The Role of Technology in Improving Student Learning of Statistics

Beth Chance[1], Dani Ben-Zvi[2], Joan Garfield[3], and Elsa Medina[1]
[1]Cal Poly – San Luis Obispo, USA
[2] University of Haifa, Israel
[3] University of Minnesota, USA

1. INTRODUCTION

It is hard to imagine teaching statistics today without using some form of technology. However, just 20 years ago that was very common. Today's statistics classes may be taught in a classroom with a computer projected on a screen, or may take place in a laboratory with students working at their own computers. Students commonly own a calculator more powerful than the computers of 20 years ago. Others may use a portable computer (laptop) at school, home and on the move. An ever growing format of teaching today is over the Internet, in the form of a Web-based course with video-taped lectures, interactive discussions, collaborative projects, and electronic text and assessment materials. The technology revolution has had a great impact on the teaching of statistics, perhaps more so than many other disciplines. This is not so surprising given that technology has changed the way statisticians work and has therefore been changing what and how we teach (Moore, Cobb, Garfield, & Meeker 1995).

This paper presents a broad overview of the role technological tools can play in helping high school and college introductory statistics students understand and reason about important statistical ideas. The main goal is to provide the introductory statistics teacher who is considering using technology in the statistics classroom with some background of how the technology tools have evolved, a sense of the research findings and open questions on how technology impacts student learning, and specific advice for implementing technology. We first summarize the impact of technology on the content, pedagogy, and even format of introductory statistics courses (Section 2). Then we highlight some of the common technological tools currently in use in statistics education (Section 3) and how they can be utilized to support student learning (Section 4). Section 5 summarizes some of the recent research insights gained with respect to using technology to aid instruction and learning in probability and statistics. While not an exhaustive literature review, the studies discussed provide additional context for Section 6, a series of practical recommendations to the instructor, along with a discussion of possible obstacles and implementation issues, and questions to consider when selecting different tools. Our goal is to provide high school and college introductory statistics instructors with concrete advice, stemming from the research literature, on using technological tools and how to avoid common pitfalls or ineffective implementations.

2. CHANGES IN CONTENT, PEDAGOGY, AND COURSE FORMAT

2.1 Changes in Content

Technology has led to numerous changes in statistical practice. Many problems that were previously intractable analytically now have approximate solutions. Many assumptions that were made so that statistical models could be simplified and usable no longer need to be made. These changes in statistical practice have a direct impact on the content that should be taught, even in introductory material. For example, an entire branch of "resampling statistics" (Good 2006) now competes with model-based inferential models in practice, while also appearing more intuitive to students. Another example is the use of statistical tables such as the *z* and *t* tables, which are no longer needed to determine rejection regions or estimate *P*-values when statistical software and calculators produce more accurate results much more quickly. In fact, many statistics educators now argue that previously standard topics in an introductory course (e.g., short-cut methods for calculating standard deviation) are no longer necessary to discuss in class. Finally, technology provides ways for us to visualize and explore data that have led to new methods of data analysis.

2.2 Changes in Pedagogy

While the impact of technology on the practice of statistics is irrefutable, just as powerful has been the impact of technology on statistics pedagogy and recommended practices. For example, the National Council of Teachers of Mathematics (NCTM) *Principles and Standards for School Mathematics* states that "the existence, versatility, and power of technology make it possible and necessary to reexamine *what* mathematics students should learn as well as *how* they can best learn it" (NCTM 2000). In particular, the Guidelines for Assessment and Instruction in Statistics Education (GAISE) curriculum framework for PreK-12 states that "advances in technology and in modern methods of data analysis of the 1980s, coupled with the data richness of society in the information age, led to the development of curriculum materials geared toward introducing statistical concepts into the school curriculum as early as the elementary grades" (Franklin & Garfield 2006). Similarly, the GAISE College Report directly recommends the use of technology for developing understanding of statistical concepts and analyzing data in teaching an introductory, undergraduate statistics course (Franklin & Garfield 2006).

