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WHAT DOES THE COMPUTER CONTRIBUTE TO LEARNING?

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Abstract—This paper describes a study conducted with Stat Lady, a computer-based approach to teaching and learning the rules of PROBABILITY, based on the postulate that learning is a constructive process, fostered by an experiential learning environment that is anchored in real-world problems. This study compared learning from Stat Lady vs learning from a paper-and-pencil Workbook version of the identical curriculum, and addressed the question: "What does the computer contribute to learning?" Findings showed that Stat Lady learners performed at least as well (and in some cases, much better) on the outcome tests compared to the Workbook group. Specifically, we found that (a) Stat Lady was clearly the superior environment for high-aptitude subjects, (b) Stat Lady subjects acquired significantly more declarative knowledge than the Workbook subjects, and (c) regardless of aptitude, the majority of learners found the Stat Lady condition to be significantly more enjoyable and helpful than the Workbook condition. Implications for the design of instructional systems and further research are offered.

Over the past three decades, computers have become progressively more important as instructional vehicles, mostly in schools, but also in industry and government. Each year, a little more learning occurs in front of computer screens, and a little less in front of teachers or textbooks. A wide array of educational software is currently available on the market covering a variety of topics (e.g. how to read with phonics or pilot a jet fighter). The implicit presumption is that computerized instruction is better than traditional instruction, like classroom lectures or self-paced workbooks. In this paper we will test this presumption, comparing learning from a computerized system (Stat Lady) to learning from a paper-and-pencil workbook. By holding subject matter and instructional style constant, these two methods differed only in terms of the medium of presentation. The goal of the experiment was to answer the question: "What does the computer contribute to learning?"

Stat Lady is an interactive learning environment instructing introductory statistics [1]. Many students have negative perceptions about statistics, and one motivation for developing Stat Lady was to make the learning experience both easier and more enjoyable. To do this, we created a learning environment that was designed to capture the learner's attention (such as engaging the learner in a betting game using electronic cash), and we interweaved the curriculum into various games and intriguing problem sets. For example, using a bag of chocolate candies as her sample space, Stat Lady would place a bet with learners concerning the outcome of randomly drawing a chocolate from the bag. After placing bets a number of times (and consequent loss of cash), learners would soon realize that many of the games suggested by Stat Lady were unfair from the learner's perspective. To "prove" this, they needed to be able to compute probabilities for different outcomes. Only then would they have the power to select which games they should play, and start accumulating money.

The theoretical basis underlying Stat Lady is that learning is a constructive process, fostered by an experiential learning environment, that is anchored (or situated) in real-world examples and problems. The constructivist approach posits that learners come to new learning situations already possessing knowledge structures on which to seat new knowledge and skills [2–4]. Moreover, there is a lot of support in the learning literature for the notion that knowledge lasts longer because the experience (i.e. "doing" rather than simply "receiving") fosters cognitive growth and structure, and is also more intrinsically motivating [5–8]. In addition, results from research on situated cognition have shown that learning is optimized when instruction is anchored in interesting and real-world problem solving environments [9–15].

