

THE DESIGN OF A WEB-BASED TRAINING SYSTEM FOR SIMULATION ANALYSIS

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ABSTRACT

Simulation beginners often spend a great amount of time to accumulate the knowledge as well as the experience to overcome the technical complexity of computer simulation. Limited by time availability, classroom instructions usually contain little simulation statistical analysis after many hours of simulation modeling and programming. However, the success of a computer simulation project depends greatly on the effectiveness of simulation statistical analysis. Internet asynchronous web learning reduces the workload of classroom teaching. To help the novice learn better simulation problem solving, this research addresses designing the usability into computer-based training (CBT) environment by focusing on the simulation experience and the interaction design. A prototype asynchronous web CBT system was built for validating our design via a three-stage formative usability evaluation.

1 INTRODUCTION

Due to time constraints in classroom settings, learning computer simulation is limited to simulation concepts, modeling and programming in general. Statistical analysis is often simplified and received a lower priority. However, a successful simulation application depends greatly on the effectiveness of simulation statistical analysis at the end. Thus, an efficient and effective way of learning simulation statistical analysis merits more research.

An effective and efficient way of learning simulation statistical analysis should balance both the quality and the quantity between the fundamental theories and practical experience in order to culture the problem-solving performance in practice (Tao 1999). Computer-based training (CBT) has been widely applied in learning after personal computer getting popular in the eighties. According to the survey of Whitehouse and Pellegrin (1995), utilizing personal computer and software to raise the knowledge of students can save up to 70% of training time. Recent popularity of Internet has brought more benefits into asynchronous distance CBT learning, such as the 24x365 availability, better interactions between students and instructors, and

virtual classroom space. Accordingly, asynchronous simulation-analysis CBT system can be used as an after-hour teaching assistant to traditional classroom learning.

The objective of this research is to design a web CBT learning system that provides effective and efficient features for the beginners to learn simulation statistical analysis. The scope is limited to simulation statistical analysis because this CBT system is intended to be supplemental to classroom learning. The target users are college students with basic statistical training and had learned or are in the process of learning simulation. Consequently, this research focuses on the part of designing such systems that will help the novice the most in addition to classroom learning. The remaining paper is organized as follows: literature review in Section 2, research design and scope in Section 3, actual design and prototype system in Section 4, followed by evaluations and conclusions in Section 5.

2 LITERATURE REVIEW

2.1 Simulation Statistical Analysis

Compared to the methodology of simulation modeling and analysis, the practical experience of simulation statistical analysis is less investigated in literature. Mellichamp and Park (1989), Ramachandran *et al.* (1988), Taylor and Hurion (1988) and Tao and Nelson (1997) had investigated simulation experimental design and analysis and proposed some theoretical framework or prototype systems. On the applications, Goldsman *et al.* (1991) solved a simulation problem with three different approaches but with same conclusion. Tao and Guo (2000) provided a mental model for simulation statistical analysis, including two cognitive principles, two design indicators and a heuristic problem-solving process. Although the above knowledge and experience of simulation statistical analysis are precious, they cannot be easily shared during the classrooms settings. Therefore, how to effectively teach or learn the simulation statistical analysis in limited classroom hours is a worthy researching issue.

2.2 Computer Based Training and Learning

Constructive educational theory emphasized utilizing artifacts for motivating stimulating learning. However, simulation statistical analysis as the content is difficult and boring to students. Gragné *et al.* (1988) and Bayer (1991) had all indicated that a CBT artifact should include the following instructional design principles: guiding attention, informing learners of the lesson objective, stimulating recall of prior learning, presenting stimulus materials with distinct features, providing learning guidance, eliciting performance, providing informative feedback, assessing performance, and enhancing retention and transfer. That means class instruction needs to be able to control the interactions between the teacher and students in order to be effective.

There are seven learning styles for CBT, including constructive learning, situated learning, case-based learning, apprenticeship learning, project-based learning, story-based learning and collaborative learning (Zu and Chang 1998), which can also be used to effectively enhance the interactions between the instructor and students.