Moore (1997) urged a reform of statistics instruction and curriculum based on strong synergies among content, pedagogy, and technology. However, he cautioned statisticians to remember that we are "teaching our subject and not the tool" (p. 135), and to choose appropriate technology for student learning, rather than use the software that statisticians use, which may not be pedagogical in nature. In fact, many types of technologies are available nowadays for the statistics teachers. Teachers are encouraged to view the use of technology not just as a way to compute numbers but as a way to explore concepts and ideas and enhance student learning (Friel 2007; Garfield, Chance, & Snell 2000). Furthermore, technology should not be used merely for the sake of using technology (e.g., entering 100 numbers in a graphing calculator and calculating statistical summaries), or for pseudo-accuracy (carrying out results to a meaningless number of decimal places) (Franklin & Garfield 2006). More appropriate uses of technology are accessing, analyzing and interpreting large real data sets, automating calculations and processes, generating and modifying appropriate statistical graphics and models, performing simulations to illustrate abstract concepts and exploring "what happens if…" type questions.

Technology has also expanded the range of graphical and visualization techniques to provide powerful new ways to assist students in exploring and analyzing data and thinking about statistical ideas, allowing them to focus on interpretation of results and understanding concepts rather than on computational mechanics. Graphing calculators alone, highly valued for their ease of use, low-cost and portability, have been instrumental in bringing statistical content to lower and lower grade levels.

As the content and focus of the introductory statistics course are changing, statistics courses are looking even more different than in the past. For example, students are evaluated less on their ability to manipulate formulas and look up critical values, and more on their ability to select appropriate analysis tools (e.g., choosing techniques based on the variables involved), assess the validity of different techniques, utilize graphical tools for exploration of data, deal with messier data sets, provide appropriate interpretations of computer output, and evaluate and communicate the legitimacy of their conclusions.

2.3 Changes in Course Format

Technology has also impacted course management in the ways information is provided to students and shared among students in a class. Course management systems like Blackboard and WebCT (both can be found at http://www.webct.com) are playing a large role, both in communication and collaboration capabilities (e.g., on-line discussion boards, video presentations and tutorials, pooling data across students, sharing instantly collected data across institutions), as well as in assessment. It is feasible to administer on-line surveys and quizzes with instant scoring and feedback provided to the students. New Web 2.0 tools such as Wiki can facilitate collaborative learning and bring about instructional change to improve student learning of statistics (Ben-Zvi 2007). These learning systems give students and teachers more opportunities for communication, feedback, reflection, and revision.

Technology has a great potential to enhance student achievement and teacher professional development, and it will most likely continue to impact the practice and the teaching of statistics in many ways. However, technology has an impact on education only if it is used appropriately. Therefore, the focus of this paper is on how technology can best be used to improve student learning. The following sections survey the different types of tools that are currently available and how technology can be used to support student learning. We summarize recent research results on the role of technology in the statistics classroom and then, building on this research, we suggest practical guidelines for selecting and using technology for teaching statistics and also describe obstacles and implementation issues regarding the use of technological tools in the statistics classroom.

3. TECHNOLOGICAL TOOLS FOR THE TEACHING OF STATISTICS AND PROBABILITY

The types of technology used in statistics and probability instruction can be broken into several categories: Statistical software packages, educational software, spreadsheets, applets/stand-alone applications, graphing calculators, multimedia materials, and data repositories. There is much overlap in the capabilities of the tools across these categories, yet no one tool seemingly covers all possible educational uses of technology (Ben-Zvi 2000; Biehler 1997). We provide a brief summary of the types of tools available and some of their benefits and disadvantages. Other resources such as *The American Statistician* (http://www.amstat.org/PUBLICATIONS/tas) or *The Journal of Statistical Software* (http://www.jstatsoft.org) regularly provide more comprehensive software reviews. The goal of this section is to provide a flavor for the types of technological tools available, highlighting some of the more common examples of each type of tool. It is important to remember that the focus of instruction should remain on the content and not the tool, and to choose technology that is most appropriate for the student learning goals, which could involve a combination of technologies. Since new software is continually being developed for K-16 education, the following discussion does not attempt to be exhaustive.