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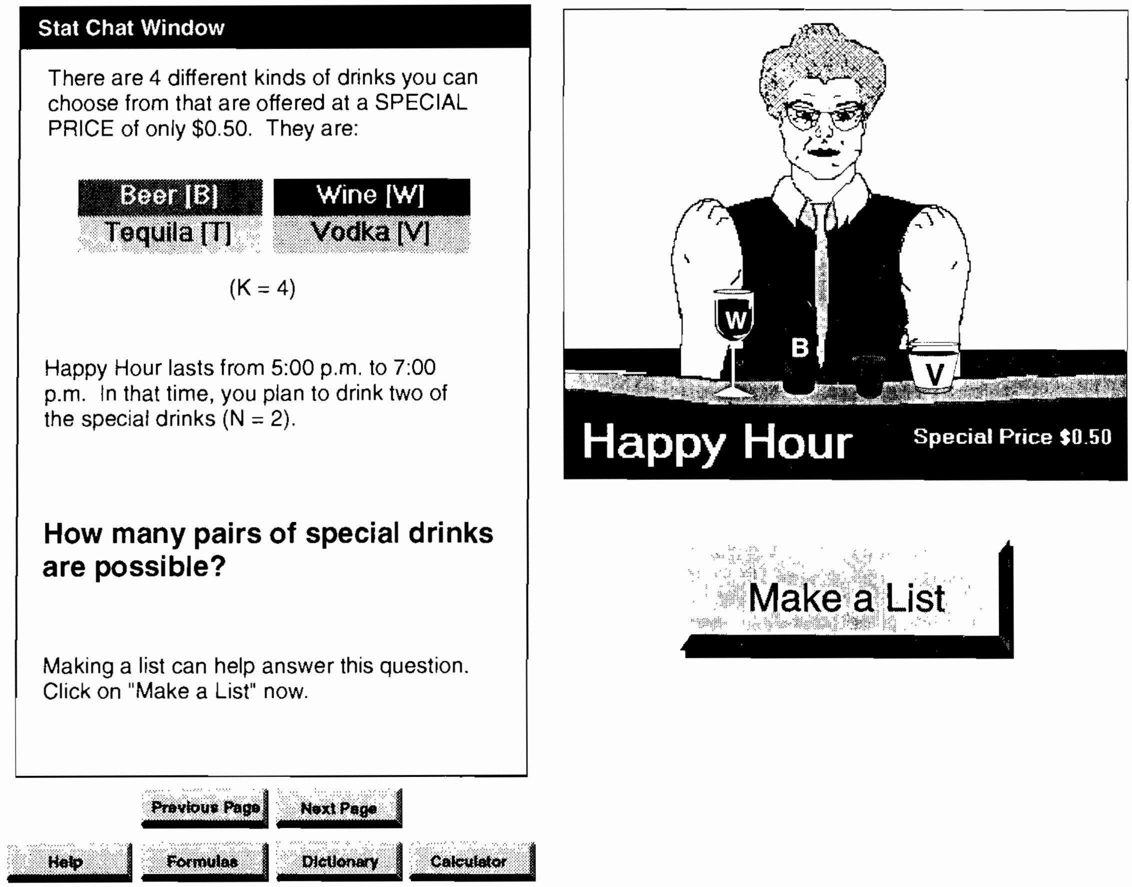

Fig. 1. Example problem from Stat Lady tutor.

Because Stat Lady was designed to reflect the premise that learning should be based on prior, familiar knowledge, she† uses real-world examples for problem-solving scenarios rather than simply providing Statistical formulas to memorize, or tables of numbers to manipulate. Some examples of real-world scenarios include: playing Stat Craps, getting a date through a Personals column, and determining the probability of various genetic traits. In addition, all Statistical concepts are presented in an interactive, *grabbable* format. For example, one problem scenario involves going to "Happy Hour" at a bar where four types of drinks are available at a special price. Learners are required to determine the number of possible pairwise permutations. Figure 1 shows the interface for the introduction of this problem set. When a learner clicks on the Make a List button, the right-hand side of the screen is replaced with simple instructions, and a blank table appears to make the list of all possible combinations. The learner constructs this list by clicking on two drink icons (e.g. two shots of tequila), which then automatically appear in the table as a paired combination. Once the table is complete, the learner must answer the question by computing the number of permutations with a formula ($K^N = 4^2 = 16$) and/or counting the pairs of drinks in the list.

We have recently begun evaluating Stat Lady's efficacy in terms of teaching Probability. Our first evaluation study compared Stat Lady to a traditional college lecture [16]. Results showed that students learning from Stat Lady were able to learn as much Probability information as students learning from a classroom lecture, even though there were several important differences between the two conditions which resulted in a Stat Lady disadvantage. For instance, the professor conducting the lectures had more than 20 years of experience teaching Statistics, whereas Stat

†We use the pronoun "she" (rather than "it") throughout to describe Stat Lady because of her genuinely human personality.

Lady was on her first teaching assignment. Also, subjects assigned to the lecture condition, by chance, entered the experiment with a greater math advantage (shown by higher quantitative SAT scores) than subjects assigned to Stat Lady. Furthermore, the majority of subjects in that experiment were more familiar with learning from lectures than from computers. Finally, that first study reported a significant aptitude–treatment interaction, where high aptitude subjects learned better from Stat Lady than from the Lecture, and low aptitude subjects learned equally in both conditions. For a complete description of these differences see Shute *et al.* [16].

