in engineering studies, in which students make extensive use of problem solving to lessen the level of abstraction present in the classroom. Students from a number of universities are currently using the tool, within the framework of a project that aims to improve the quality of learning. The pedagogical implications are mentioned, since the tool can be effective with basic, intermediate and high level learning, particularly if the problems are carefully designed.
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INTRODUCTION

The objective of this work is to present a web-based tool, known as e-status, which allows students in introductory courses to solve exercises in probability and statistical inference. The original idea came about 4 years ago, while the authors were attempting to cater for students' demand for problems.

Our teachers (between 8 and 10 are involved each semester) teach a large introductory statistics course that forms part of the second year of the Degree in Informatics Engineering at the Technical University of Catalonia (UPC), to over 250 students. The course usually lasts 15 weeks and students attend 6 h of statistics lessons a week. Students are divided into groups of 80, and smaller groups are arranged for the

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laboratory work. Students learn to analyze and summarize sets of data, with the help of computer tools.

The assessment methods used in our statistics course are as follows (Muñoz et al., [1]):

- One test after the seventh week including calculations and basic questions.
- Exercises every 2 weeks that are marked in the classroom.
- One group project with realistic simulated data, covering a broad range of course objectives.
- Lastly, the final exam.

We have developed this tool as a complement to the learning materials used. In addition, it provides feedback to the teachers and students.

It is well known that introductory statistics courses require a considerable amount of work of each student, who in turn requires exercises and practical cases in order to grasp the concepts learned over a very short period of time. Exercises are undoubtedly a good complement to the theory lessons. They show how the concepts explained in the classroom are applied in real or simplified cases, and they facilitate students' comprehension of these ideas through a process of learning by doing.

Why a web-based tool? Although our students are contact learning students, they will appreciate a tool for practicing statistics problem solving that is available anywhere, and that immediately informs them of which answers were correct and which ones were wrong. As Li et al. [2] pointed out: "*the web-based education possesses many advantages for engineering educators over other instructional approaches: First, web-based instruction present information in a non-linear style, allowing students to explore new information via browsing and cross-referencing activities. Second, web-based teaching supports active learning processes emphasized by constructivist theory. Third, web-based education is enhanced understanding through improved visualization and finally, the convenience, it could be used any time, at any place.*"

The difference between our project and most web-based tools (a list of examples would fill many pages) is that our software is dynamic: every problem presents new sample data that is generated randomly. The student could do the same exercise again but the data (and the solution) would be different. A similar tool to e-status is ACME, by Poch et al. [3]: they use also an internet/computer-based algebra system (Mathematica, in this case) in order to achieve a high degree of interactivity and feedback. ACME and others, such as WeBWorK (Gage et al. [4]) allow algebraic calculus. This is not the case with e-status: it only accepts numerical input as its focus is mainly on statistical computation.

We agree with Roberts and Simonyi [5]: "A major challenge in teaching introductory courses to a large, diverse audience is the wide variation in background and ability that exists in the undergraduate population, which makes it hard to find the appropriate level of instruction." It is for this reason that we have designed a product that allows the weaker students to practice the more difficult concepts as many times as they need, without obstructing the progress of the advanced students.

The methodology proposed is not limited to informatics students only; it could be extended to many other courses that have a mathematical basis, particularly engineering studies. It is well known that students make extensive use of problem solving in order to lessen the level of abstraction present in theory lessons. This is not just a means to reach educational objectives, but also a goal in itself, as recommended by the Accreditation Board of Engineering and Technology (ABET) in reference to education in the fields of maths and science. Kim et al [6] made the following remark: "*Engineering programs must demonstrate that graduates have (i) the ability to apply their knowledge of mathematics, science and engineering; (ii) the ability to identify, formulate, and solve engineering problems; and (iii) the ability to use the techniques, skills, and modern engineering tools necessary in engineering practice.*"

The article is organized as follows. In the Section "Description of the Environment," we present the description of the environment. Section "Background and Motivation" introduces some motivating items. In Section "Success Factors," we suggest a list of factors closely related to the success of the methodology. Finally, in "Conclusions," we present the conclusions derived from the work.