3.1 Statistical Software Packages

Statistical packages are software designed for the explicit purpose of performing statistical analyses. Several packages have been used by statisticians for many years, including *SPSS* (http://www.spss.com), *S-plus* (http://www.insightful.com), *R* (http://www.r-project.org), *SAS* (http://www.sas.com), and *Minitab* (http://www.minitab.com). While development of these packages has focused on uses by industry, they have also evolved into more menu-driven packages that are more user friendly for students. The term menu-driven is used to describe a software program that is operated using file menus instead of commands. Menu-driven is commonly easier for most users as it allows the user to navigate using the mouse and to hunt and peck a bit more, which has both advantages (students don't feel as lost) and disadvantages (often using a trial and error strategy rather than real thought when choosing a command). As these packages become more user friendly, they are being increasingly used in introductory courses.

The statistical package *Minitab* in particular has always had a pedagogical focus and is becoming increasingly feasible as a tool that allows student exploration and construction of ideas (e.g., writing "macros" for repeated sampling, graphics that update automatically as data values are added or manipulated, ease of changing representations). *DataDesk* (Velleman 1998; http://www.datadesk.com) is a similar package but has focused on data exploration and interactive graphics from its initial development. *DataDesk* provides many unique tools that allow students to look for patterns, ask more detailed questions about the data, and 'talk' with the program about a particular set of data. *R* (Verzani 2005) is a language and environment for statistical computing and graphics that provides a wide variety of statistical and graphical techniques, including linear and nonlinear modeling, statistical tests, time series analysis, classification, and clustering. It is freely accessible and is being increasingly used in introductory statistics classes. Additional add-ons can be downloaded to improve the graphical interface of the program (http://socserv.mcmaster.ca/jfox/Misc/Rcmdr).

More cost effective alternatives to these packages include student versions which are smaller in scope (does not work for as large of data sets) and several stand alone statistical packages are also now available for free or at minimal cost, online. For example, *StatCrunch* (West, Wu, & Heydt 2004; http://www.statcrunch.com), is a fully functional, very inexpensive, Web-based statistical package with an easy-to-use interface and basic statistical routines suited for educational needs.

3.2 Educational Software

Different kinds of statistical software programs have been developed exclusively for helping students learn statistics. *Fathom* (http://www.keypress.com/x5656.xml), a flexible and dynamic tool was designed with the input of many statistics educators and educational researchers to help students understand abstract concepts and processes in statistics, and does not attempt to have the capabilities of more traditional statistical software tools. Erickson (2002) described *Fathom* as a dynamic computer learning environment for teaching data analysis and statistics based on dragging, visualization, simulation, and networked collaboration. The strongest features of *Fathom* are the easy access to multiple, linked representations (see Figure 3), including sliders (see Figure 1), the ability to build and run simulations, and the many different ways of importing data from a variety of sources. One small example of the very dynamic, interactive features of *Fathom* is pointing on the edge of a histogram bar and dragging the bar, which immediately updates the graph (see Figure 2).

TinkerPlots was developed to aid younger students' investigation of data and statistical concepts (Konold & Miller 2005; http://www.keypress.com/x5715.xml). This tool has been widely field tested in math classes in grades 4-8 in both the United States and other countries (e.g., Ben-Zvi 2006) with very positive results. Students can begin using *TinkerPlots* without knowledge of conventional graphs or different data types, without thinking in terms of variables or axes. By progressively organizing their data (ordering, stacking, and separating data icons), students gradually organize data to answer their questions and actually design their own graphs.

InspireData (http://www.inspiration.com/productinfo/inspiredata) is a commercial extended version of *TableTop* that also focuses on visual representations in helping grade 4-8 students "discover meaning as they collect and explore data in a dynamic inquiry process." This package also offers linked representations, animations, and easier annotation of data analyses and presentations.