2.3 Interactive System Design

Newman and Lamming (1995) indicated that understanding target user's mental model could help designers to appropriately design the interior of a learning system. End users can effectively learn the proper system interactions through an external system image that is usually the user interface in interactive system environment. A good design of the user interface let the end users learn the system easily and thus can focus more on the learning instead of the use of the user interface. The Internet or World Wide Web (WWW) introduces more concerns into traditional interface design, which ought to be considered together.

Norman (1986) proposed a model of a seven-stage interaction, including goals, intention, action specification, execution, perception, interpretation and evaluation. Based on Norman's model, whether the goal of a web learning system is met depends on user's participation in the evaluation. Therefore, the combination of prototyping system development and usability test provides a better approach to explore and satisfy users' needs. Also, a formative evaluation is a better option that can avoid the problems caused by a summative evaluation only evaluates an interactive system development at the end.

3 RESEARCH DESIGN AND SCOPE

Based on the above issues and related review, this section describes the problem definition in Section 3.1, user profile in Section 3.2, organization of analysis experience in Section 3.3, interaction design principles in Section 3.4, and evaluation design at the end.

3.1 Problem Definition

To meet the usability goals of efficiency and effectiveness, this research focuses on two important issues, simulation statistical expertise and the easy-of-learning of the asynchronous CBT environment for simulation novice. In other words, we propose a simple experience organization model for simulation statistical analysis and a set of guidelines with demonstrations for designing a web CBT system that balances both the domain knowledge and experience of simulation statistical analysis.

3.2 User Profile

In order to meet the usability goal, we describe the user profile as follows. The user is computer literacy but may not be at the expert level, has web experience but minimum contacts with web learning systems, has knowledge of introductory probability and statistics but may not be familiar with statistical analysis software, prefers practice during learning and cares about quality not quantity of learning, wishes to gain problem-solving skill in short period of time, and is interested to learn simulation statistical analysis in a pressure less environment.

3.3 Organization of Analysis Experience

The expertise in simulation analysis as a content for the novice needs to be incrementally adaptable in terms of its representation. We address the teaching contents in this research by collecting and proposing contextual problem-solving guidelines, problem-solving process and learning unit design in ascending order in terms of the level of description. Contextual problem-solving guidelines are the finest tactics the expert applied to solving a problem, and are embedded in the problem-solving process. The learning unit design presents the segmentation of the learning contents, which includes both the guidelines and the process.

3.4 Interaction Design Principles

In the analysis and design of interactive systems, design guidelines provide designer suggestions and solution strategies to individual design problems. Literature has rich teaching and interface design guidelines where supplemental, conflicting or overlapping effects may exist among guidelines. Moreover, after a certain number of design guidelines have been applied, the improvements start showing insignificant marginal effects. Therefore, the approach for adopting design guidelines in this prototype system development is to use trial-and-error and hopes to achieve 80% of usability goals with minimum set of guidelines. However, the achievement of usability remains to be judged by the users.

This research applied mostly categories of instructional design (Bayer 1991; Gragné *et al.* 1988) and interface design guidelines (Zu and Change 1998; Dix *et al.* 1998;

Marcus 1992; Shneiderman 1992). We also applied self-inductive guidelines from experiences and observations over the Internet.

3.5 Evaluation Design

Formative evaluation is used in this research to avoid finding critical problems only after the prototype system development is completed. A three-stage of formative evaluation, including user's testing evaluation, experts' constructive and executive evaluation and user's summative evaluation, is described as follows:

User's testing evaluation. The purpose is to conduct an informal evaluation on the initial design of teaching system and interface, so that users' can feedback the discrepancy as much as possible and as early as possible. The data sets are collected from students browsing through the initial prototype system by means of observation and audio recording. Retrospective interview and verbal protocol analyses are performed for qualitative results.

Expert's constructive and executive evaluation. The purpose is to evaluate the contextual design, instruction style and interface design from experts' perspective. The data sets are collected from experts' heuristic evaluation. Retrospective interview is performed for qualitative results.

User's summative evaluation. The purpose is to understand the usability and learning effects of the final prototype system implemented for this research. The evaluation first compares all subjects test scores for understanding the performance differences before and after the learning session. Because the subjects are divided into control group who learn by a written materials and experiment group who learn by a CBT system, the after-learning scores are also compared for the two groups. Then a usability survey about the prototype system is distributed to the experiment group. All these evaluations are analyzed quantitatively.