DESCRIPTION OF THE ENVIRONMENT

The application is mainly geared towards the following profiles: teachers, students, and administrators. Administrators take on organization tasks such as creating courses, and assigning teachers and students to a course, but they do not have teaching responsibilities. Visitors, or guests, are also considered, and they can log in anonymously and test specific problems, but they do not play a relevant role in the environment. The problems will be accessible to visitors in order to demonstrate the capabilities of

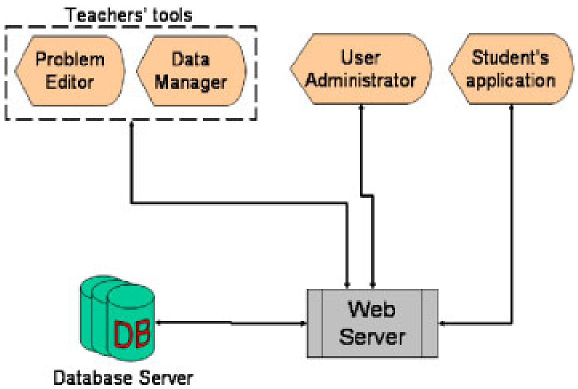

Figure 1 Architecture of e-status.

e-status to the general public. The application is available at http://ka.upc.es/estatus.

The tool consists of several components, as seen in Figure 1. One is designed for the teacher, one is to be used by the student, and another is designed for administrators. There is also a main database. All of these components are managed by the web engine installed in a web server. Before we discuss these parts in detail, it is useful to define what we understand a problem to be, since this is the very foundation of e-status.

What Makes a Problem?

Usually, in the educational world, we think of a problem as a (real or imaginary) situation with a number of unknowns that can be deduced from an explanation. The goal is to find out how students apply their knowledge and reasoning to find the solution.

Many mathematical problems possess a solution that can be deduced analytically. This is the kind of problem considered in this work. From now on, a *problem* is an object consisting of:

- A Situation. A text describing the circumstances.
- A model. A set of equations according to the structure *symbol* := *expression*. A symbol is an identifier such as x, p_valor, or z95, that is, a sequence of letters, numbers, and some special characters. An expression is typically a mathematical expression, written according to a set of rules (known as *the grammar* of e-status).
- The data. The known parameters of the problem. They are in fact a subset of the symbols appearing in the model; more precisely, they are the expressions they identify.
- A test. A set of questions addressed to the student, each comprising a text and the symbol for the answer. A question could also be enriched with items such as hints.
- The metadata. Additional items related to the problem, for example author, date of creation, lesson, title, difficulty, etc.

Let us consider a simple problem:

<u>Situation</u>	`The number of defective components present in a large batch is distributed as follows:`	
<u>Model</u>	`X: = [0,1,2,3,4,5]`	
	`P: = uniform(0,1,6)`	*six numbers uniformly in [0,1]*
	`P: = P/sum(P)`	*standardize to sum up to one*
	`Y: = P*X`	
	`Mu: = sum(Y)`	*expected value of X*
	`Lt2: = P[1]+P[2]`	*P(X < 2)*
<u>Data</u>	`X P`	
<u>Test</u>	`Give the mean number of defective components in a batch.`	`(mu)`
	`What is the probability of observing less than two defective components in a batch?`	`(Lt2)`
<u>Metadata</u>	`title: defective components; lesson: probability distributions`	

Some of the features of this grammar are:

- Common types considered. Integers, real numbers, and Boolean expressions (true, false) can be defined for numbers, constants, vectors or matrices.
- Common operations and their precedence order. Exponentiation, multiplication, division, addition, subtraction, etc. For the Boolean type: negation, logical, and logical or.
- Arithmetic functions. Trigonometric, square root, log, and exp, etc.
- Special functions. As in vector or matrix processing, special attention is paid to the family of probability and statistics functions (random generation, probability distributions, etc.).
- Some functions and operators can be overloaded, that is, that they can manage either

scalars or vectors, or even matrices, if the operation is allowed and the result is well defined.

How Do the Students Solve a Problem?