Some of these educational packages are also making it easier for students to access large data sets (e.g., Census data) and for teachers to access pre-developed classroom exercises. The limited statistical capabilities may prevent their use beyond an introductory course (though they are expanding, e.g., *Fathom* now offers multiple regression), but has benefits in being less overwhelming to the students and being more geared to the point-and-click generation.

3.3 Spreadsheets

Spreadsheets such as *Excel* (http://office.microsoft.com/) are widely available on many personal computers. However, care must be exercised in using *Excel* as a statistical educational package. Statisticians often criticize *Excel*'s calculation algorithms and choice of graphical displays (Cryer

2001; McCullough & Wilson 1999). For example, it is still very difficult to make a boxplot in *Excel*. *Excel* does have some strengths in helping students learn to organize data and in "automatic updating" of calculations and graphs as values are changed, and some advocate *Excel* due to its widespread use in industry and relatively easy access (Hunt 1996).

3.4 Applets/Stand-alone Applications

Over the last decade there has been extraordinary growth in the development of on-line applets that can help students explore concepts in a visual, interactive and dynamic environment. An applet is a software component that usually performs a narrow function and runs typically in a Web browser. Many of the applets are easy for students to use and often capture an interesting "context" for students, e.g., the Monty Hall problem (see for example http://www.shodor.org/interactivate/activities/AdvancedMontyHall), Sampling Reese's Pieces (see for example http://www.rossmanchance.com/applets/Reeses/ReesesPieces.html). In addition, a large number of computer programs can be downloaded from the Internet and run without an Internet connection that allow students to explore a particular concept (e.g., *Sampling SIM* allows the student to explore the nature of sampling distributions of sample means and sample proportions, freely downloadable from: http://www.tc.umn.edu/~delma001/stat_tools/software.htm).

While these tools are too numerous to list here, the *Consortium for the Advancement of Undergraduate Statistics Education* (CAUSE, http://www.causeweb.org) provides a peer-reviewed annotated list of such tools. Applets can also be found with the online *National Council of Teachers of Mathematics* (NCTM) *Principles and Standards for School Mathematics* Electronic Examples (http://standards.nctm.org/document/eexamples). What these tools often gain in visualization and interactivity, they may sometimes lose in portability. And while they can be freely and easily found on the Web, they are not often accompanied by detailed documentation and activities to guide student use. The time required for the instructor to learn a particular applet/application, determine how to best focus on the statistical concepts desired, and develop detailed instructions and feedback for the students may not be as worthwhile as initially believed.

3.5 Graphing Calculators

Perhaps the most portable tool and one that is being increasingly used in lower grade levels is the graphing calculator. A graphing calculator is a learning tool designed to help students visualize and better understand concepts in mathematics, statistics and science (Dunham & Dick 1994). Advancements in technology have made the graphing calculator a powerful tool for analyzing and exploring data. Data can often be downloaded from the Web, saving students time from keying in data. Some models provide an accessible way for students to collect and measure light, temperature, voltage, or motion data, and much more. Many statistical calculations, including inference procedures and probability distributions are now standard in most brands. Simulations can also be run in a reasonable time frame allowing students to explore concepts such as sampling distributions. Student learning time is short with such technology and schools can purchase one classroom set for use at school or in a particular course. However, beyond the introductory statistics course, they are not a reasonable substitute for statistical packages.

Students also need to be wary that the output given by the graphing calculator is not sufficient communication of statistical results (e.g., "calculator-speak," graphs with no labels and scales).

Five patterns and modes of graphing calculator tool use emerged in a qualitative mathematics classroom-based study: computational tool, transformational tool, data collection and analysis tool, visualizing tool, and checking tool (Doerr & Zangor 2000). These researchers also found that the use of the calculator as a personal device can inhibit communication in a small group setting while its use as a shared device supported mathematical learning in the whole class setting.