4 ACTUAL DESIGN AND PROTOTYPE

4.1 Statistical Analysis Experiential Principles

In computer simulation, there are some specific concepts that are not clear to information-technology capable practitioners, such as initialization bias in steady state system, correlated data and time-persistent variables, which makes learning experimental design and analysis more difficult. The problem-solving principles in this research are based on the framework and the concept of sequential experiment from Tao and Nelson (1997) and expert experiences from Goldsman *et al.* (1991) and Kleijnen (1987). We organize these experiential principles into six different categories: paradigm, system or parameters or alternative systems, resource or experiment or design, output data, statement or scope or result, and analysis or procedure.

4.1.1 Paradigm

The goal of paradigm is to provide practitioners a correct mindset about simulation problem-solving analysis, which is an incremental and data-driven process. Some of the principles are as follows:

Principle 1-1 Perform a simple pilot run for generating minimum data at the very beginning. The main purpose of this minimum initial data set is to support the practitioner's first experimental design. Another purpose is to assist inspecting the simulation model and program in order to find any possible errors as early as possible.

Principle 1-2 Design next optimal experiment from accumulated data. The purpose is to minimize expected deviation or potential error and conserve time and other resources for subsequent experimentation.

Principle 1-3 Nonlinear reasoning logic. Based on existing data, a simulation process can be revised without following the fixed path. In other words, a task path $A \rightarrow B \rightarrow C$ can be altered if necessary. For example, when searching for the best system, one does not need to examine statistical assumptions for each alternative. However, the assumption still needs to be validated in final analysis.

4.1.2 System/Parameter/System Instance

A system is like a black box with one or more parameters and takes prescribed input and produces corresponding output, while parameters are a collection of constants that define an instance of a system. Accordingly, a system instance is a system with a set of fixed values of the system-dependent variables.

Principle 2-1 Collect the problem properties continuously. This will affect the selection of analysis procedures, e.g., initial error detection is required for steady-state systems, but not for the terminating systems.

Principle 2-2 Take advantages of existing data for predicting future analysis during the problem-solving process. The potential benefit is that data calculation time can be saved and analysis complexity can be reduced. For instance, when testing the minimal number of machines to complete 95% of jobs on schedule, we may start with 6 machines and then jump to 10 machines if the result is relatively poor. If the 10-machine system still does not work, then we do not need to consider the 8 or 9 machine systems.

Principle 2-3 Divide the major task into smaller ones that can be solved easily or easier. For instance, one can divide a large-scale queueing system into subsystems or focus the analysis on the bottlenecks, which may greatly simplify the experimental design and speed up the entire process.

Principle 2-4 Group system instances based on the similarity at the early stage of problem-solving process. For example, if we compare four different bank system instances: one waiting line for four clerks; one waiting line for six clerks; multiple lines for four clerks; multiple lines

for six clerks. We can classify them into two groups according to the structure of waiting lines. Then we compare one-line systems with multiple line systems before deciding on the number of clerks.

Principle 2-5 Eliminate inferior system instances. Goldsman *et al.* (1993) had classified system instances into three groups: potential, inferior and the remaining. If there are too many system instances need to be studied, we should try to identify and eliminate the inferior group from the analysis.

4.1.3 Design/Experiment/Resource

A design consists of the number of replications, the stopping time for each replication, the random number assignment, and the data aggregation technique, which is subject to various resource constraints:

Principle 3-1 A design interrelates with many resources. Typical resources are time, data, and information. All resources can be converted into time for comparisons. For instance, doubling the precision of output results usually quadruples the CPU time.

Principle 3-2 Keep in mind the remaining time. Every run can generate data containing averages and standard deviations. If the expected precision is not met, another experiment may be needed and is subject to the time availability. Even though computer speed is increasing, it is hard to make up the wasted time due to design errors.

Principle 3-3 Design with available resource in mind. For instance, we may design an experiment that can produce a very precise solution but requires 20 days. If the project needs to be closed within 10 days, we should choose another design that is less precise but requires only 8 days. In simulation, there is no perfect design but an acceptable design.