Let us define an *exercise* as the solution provided by a student to an instance of a given problem. The *instance* of a problem is an example of the situation, data, and questions present in the test. For the previous problem, the instance would be something like this:

> **Defective components**
>
> The number of defective components present in a large batch is distributed as follows:
>
> X = [0, 1, 2, 3, 4, 5]
> P = [0.12, 0.28, 0.24, 0.07, 0.19, 0.10]
>
> 1. Give the mean number of defective components in a batch. (____)
> 2. What is the probability of observing less than two defective components in a batch? (____)

A good response would be 2.23 as the solution for the first question and 0.40 for the second. Each instance gives random values for the probability distribution *P*, and the correct answer can not be known in advance: only values matching symbols mu and Lt2 are correct. Obviously, the example illustrates the basic capabilities of the tool. Far more elaborate problems could be proposed, provided that the solution can be expressed through the embodied grammar.

Architecture

As seen in Figure 1, the tool comprises several elements: the web engine, the database, and the different modules for each of the user profiles: teachers, students, and administrators.

The teachers' application. A web application is used for the manipulation of the problems. The core of the program, that is, the parser of the grammar, is written in Java. Web technologies such as PHP and servlets for page displaying are also used. Teachers use their own username and password to identify themselves and log into the application, which provides the following services:

- File management. Creating new problems, saving them or retrieving them from a database, modification of existing problems, etc.
- Folder management. Teachers with permission to log into the application can see their own folders and public folders from other teachers, so sharing problems is easy.
- Editing. Each component of the problem can be edited, with the assistance of the program. The person editing a problem ought to be familiar with the syntax of the expressions appearing in the Model section. The grammar defined for the expressions is far from unusual; we have tried to make it as close to standard as possible.
- Problem management. Teachers can assign a problem to a course, leaving it available for their students.
- Testing. The author can verify the correctness of the case by creating an instance and asking for the correct values for each question.
- Follow-up. It includes problems that have been solved and how many times as well as the results obtained. The output can be displayed either graphically or tabulated. The teacher gets ready feedback from the students in a easy way.

For teachers, possibly the most interesting task is the creation of problems. Not only must they know grammar, but also they must design good problems as well. This is relevant insofar as how the questions are posed. Let us see some examples of expressions appearing in a typical problem:

Model	`n: = 10`	*size sample set to 10*
	`X: = 100+10*Normal(n)`	*sample from N(μ=100, σ=10)*
	`Mean: = Sum(X)/n`	`Sum` *returns the sum of* x_i
	`Var: = Sum((X-Mean)^2)/(n-1)`	*constant subtracted to vector*
	`Stdev: = Sqrt(Var)`	`Sqrt` *is square root*
	`Risk: = 0.05`	
	`T: = TInvcdf(n−1, 1-Risk/2)`	*evaluates the inverse of a CDF*[1]
	`R: = T*Stdev/Sqrt(n)`	
	`CI_l: = Mean − R`	
	`CI_u: = Mean + R`	
	`OK: = CI_l < 100 and CI_u > 100`	*is μ within the 95% interval?*

[1]CDF stands for "Cumulative Distribution Function," or the probability that a value is less than that specified, given a reference distribution such as the Student's *t*-distribution, seen above.

The model above shows how we can obtain a 95% confidence interval for the mean population μ from a sample, which the students would see as the problem data. The mean μ (100) is unknown to the student, and it is expected that 95% of the intervals built from the sample enclose μ. Instead of simply asking "*is* μ inside the interval?", a teacher aiming for comprehensibility would perhaps pose the question in another way, such as: "do you have any reason to believe that this sample is not significantly biased from the center?"

The students' application. Any student enrolled on a course can access the application by entering a website hosted by the department web server. They must authenticate themselves with a user name and password and, once verified, they can:

- Pick a problem on which to practice on their own time, which encourages autonomous learning.
- Choose a block of problems (which can cover different lessons and are arranged like an ordinary exam).
- Take an assignment, perhaps as part of the assessment process.
- Monitor their progress. Students can find information on particular exercises, or indicators of their performance as compared with that of other students. Scores percentiles are a good way for students to track their progress.