3.6 Multimedia Materials

These materials often seek to combine several different types of technology. For example, *ActivStats* (http://www.activstats.com) has been used in college classrooms, combining videos of real world uses of statistics, mini-lectures accompanied by animation, links to applet-like tools, and the ability to instantly launch a statistical software package and analyze a data set. An advantage of such an environment is that students only need to learn one type of technology. In fact, more and more, entire lessons and even textbooks are written around these types of embedded technology to make them a "living" textbook, e.g., *CyberStats* (http://www.cyberk.com; Symanzik & Vukasinovic 2006). Many other multimedia resources are currently being developed around the world, several of which were described in the proceedings of the International Conferences on Teaching Statistics (ICOTS-5, Pereira-Mendoza, Kea, Kea, & Wong 1998; ICOTS-6, Phillips 2002; ICOTS-7, Rossman & Chance 2006).

3.7 Data and Materials Repositories

Another popular and important use of the World Wide Web in statistics instruction is in locating and using pedagogically rich data sets and exploratory activities for use with students (e.g., Schafer & Ramsey, 2003). Numerous data repositories exist. *The Data and Story Library* (DASL, http://lib.stat.cmu.edu/DASL) and the *Journal of Statistics Education* (JSE) *Dataset and Stories* feature (see http://www.amstat.org/publications/jse/jse_data_archive.html) are excellent starting places. These data sets come with "stories" outlining their background and classroom uses. CAUSE (http://www.causeweb.org) is again a good resource for datasets and peer-reviewed classroom activities.

The many types of tools and resources listed above offer great choices for instructors, as well as decisions about how to best use these tools, how often to use them, and for what purposes and activities. While many of the tools described are bona fide research tools, others have been developed primarily for learning purposes. We next discuss issues related to the uses of technological tools in helping students learn and reason about statistics.

4. HOW TECHNOLOGY CAN SUPPORT STUDENT LEARNING

As more and more technological tools become available, and as student facility with such tools greatly increases, it is becoming increasingly important to focus on the best ways to use such tools in the classroom. Below we provide examples of some of the effective uses of technology in the statistics classroom. It is important to keep in mind that many of these learning tools have different goals and it may be necessary to employ different tools for different learning goals and that a combination may best aid students. If using a combination of technologies, it is important to address learning curve issues for students. There's always overhead in learning to use a tool itself before students can benefit from the tool for learning statistics. Students do seem adapt at learning to use different types of software in the same course but teachers may also aim for a more consistent look and feel, at least in the instructional aids they provide to accompany the tools, and to consistently provide guidance on when to use the different tools (e.g., in assessments).

Automation of Calculations. With technology students can carry out many calculations (and graphing tasks) in a short time, with high accuracy and few errors. For example, allowing the computer or calculator to calculate the standard deviation saves cognitive load and actual classroom time that can instead be spent on the larger concept of variation and on properties of the calculated value. Reducing the focus on computations frees students to spend more time focusing on understanding the concepts. There is also less focus on data entry, manipulating numbers in formulas, and on exercises using only small and/or artificial data sets. Interactivity, such as sliders, can really help students focus on the effects of changing pieces in the calculation without the burden of recalculating numerous terms (Figure 1). Assessment tasks can evaluate student ability to explain concepts and justify conclusions rather than on how they perform rote calculations.

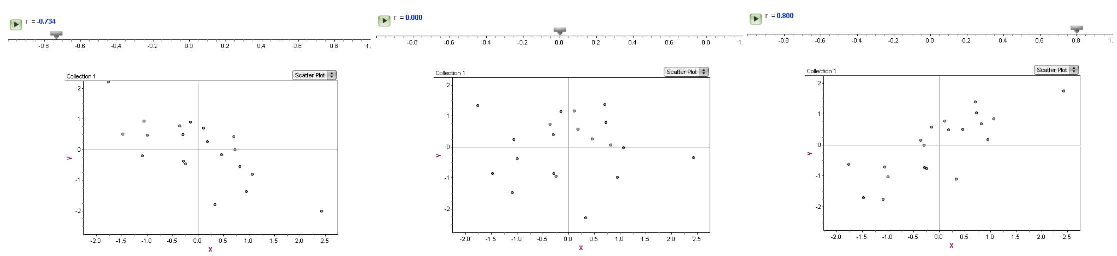

Figure 1a. A *Fathom* slider allows students to gradually change the value of the correlation coefficient while a scatterplot immediately updates to reflect the new strength of association between the variables.