Principle 3-4 Dynamically design parameters during the experiment process. For example, a pilot run for a steady-state problem produces 2000 observations and the output analysis suggests that the initial deletion period should be at least 1000 observations. In this situation, one should increase the run length immediately to avoid wasting time before the production run.

4.1.4 Output Data

Simulation generates a lot of data that should be carefully utilized to perform statistical analysis:

Principle 4-1 Incremental data generation. One should accumulate simulation data during the complete problem-solving process. If there exists 10 pilot runs before the production run, then the production run can use different random number streams. This saves a lot of data generation time and reserves the track of the whole process.

Principle 4-2 Manage the data size by batching data. For example, if the output data contains 30000 observa-

tions, then it can be better managed as 30 batches, each has 1000 observations. This saves the storage space and the analysis time.

4.1.5 Statement /Scope /Result

In the process of simulation sequential analysis, results at different stages have different scopes and applications. Therefore, results can be recorded as statements for further references:

Principle 5-1 Anything said about the system instance is a statement. Statements are accumulated information and are useful for next design or experiment.

Principle 5-2 Keep original documentation during the problem-solving process. Maintaining intermediate results helps to understand the relationships between the final results and the designs and experiments in order to make correct decisions. The scope indicates the data used and statements referred for reaching a new statement.

Principle 5-3 Propose suggestions to simulation results. For example, a simulation study may identify two competitive system instances with the same overall performance. If each instance excels in different performance measures, then a suggestion along with the results should be provided to the decision maker.

4.1.6 Analysis /Procedure

An analysis derives statements about systems while a procedure is a function of data and statements that produces a new statement:

Principle 6-1 Use existing tools to save time. Commercial versions of simulation software often provide adequate support to perform the output analysis. If not, one can use statistics software or Excel spreadsheet as well as programming languages, such as C, to calculate variance or perform pair-wise hypothesis testing. Any tool that is familiar to the practitioner is better than the others.

Principle 6-2 Use statistical procedures within user's capabilities. For example, if one wants to compare system instances and is not familiar with MCB, then less powerful methods such as ranking-and-selection may provide a better choice.

Principle 6-3 Use visual methods for exploring data. Visual illustrations may provide more insight than data listing. For example, scatter plots or histograms are simple to read and understand than data tables.

Principle 6-4 Confirm the visual judgment with test procedures. Although visual illustrations are easy to understand, it is still necessary to confirm the result using more rigid methods. However, how to decide the discrepancy depends on the practitioner's experience and time constraint.

The above six categories of experiential principles may not be complete due to references and time constraints. But they are adequate for this research to validate the ex-

perts' problem-solving processes and to derive a simple and useful flow to assist the learning of an online simulation analysis system.

4.2 Problem-Solving Process

The principle of conceptual design is to identify the intended mental model and hide the complex insight by providing a simple representation. As a result, the expert's problem-solving model is simplified as shown in Figure 1.

The CBT system is intended to be used after the simulation model is constructed. Thus the model starts with multiple system comparison and includes some of the experiential principles listed in the preceding section.

Step 1 judges the system type and needs to apply principle 2-1. Step 2 decides a project to start with and can apply principles 2-3 and 2-4. Steps 3 and 4 need to determine whether to apply Variance Reduction Technique (VRT), such as Common Random Number (CRN). Step 5 simulates minimum data for leading next design and can apply principles 1-1 and 1-2.