Following this initial evaluation, we conducted a second experiment to test Stat Lady's efficacy. The experiment presented in this paper compared learning from Stat Lady (i.e. the original, computerized version) with a paper-and-pencil Workbook version of Stat Lady. For these two learning conditions, the following variables were the same: the curriculum (i.e. content and sequence of problem sets), presentation style, examples, and help. What differed was whether the material was presented on paper or a computer screen. As mentioned, our goal was to determine the degree to which the computer contributes to learning, beyond traditional paper and pencil instruction. We made the following predictions:

(a) Condition main effect

Subjects learning from Stat Lady would perform better on the outcome measures than subjects learning from the Workbook condition because the computer's environment is more enticing—dynamic, colorful displays, sound effects, and immediate feedback.

(b) Condition by knowledge type interaction

Subjects learning from Stat Lady would acquire greater procedural skill than Workbook subjects given the ease of manipulating objects in the environment into lists and practicing new skills in the solution of related problems. Declarative knowledge acquisition would be comparable across treatment groups.

(c) Condition by aptitude interaction

Due to the disordinal interaction found in the previous study [see 16], high aptitude subjects were expected to learn more from Stat Lady, while low aptitude subjects were expected to learn more from the familiar Workbook environment given differential abilities in adapting to novel learning environments.

(d) Enjoyment main effect

Stat Lady subjects would enjoy their learning experience more than those learning from workbooks because of the computer's dynamic and colorful graphics, sound, and provision of immediate feedback.

METHOD

Subjects

The subjects used in this study were obtained from local temporary employment agencies ($N=311$), and assigned to one of three conditions: Workbook ($N=104$), Stat Lady ($N=107$), and Control ($N=100$). There was approximately an equal number of males and females, per group, with an age range from 17 to 28 years. All subjects were high school graduates, or the equivalent.

Materials

Computerized instruction. Stat Lady [1] is written in Visual Basic 2.0 and runs on 386/486 computers under Windows 3.1. She instructs a range of topics in introductory Statistics, but for this experiment, we focused on the Probability Module. The curriculum for this module resulted from our inspection of six introductory Statistics textbooks, and extraction of the most commonly instructed Probability issues. Stat Lady's domain expertise spans the entire curriculum, from declarative knowledge of Probability concepts (e.g. elementary event, sample space) to procedural skill on how to compute certain kinds of probabilities, e.g. conditional probability, binomial expansion.

The most important feature of Stat Lady is the interactive learning environment where students are encouraged to get actively involved in the learning process. In addition, Stat Lady uses colorful, graphic displays to motivate learners. For example, she has a large wardrobe of problem-relevant costumes, such as a chef's outfit for a problem set on pizzas, and a Las Vegas dealer's outfit for playing Stat Craps. Other features of the tutor include animation (e.g. Stat Lady shuffles and deals cards, flips coins) as well as speech and sound effects. For example, after getting an answer correct, Stat Lady may tell the learner, "Oh, isn't that SPECIAL?!" and there may be a drum roll accompanying Stat Lady as she cart-wheels across the screen (for the correct solution of really hard problems).

Unlike some Statistics professors, Stat Lady is consistently good-natured and knowledgeable—talking with learners, not at them. Furthermore, she provides immediate on-line support, and gives context-sensitive feedback in response to problem-solving activities. For instance, if a learner incorrectly answered a problem with the sum of two probabilities (rather than the product), Stat Lady would respond that, "It looks like you used the Addition Rule, but you should have used the *Multiplication* Rule in this problem because . . .". A probability dictionary is always available, consisting of a listing of relevant probability concepts and rules. For each entry, the concept is defined and an example is provided. Bold-faced words within definitions are also accessible, in a hypertext format. Other support features of the tutor include an on-line Formula & Rule Reference Book and mouse-sensitive calculator.