The program shows an instance, probably generated using random data, and waits for the students' answer. Students may find hints included by the teacher, such as reminders ("This question is asking you for the standard error mean"), a web address ("This link has some useful examples"), or even the chance to check answers where an error early on in the problem would result in inevitable errors in the subsequent stages. Finally, it informs the student of the result: correct and incorrect responses, along with an overall score provide students with an idea of their progress.

The database and its administration. Students, problems, and exercises are some of the elements involved in the process. In order to obtain the best possible performance for data processing (mainly searches, input, and output), the elements and the relationships between them are organized by a Database Management System (like SQL Server). Administrators, teachers, and students communicate with the Database over the Internet. Queries for specific operations that are allowed in specific profiles have been implemented using web-oriented languages like PHP, Java, and servlets.

Some functions are included for normal operation. Accessible only to teachers or authorized persons, these include:

- Creating and deleting a course.
- Assigning a set of students to a specific course.
- Retrieving data about a student.
- Grouping several problems into a block.
- Defining assignments. Usually, the teacher specifies the timeframe (i.e., when the problem(s) will be available to the students (e.g., the week from May 11 to May 18)).
- Collecting assessment statistics, which will be useful in the evaluation of the students.

Moreover, the administrator must consider profiles other than those of students or teachers. These profiles could include those of teachers not involved in a course but interested in its subject matter, or guests from any location accessing the material online. The administrator is also responsible for feeding appropriate problems to the area accessible to guests.

BACKGROUND AND MOTIVATION

Schumacker [7] mentioned that, under a psychological method called Andragogy,[2] "*the teaching process should be seen as a process of guided interaction between the teacher, the student, and the materials of instruction. [. . .] Andragogy embodies a seven-step process that calls for adult educators to:*

- *Set a cooperative learning climate.*
- *Create mechanisms for mutual planning of instruction.*
- *Arrange for a diagnosis of learned needs of interests.*
- *Enable the formulation of learning objectives based on needs and interests.*
- *Design sequential activities for achieving the learning objectives.*
- *Execute the design by selecting methods, materials, and resources.*
- *Evaluate the quality of the learning experience and needs for further learning*."

This is the direction we have planned to follow with e-status, as a tool for the development of

[2]Andragogy: An attempt to develop a theory specifically for adult learning. (http://tip.psychology.org/knowles.html)

innovative learning scenarios. According to Dhanarajan [8], information and communication technologies (ICTs) allow the immediate transfer of information and an agile interaction with the system, making it possible to accomplish most of the points mentioned above. Point 5 is of particular importance: activities to be done by the students throughout the course must be planned carefully from the beginning. Point 6 is related to the problem creation stage, which is critical if we are to promote effective learning and a positive response from the students. Point 7 will be discussed extensively below.

Our aim is to be more efficient in the following aspects of the teaching process: training, instant feedback for students, and feedback for teachers (as shown in Fig. 2). There is no doubt that feedback can be used to test the quality of this learning experience. Low usage of the tool, uneven use of the proposed problems, or persistently poor responses on some problems are alarming indicators that can mean a variety of things. Teachers must be aware of signals like these and introduce changes as needed. Formative evaluation techniques are easy to introduce in this system, which carry significant advantages over pure summative evaluation:

- Evaluations are intended, by the evaluator, as a basis for improvement.
- Cumulative errors and delays are avoided, since they are rapidly detected, and
- The pace of the course can be altered according to students' needs to fill specific gaps in knowledge.

The objectives of the e-status project are:

- To build a pedagogical system to help the students learn statistical reasoning through solving problems with a degree of inherent uncertainty.

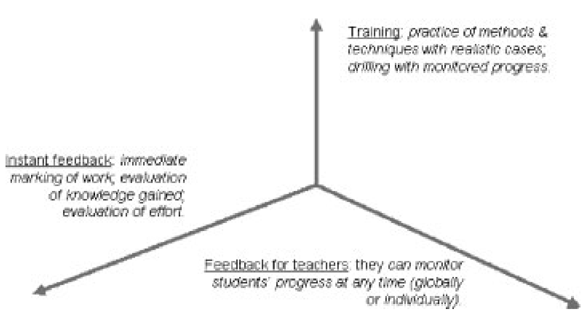

Figure 2 Key factors for effective teaching.