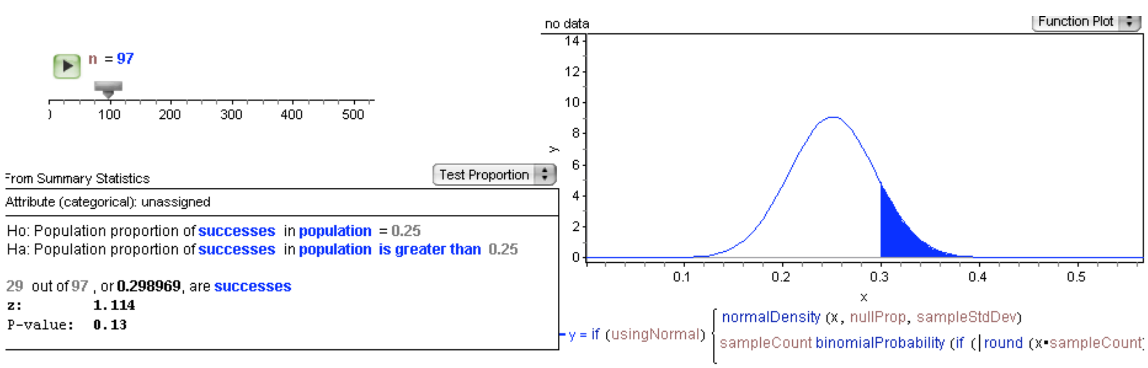

Figure 1b. A *Fathom* slider allows students to change the sample size in a one-sample proportion z-test and instantly see the effects on the sampling distribution, test statistic and P-value.

Emphasis on Data Exploration. The use of technology amplifies students' ability to produce many graphs quickly and easily, leaving students more likely to examine multiple graphs and different representations (Pea 1987). For example, students can think more about the effect of bin size in a histogram (e.g., smaller bin sizes in a graph may reveal bimodal behavior that was initially hidden, see Figure 2). *Fathom*, for example, allows students to click on the edge of the bar and drag, immediately updating the graph in a dynamic and interactive representation. Students may also see how different graphs of the same data provide different pieces of a story by generating different graphs on the same screen (Figure 3).

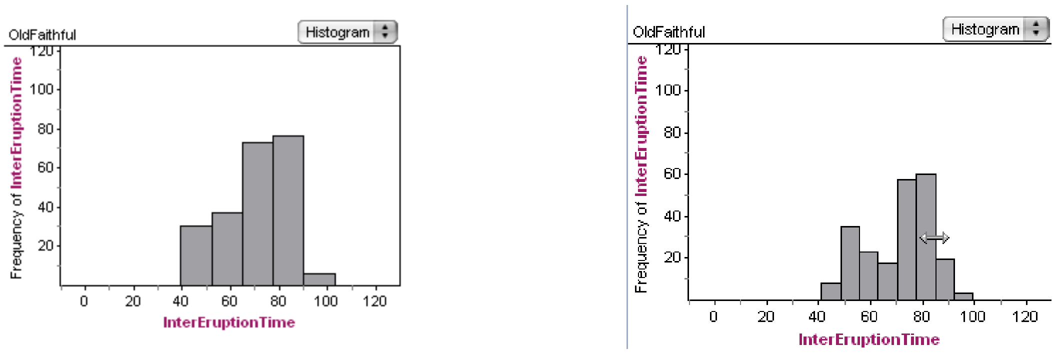

Figure 2. Bin widths are changed in Fathom just by dragging the edges of the histogram bars.