Paper and pencil instruction. The Stat Lady Workbook was a paper and pencil version of Stat Lady, developed following the first evaluation using Stat Lady. This workbook used the identical instructional text, graphical representations (i.e. actual screen dumps from the tutor), and problem-set items as the computer version. Figure 2 shows the pages in the workbook corresponding to the same problem set shown in Fig. 1. Identical wording was used to introduce this problem set, as well as the graphical representations of the drinks. Learners were required to fill in a table of drink pairs prior to answering the question, but in the workbook, they had to write down the pairs on paper.

Because there were three parts to the tutor, we developed three Instructional Workbooks, bound separately and administered one at a time. We also created three associated Answer Booklets (color-coded to match their workbooks). The answer booklets reiterated problem statements, provided workspace for solving problems, and slots to write down final answers. A help booklet was available at all times consisting of a paper-and-pencil version of Stat Lady's on-line Dictionary, formula & rule reference book, and help for problems within each of the three parts. We created three answer keys, containing all of the correct answers as well as problem-specific feedback for each of the three workbook parts. Finally, subjects in the Workbook condition were assigned calculators, a pair of dice, and other props to simulate the experiential learning environment [underlying Stat Lady.

Cognitive measures. Following instruction, cognitive abilities were assessed with the CAM-4 battery of computerized tests [17]. This battery assesses the following cognitive abilities: working-memory capacity, information processing speed, inductive reasoning, associative learning, and procedural knowledge and skill. Information from these tests was used to investigate possible aptitude–treatment interactions.

Affective measure. Earlier, we hypothesized that subjects would differ in terms of their enjoyment of the learning experience. To gauge this affective factor, we administered a survey at the end of the instructional part of the study. The survey addressed issues related to subjects' learning experience and preferences for various learning environments. The following items in the survey were rated on a five-point scale (from strongly agree to strongly disagree): Learning from the tutor/workbook was an enjoyable experience. The tutor/workbook instructions were clear. The tutor/workbook help was beneficial. My learning experience today was fun. The remaining items were answered with yes/no responses: Do you feel that you learned anything? Have you ever taken a computer-administered course before? Have you ever taken a workbook course before? Do you prefer learning from a workbook? Do you prefer learning from a computer? Do you prefer learning