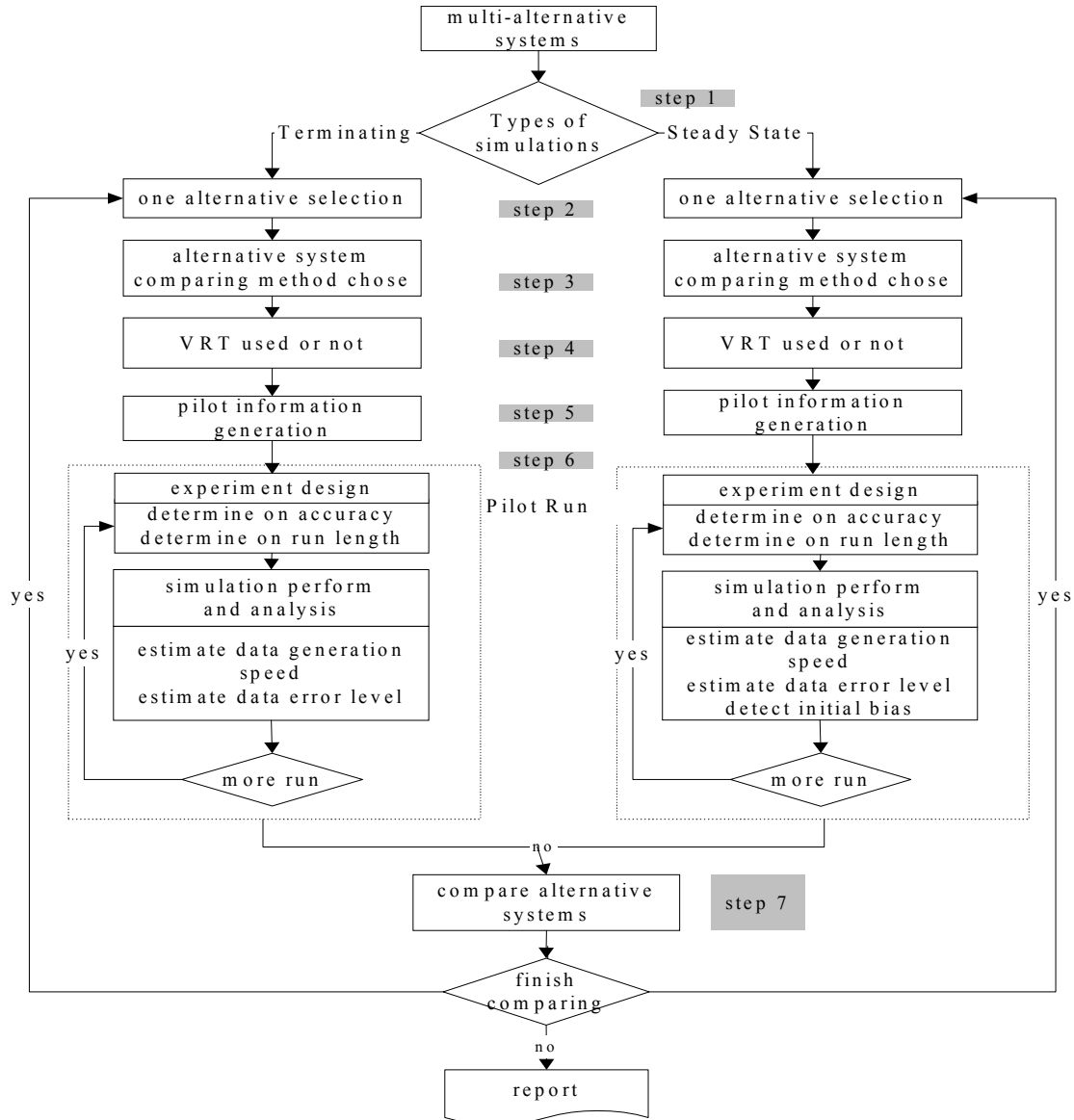


Figure 1: Problem-Solving Flow of Simulation Analysis

Step 6 enters pilot run procedure that starts with experimental design (principles 3-1, 3-2, 3-3, and 3-4), followed by simulation execution and output data analysis (principles 2-2, 4-2, 6-3, and 6-4). At the end, principle 4-1 may be used to judge whether remaining execution time is enough. Step 7 compares alternative systems and draws conclusions based on principles 5-2, 5-3, and 6-2.

This problem-solving process is based on the multi-system comparison. For single system evaluation, it still starts with Step 1, but Step 7 is ignored. The purpose of this problem-solving process is to incrementally design and experiment simulation problems, i.e., iterates the pilot run process. It is intended to be a simplified expert model for beginners and emphasizes learning problem solving while building the mental model.