- To help students avoid reaching conclusions led by prejudice or intuition.
- To define a methodical plan to reach a solution, and
- To teach students how to interpret numerical and graphical data.

We are in agreement with Garfield [9]: "*As goals for statistics education change to broader and more ambitious objectives, such as developing statistical thinkers who can apply their knowledge to solving real problems, a mismatch is revealed between traditional assessment and the desired student outcomes. It is no longer appropriate to assess student knowledge by having students compute answers and apply formulas, because these methods do not reveal the current goals of solving real problems and using statistical reasoning*".

The development of mathematical thinking in our students is crucial to their professional future: their ability to manage a problem and lead it to an efficient solution is closely related to their analytical abilities. However, students will achieve an appropriate level of mathematical reasoning only if they face a variety of situations that compel them to apply their skill. In turn, their skills are reinforced by this process. These skills, collectively known as *intellectual habits*, comprise several levels:

- Comprehension and knowledge
- Application
- Analysis
- Synthesis, and
- Evaluation

These levels are related to their ability to transfer knowledge from one field to another, their competence in facing new problems, and what is generally referred to as critical or reflexive thinking. These levels, based on Bloom's taxonomy, are dealt with in detail in Besterfield-Sacre et al. [10]). As Figure 3 illustrates, computer tools such as e-status are a powerful way to strengthen these habits, especially the lower levels (which are simpler to implement in a program). Analysis, synthesis, and capabilities for evaluation require more work from the students, and a direct implication of the teachers is necessary in order to assess their answers. Computer resources can therefore play only secondary roles, which are far from negligible, however. For instance, published problems could be discussed in the classroom.

Notice that we are not focusing on the higher levels of intellectual thinking. These levels should be reinforced with other methods.

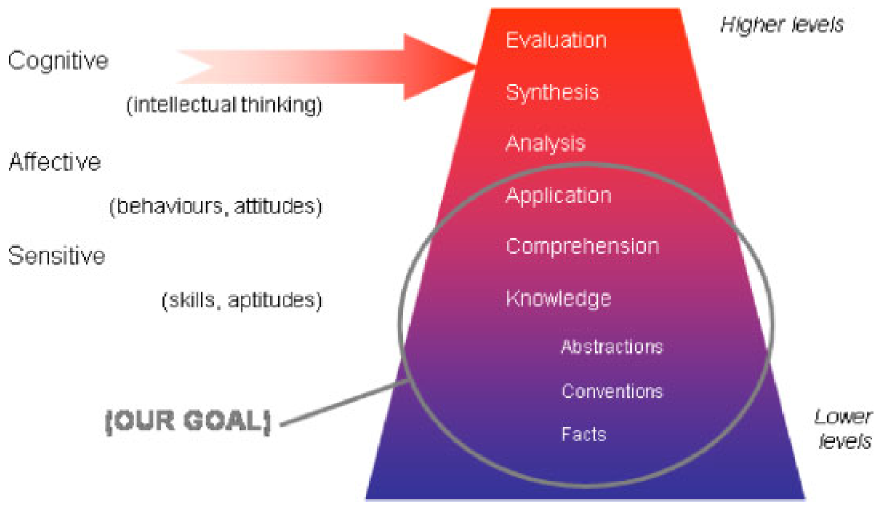

Figure 3 Types of learning according to Bloom's taxonomy.

SUCCESS FACTORS

Some important features of the tool, related to pedagogical considerations, are worth mentioning:

- e-status is not only a tool for fostering mechanical learning: computations can be carried out by computer (and students practice with the software used in the course).
- Students are encouraged to try a diversity of problems by the score system.
- To sum the means of each problem solved at least once.
- The message to the students is therefore: "try to work on many problems, and do not waste your time on a particular one."
- This score is useful in ranking the student within the class, but competition might be a negative factor. Instead, cooperative learning can be promoted. For instance, a group is encouraged to reach a given mark together.