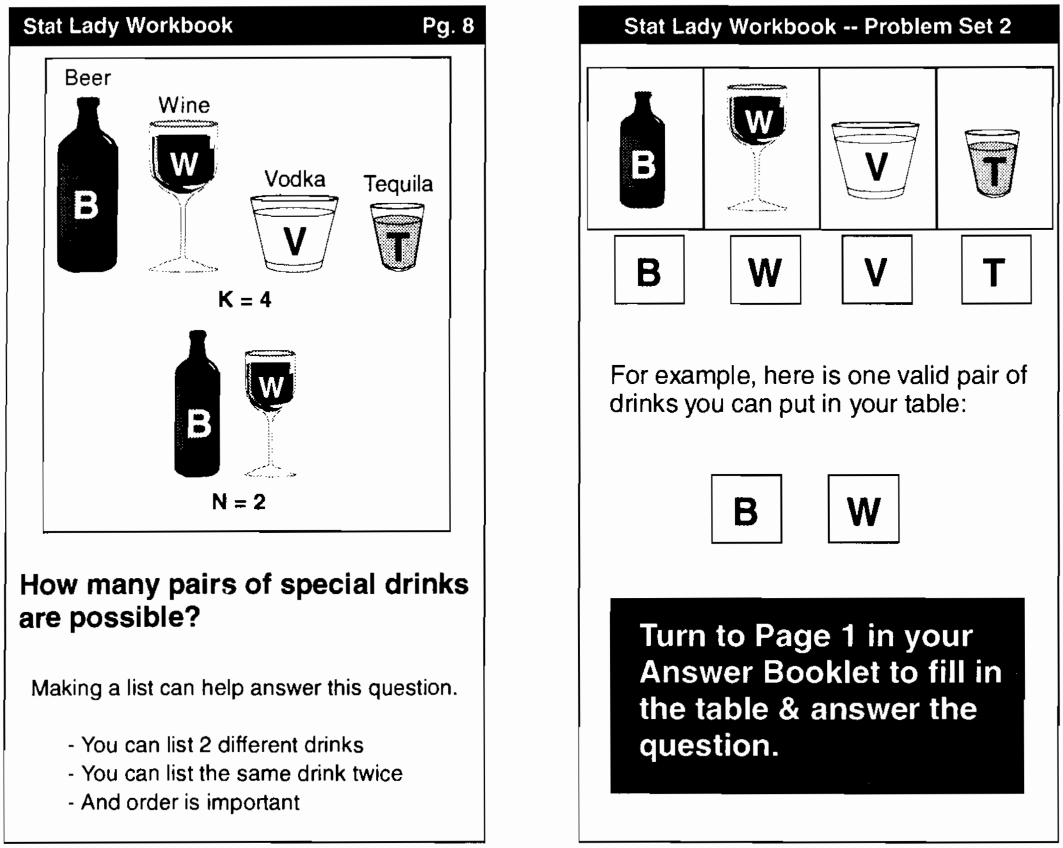

Fig. 2. Example problem from workbook (same problem set as Fig. 1).

from a Lecture? Because these data were anonymous, we could not join them to actual outcome data, but we did have information about the conditions under which the respondents had learned.

Procedure

The first 110 subjects that arrived for testing were assigned to the Stat Lady environment. The next 110 subjects were assigned to the Workbook evironment, and the final 100 subjects were assigned to the Control group. Not all subjects were able to complete all parts of the study, so their data were dropped (final $N=311$). Subjects were tested in groups of approx. 20 persons, and each treatment group participated for two full days.

Day 1. All subjects began the experiment by completing a 1-h pretest (paper-and-pencil) assessing statistical knowledge and skills. This was the same test used in the previous study, and consisted of two parallel forms. After subjects completed the pretest, the proctors provided a brief overview of upcoming events, and some preliminary training on the respective interfaces. That is, the Workbook group received 10 min of instruction on how to use the workbooks and coordinated booklets. Similarly, there was 10 min of computer-administered instruction for the Stat Lady learners to familiarize them with their computer environment, e.g. how to move the mouse around, view dictionary items, and so on. This preliminary guidance was followed by approx. 4.5 h of Probability instruction using Stat Lady or the paper-and-pencil workbook. The three sections of the tutor and workbook were administered separately, each lasting about 1.5 h. Following instruction, all subjects were administered a parallel posttest (1 h). Control subjects received no instruction, and were only administered the pre- and posttests (separated by a 4.5 h interval). After the posttest, all subjects completed a questionnaire about their attitudes towards the learning experience, then left for the day.

Day 2. All subjects were administered the CAM-4 battery of computerized tests which required

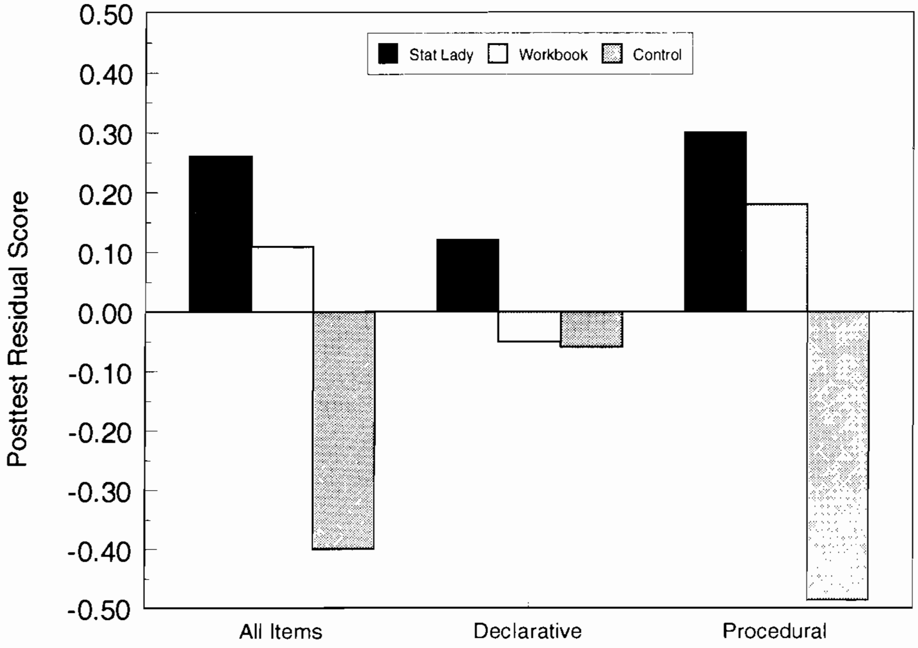

Fig. 3. Learning from Stat Lady by Condition (all items and separated into knowledge type).