4.3 Learning Unit Design

Our learning environment includes five major instruction units: learning guidance, introduction to simulation, simulation theory, problem-solving tactics, expert problem-solving flows, and case-oriented learning. Learning guidance is to provide a roadmap for three different levels of users. Introduction to simulation briefly introduces simulation characteristics, applicable domains, and pros and cons. Simulation theory presents brief but fundamental simulation knowledge that includes methods and techniques in input/output data analysis. Problem-solving tactics and expert problem-solving flows are as seen in Section 4.1 and 4.2. Case-oriented learning assists the users to learn from solving a problem with embedded tactics and expert process.

The prototype system also includes student record management, message board, and online discussion. In summary, the above learning units provide an integrated learning framework and emphasize both the knowledge and experience during the learning. The focal point is on the problem-solving tactics and case-oriented learning units to maximize the effectiveness of the system.

4.4 Design Guidelines and Demonstrations

We use two screen shots (in Chinese) to present the primary design guidelines for better illustrations.

4.4.1 Example 1: Figure 2

The left side of screen shows the five teaching units (circle A). The following discussion is divided into eight parts.

- (1) The upper screen shows the path of the learning contents (circle B), “case-oriented learning>single system instance >steady state > start simulation > determining sample size”, which not only indicates current position, but also provides hyperlinks to previous screens.
- (2) A little blue palm (circle C) near the right edge of the screen provides a pop-up window that explains the

purpose of current screen. This applies the guideline for **providing instant online help on a needed basis**.

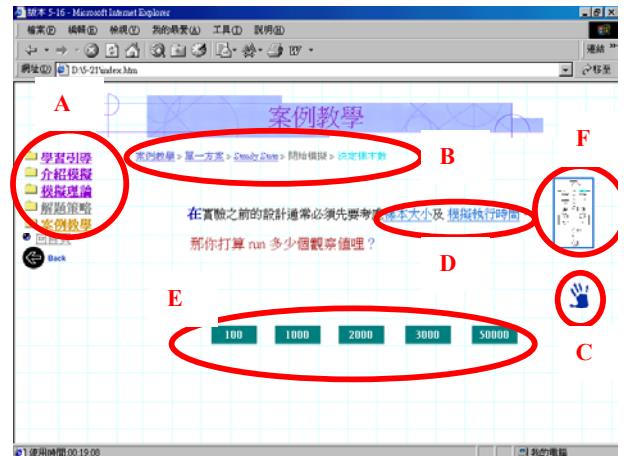


Figure 2: Sample Screen # 1

The first two parts apply guidelines of avoiding lost, reducing short-term memory load, stimulating recalls of prior learning and providing convenience reversal browsing.

- (3) In the middle of the main screen shows the dialog between the user and the system. As indicated by the path in (1), the current step is determining initial sample size at the very beginning of the simulation process. The system prompts to decide the sample size and simulation time, where the user can click the hyperlinked words “sample size” or “simulation time” (circle D) for explanations before making decisions. The applicable guidelines are **providing online help for critical terminology** and **hiding unnecessary information**.
- (4) The prompted system message in (3) is in black font color with blue underline representing hyperlinks. Also, the prompted question asking for sample size is in red color with five selection buttons in green (circle E) listed below. The guidelines applied here are **using up to seven colors for segmenting different purposes of information** and **providing stimulus materials with distinct features**.
- (5) The green buttons (circle E) provide alternative answers on the label to the current question. If an inappropriate answer is clicked, the system pops up an explanation window instead of proceeding to next step. After the user exiting the pop-up window, the system retains the same question until appropriate answers are selected. The purpose is to **provide situated learning environment, emphasize constructing knowledge by user, provide information feedback and provide learning guidance**.
- (6) The question in the dialog actually represents one of the difficult decisions of simulation statistical analysis

- for beginners. Experiential principle 1-1 is hidden during the process described in (5).
- (7) The right edge of the screen, above the little blue palm, shows a little flow diagram (circle F). By clicking the image, a full screen of the problem-solving flow diagram as seen in Figure 1 will display with the blue area representing the current step of the process. The guidelines applied are **providing recall of prior learning** and **providing learning guidance**.
- (8) The screens are designed to use paging instead of scrolling as much as possible in order to **avoiding wearing out user patience due to long transmission over the Internet** and **reducing cognitive pressure of long documents**.