The task of the teacher is, broadly speaking, to provide the students with a basic knowledge, so as to stimulate their learning, and to use suitable tools to measure their progress and achievement within the course goals. Teachers seek to consolidate the students' basic knowledge, in order for them to gain more interest in more specialised areas.

Taking into account that some goals can be related to the higher levels of the intellectual domain, and thus require direct intervention on the part of the teacher, our method can clearly be useful in stimulating students' involvement in the subject matter of the course. The tools provided for monitoring of students' work can be effective in making the teacher's tasks of supervision easier. This will in turn facilitate useful actions within a short space of time. Moreover, by promptly returning a score for the exercise, we reach an important objective in any educational field: students are given immediate feedback of their progress, which entails an effective evaluation stage in the teaching/learning process.

Finally, some simple advice is necessary. What is sought is the implication of the instructors in the methodology, as their commitment is a key factor in achieving a high student participation. Certainly, some of the suggestions below are no different from general rules for designing effective "traditional" problems. However, it should be clear that technology will never transform a deficient problem into an interesting one.

What teachers should consider

- Composing the wording and the questions accurately.
- Providing cases for each lesson in the course.
- Presenting a variety of new situations (i.e., leave aside your old bag of balls).
- Avoid always using the same type of questions (e.g., "*compute the mean of the sample*").
- Including different degrees of difficulty. Take into account that introductory exercises are necessary in order to encourage weaker students, but advanced students may be bored if they do not find challenging problems.
- Making the problems relevant to the course content, and suggesting a specific order for doing them.

- Posing questions that challenge students at each knowledge level, not just problems that involve ‘‘mechanical’’ skills.
- Elaborating good sets of problems (go over the course contents of every lesson).
- Informing the students how e-status participation affects the final assessment. If they feel the effort is not worth it, they probably would not use the tool.

What students should take into account

- Alternating study and problem solving.
- Spend the necessary time: do not answer without thinking carefully.
- Doing the same problem several times is advisable and useful, but students should also know when to move on to another problem.
- Students should monitor their progress regularly, and work on improving their weaker points.
- If they do not understand questions, or repeatedly produce incorrect answers, they should look for another way forward (e.g., asking the teacher for help).

CONCLUSIONS

When used systematically, tools based on ICTs ought to induce a significant improvement in the quality of teaching. As stated above, students can strengthen their knowledge acquisition, and teachers have the means to follow up the students. Teachers are also able to change teaching activities as necessary throughout the course, so that students can attain better results.

Preliminary tests show that students are interested and curious in e-status, mainly owing to the novelty of the application. Tests have proved to be useful in detecting the shortcomings of the interface and have given rise to suggestions for improving the application. At present, the authors are involved with teachers from three different universities in Catalonia, Spain, in the real-life operation of e-status. The courses involved are from a variety of fields, such as computer science, medicine, biostatistics, and environmental science. The participation ranges from 20 to more than 200 students. This project is an effort to assess a variety of learning by problem-solving strategies, by observing student responses to the application, and determining how to integrate distance learning with classical teaching methods.

This work will continue as the results obtained are analyzed, as validating the method would be desirable. Furthermore, verifying that e-status clearly improves academic performance in comparison with traditional methods would also be desirable (according to statistical methodology, broadly used in many fields, particularly in clinical trials). However, we are aware that these sorts of conclusions may not be drawn lightly, since one cannot isolate the many factors that affect students’ learning. A random assignment of students, that is, to partition them at random so that some gain access to e-status while others do not, would not be appropriate. This is firstly due to ethical reasons: many students would understandably feel discriminated against if they were not granted access to the tool. Second, it would be unfeasible to design a double-blind experience, that is, to keep participants from knowing each other’s treatments.

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BIOGRAPHIES

José Antonio González received his BSc degree in computing science in 1990 and the PhD in 1997 from the Technical University of Catalonia (UPC; Barcelona, Spain). His main areas of interest include numerical optimization and modeling, and research in teaching statistics using information and communication technologies (ICTs). He is currently a lecturer in the Department of Statistics and Operations Research of UPC. He is also a member of the Sociedad de Estadística e Investigación Operativa.

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