almost 8 h to complete (with breaks included in this time frame). At the end of the day, subjects were told about the purpose of the study, and paid for their participation.

To examine differences between conditions in terms of the type of the knowledge acquired, we classified items on the pre- and posttests into two categories: Declarative knowledge (9 items) and Procedural skill (17 items). The *declarative knowledge* items required the retrieval of a statistical concept or definition, while *procedural skill* items required the application of a Probability formula. Reliability measures and a detailed description of the two forms can be found in Shute *et al.* [16].

RESULTS

To control for differences in incoming knowledge, we derived a learning outcome measure that was not confounded by pre-existing knowledge and skills. We regressed posttest onto pretest score and saved the residuals. The "post-residual" represents outcome score, controlling for pretest data. Post-residuals were saved for each individual and used as our dependent measure.

A MANOVA was computed on the residualized test data with the following independent variables: *condition* (Stat Lady, Workbook, Control), *type of problem* (Declarative, Procedural), and *aptitude* (low, high). First, the main effect of condition was significant: $F_{2,308}=9.61$ ($P<0.001$). The left-hand side of Fig. 3 shows this result, i.e. the three bars corresponding to "All Items". As shown in the figure, the main effect was due to differences between the two experimental conditions vs the Control group. There was a slight (but not significant) difference between the Stat Lady and Workbook conditions ($F_{1,208}=0.79$).

The condition-by-knowledge-type interaction was also significant: $F_{2,308}=10.54$ ($P<0.001$). This interaction is also shown in Fig. 3, on the right-hand side. Stat Lady subjects acquired significantly greater declarative knowledge compared to Workbook subjects, who learned no more than the Control group. In terms of procedural skill acquisition, Stat Lady subjects acquired slightly more skills than Workbook subjects, and both experimental conditions acquired greater procedural skill in relation to the Control group.

Next, we examined the data for an aptitude-treatment interaction. An aptitude factor score was computed from the six cognitive measures obtained from the CAM-4 battery. Results from the MANOVA showed a significant condition-by-aptitude interaction: $F_{4,291}=2.60$ ($P<0.04$). We