4.4.2 Example 2: Figure 3

Figure 3 presents a similar screen as in Figure 2, except without the little blue palm and red color question. The purpose is to be **consistent** and **providing only necessary information or functions**.

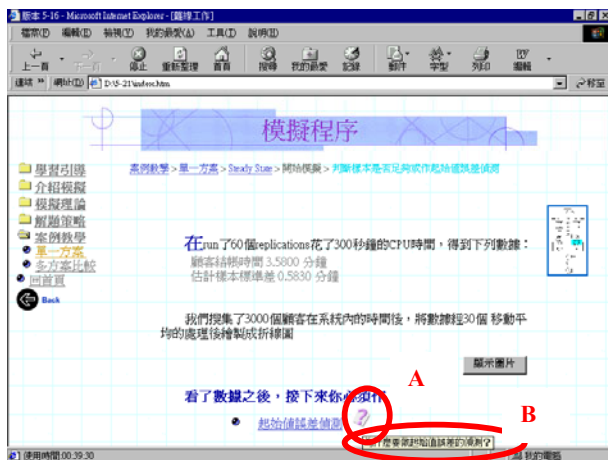


Figure 3: Sample Screen #2

The bottom of the screen shows a pink question mark (circle A). By clicking the image, the explanation (of initial bias detection) pops up for that option. It is a similar function like the little blue palm in Figure 2, but only applicable when choosing the next step. The applicable guideline is also **providing instance online help on a needed basis**.

Either little blue palm or pink question mark provides optional online help. However, the user may not know their usage at the first look. Therefore, the system provides bubble balloon (circle B) that offers a brief explanation when the cursor is near the image. The purpose is to provide **interactive proactive clues**.

The screen layouts in Figures 2 and 3 addresses the **con-cise** principle by adapting the following features: page-long content, short paragraphs, wide spacing between paragraphs and sentences, hiding unnecessary information with hyper-link, color segmentation, hierarchical information with se-

lection buttons, and primary information in the middle with bright background color.

In order to **retain user's learning interests** for long hours of complicated and difficult domain knowledge and experience, the system contains images/graphics in the learning activities as well as background music to entertain the users.

5 EVALUATION AND CONCLUSION

Formulation evaluation was used for the prototype system, including target users' testing evaluation, expert's constructive and performance evaluation, and target users' summative evaluation. Only the target users' summative evaluation is described below.

We conducted a user evaluation to 30 university students who had completed a 3-credit-hour simulation introductory course. The students were divided into control and experiment groups with the control group studying a written material while the experiment group studying the CBT prototype system. Each session lasted 60 minutes that included a 10-minute introduction and practice, a 10-minute simulation test, a 30-minute simulation learning, and another 10-minute test. The experiment group filled one additional questionnaire regarding the prototype system. Based on our usability goals on efficient and effectiveness, the evaluation included subjective interface opinion and objective learning scores in which the performance of overall population and control versus experiment groups were compared.

Learning performance analysis was based on the student's subjective opinions on the questionnaire, and the objective test scores before and after the learning period. First, the t-test results indicated that the test scores after the learning periods are not very different between the control and experiment groups. That is, learning the written material and the prototype CBT system made no significant different on the test scores. One possible explanation is that the 30-minute learning may not be long enough to detect possible differences. Also, it would be better if the experiment were performed in the simulation class instead of two months after the course.

However, the additional questions in the same test indicated that two items "boring" and "interesting" made significant differences between the two groups with $\alpha=0.05$, while "convenient" and "effective" did not. That is, subjectively speaking, the experiment group felt more interesting and fun learning simulation analysis. This suggests if learning time increases, the performance may starting showing significant difference on test scores since the prototype system maintains the learners' motivation better than the written format. Also, the interactions on the prototype system provide options for constructive learning that cannot be included in the written format.

Even though the t-test showed insignificant difference on the "convenient" item. The data revealed that control group favored the written format. It is probably because

the written format can be easily carried around. Since the material has the same content as the prototype system, a good option is to make written material downloadable for students using the CBT system.

Finally, the test scores before and after the learning period showed significant differences; therefore, the intended knowledge and experience appeared to be useful for assisting learning simulation analysis.

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