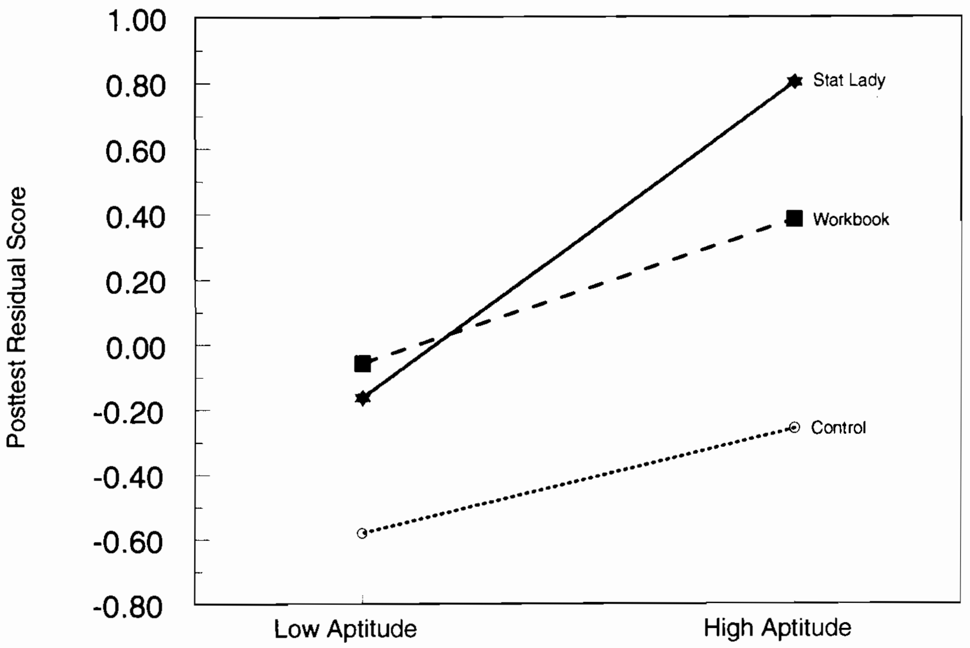

Fig. 4. Aptitude–treatment interaction.

Table 1. Percentage of positive responses to survey data by learning condition

Survey item	Stat Lady	Workbook	*f*	Significance
Enjoyed the experience	**96**	68	13.32	$P<0.004$
Perceived instructions as clear	**94**	59	18.46	$P<0.001$
Found HELP beneficial	**95**	71	8.78	$P<0.004$
Had fun	**90**	48	34.37	$P<0.001$

computed median splits on the aptitude data, and plotted the results of the ATI, shown in Fig. 4. Our hypothesis was supported: high-aptitude subjects did perform better when assigned to the Stat Lady condition. On the other hand, low-aptitude subjects performed slightly better in the Workbook condition (but not significantly different from Stat Lady).

Finally, we analyzed the survey data to see if there were group differences in terms of how subjects felt about their learning experience. The following four (out of 10 possible) variables showed significant group differences: Had Fun, Enjoyed the Experience, Perceived Instructions as Clear, and Found Help to be Beneficial. The percentage of positive responses by condition are shown in Table 1. Stat Lady subjects had more fun learning, perceived their instructions as clearer, and the tutor's help as more beneficial than Workbook subjects, although the content in these two conditions were the same (i.e. identical instruction, examples, problem sets, help).

DISCUSSION

Stat Lady was designed to make learning Statistics more meaningful, and hence, memorable. We sought to achieve this goal by embedding the curriculum in real-world examples, using prior knowledge on which to seat new knowledge, and attempting to make the learning experience more enjoyable by presenting the material in a game-like environment. Furthermore, the hands-on nature of Stat Lady was believed to render abstract probability concepts concrete. The experiment presented here examined the computer's contribution to learning by holding instructional content and style constant, and varying the instructional medium (computer vs workbook—both experiential environments).

We initially hypothesized that, even though the instructional material was identical across methods, Stat Lady subjects would perform better than Workbook subjects on the outcome measure because the computer is more motivating and exciting, rendering the subject matter more memorable. However, this hypothesized advantage was expected to be tempered somewhat because the tests were administered on paper, similar to the Workbook learning environment (and dissimilar to the computer learning environment). Although performance on the combined learning outcome measure (declarative and procedural knowledge) did not differ significantly between the two experimental conditions, there was a Stat Lady advantage. Furthermore, both groups performed significantly better than a Control group. We were encouraged by these results because people in the general population are typically less familiar with computer technology and more experienced with textbook and workbook kinds of learning. So, the many potential benefits attainable through Stat Lady's "bells and whistles" may become obscured by this differential familiarity factor.

On a more specific note, we hypothesized that the Stat Lady environment would promote greater procedural skill acquisition, given the interactive design of the tutor. That is, Stat Lady's environment *required* learners to actively engage in hands-on problem solving within a safe and helpful arena. Whereas Stat Lady subjects did acquire more procedural skill than Workbook subjects (see Fig. 3), this difference was not significant. That is probably because we tried to make both environments active and experiential, e.g. learners had on-line dice to roll in Stat Craps, and a real pair of dice to roll in the Workbook condition. Thus both groups received a lot of valuable "hands-on" learning opportunities.

In terms of declarative knowledge acquisition by learning environment, we found that Stat Lady subjects acquired greater declarative knowledge than Workbook subjects. While not explicitly predicted, this confirmed findings from the first experiment [16] comparing Stat Lady to a classroom lecture. What is unusual about the current finding is that Workbook subjects learned *no more* declarative knowledge than a no-treatment Control group (see Fig. 3) suggesting the computer environment was clearly superior in the presentation of definitions and concepts. This may be attributed to the computer's use of color and sound effects to draw attention to various new concepts, as well as the ease of accessing the on-line Dictionary. Furthermore, the Dictionary's definitions were related in a hypertext format whereby learners could proceed quite easily from one concept to another. The Workbook Dictionary was static (i.e. paper and pencil) and therefore not quite as easy to use.

We also found partial support for our prediction that high-aptitude subjects would learn more from Stat Lady, while low-aptitude subjects would learn more from the familiar Workbook environment. Findings from the current study replicate findings from the previous one. That is, high-aptitude subjects were seen to greatly benefit from the Stat Lady environment, while low-aptitude subjects performed about the same in each condition. This can be attributed to the greater ability of high-aptitude subjects to adapt to novel learning environments. The sooner subjects learned how to navigate the environment, the sooner they could begin playing, betting, listing, counting, and, in general, learning the subject matter in an active, constructive manner. In contrast, low-aptitude subjects were relatively handicapped, having to invest more cognitive effort at the outset as they learned to get around in the novel environment. Only after they were successful could these subjects begin to attend to the curriculum.

Finally, we examined group differences in terms of different perceptions of the learning experience. Stat Lady subjects not only reported a greater enjoyment of their learning experience, they also felt their instructions were clearer, and the on-line help more beneficial, although the text for instructions and help was actually the same across conditions. In conclusion, subjects enjoyed themselves more when learning from Stat Lady, and also learned significantly more declarative knowledge, and slightly greater procedural skill compared to the Workbook group.

So, what does the computer contribute to learning? The results of the present experiment give us three preliminary answers, given this particular domain. First, it appears that Stat Lady (compared to a lecture in a previous study, and a workbook in the current one) is clearly the best environment for high-aptitude subjects. Low-aptitude subjects show no difference in learning outcome by either of these two treatment conditions. Second, the computerized version of Stat Lady appears to instruct declarative knowledge better than a traditional paper-and-pencil workbook. Thus, students may benefit from computerized learning when definitions and concepts are the outcome goal. Third, regardless of aptitude, the majority of learners were very receptive to the interactive and entertaining nature of Stat Lady, and found her to be entirely enjoyable. This suggests that if learners can learn more from an enjoyable computer environment, instructors should do what they can to incorporate this kind of interactive climate into the curriculum. However, instructors should exercise caution in selecting among available computerized instructional programs. Some software is just as boring and difficult as the worst traditional instruction environment. We suggest that learning environments incorporate creative, hands-on problem solving scenarios to encourage learners to become actively involved in the learning process. This will not only improve learning outcome, but also enhance enjoyment of the learning experience.

Implications and future directions

One implication of this study suggests that it may be beneficial to take a *macroadaptive* approach to tutoring and consider general learner aptitudes before assigning individuals to instructional environments (cf. [18,19]). For instance, if aptitude testing took place prior to instruction, high-aptitude students could be placed into the Stat Lady environment to receive the majority of instruction. This would allow instructors more time to provide specialized instruction for low-aptitude students. Additionally, we could develop a modified version of the tutor that allows for more remediation when needed, or more input from a human tutor while the student is learning from Stat Lady.

Findings from this study, in conjunction with results from the initial evaluation, show that students learn declarative knowledge better from the computerized version of Stat Lady than more traditional instructional formats. In most introductory courses, we begin by teaching definitions and concepts that are specific to the domain. When learning Probability concepts, students benefit from computer-delivered instruction for this initial phase of instruction. In general, results from this study suggest that an ideal pedagogical approach for teaching Probability may include elements of both the computer and traditional workbook or lecture. Future research on Stat Lady can help determine the best combination of instructional approaches to optimize learning. We are planning such a test now at the Air Force Academy, comparing learning under the following conditions: Stat Lady alone, Stat Lady as a supplement to an existing Statistics course, and the Statistics course alone. Although one should be cautious in generalizing these findings outside of the specific domain, we believe that the results from the upcoming field test will provide important information about the contributions of computer tutors as instructional tools.

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