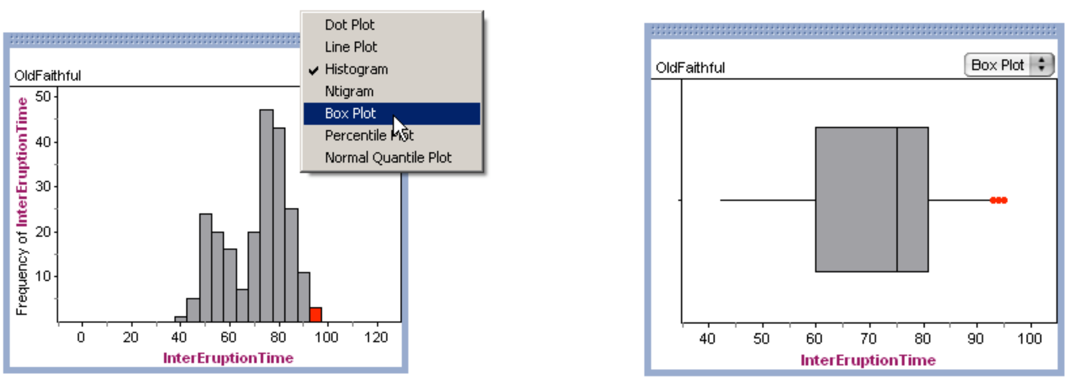

Figure 3. Students easily make transitions between graph types while specific cases are highlighted in all graphs simultaneously (*Fathom*).

Technology should be utilized in the classroom to encourage students to explore data sets more in depth, to allow the data to tell a (possibly unexpected) story to the student, and to consider related conceptual issues (e.g., Erickson 2001).

Visualization of Abstract Concepts. Technology enables visualization of statistical concepts and processes (Biehler 1993), demonstration of complex abstract ideas and provision of multiple examples in seconds. Students are better able to explore and "see" statistical ideas, and teachers are better able to present them to students. Such tools give students and teachers much more flexibility to ask "what if" questions. For example, we can select an individual data observation and drag it to immediately see the effects on the graph and numerical calculations (Figure 4).

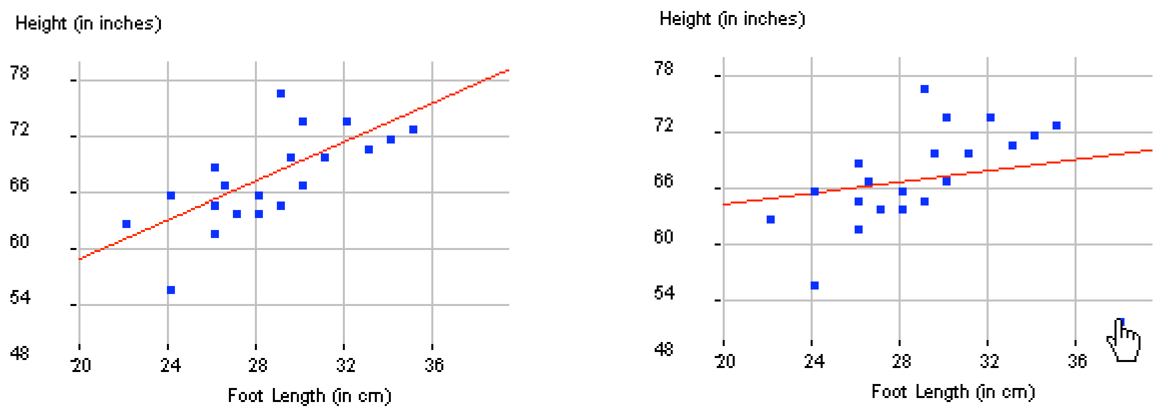

Figure 4. The applet “Least Square Regression” from the Rossmanchance Applet Collection (http://www.rossmanchance.com/applets/index.html) allows student to add and drag a new observation to see how the regression line changes as the point relocates.

Another example is how *TinkerPlots* allows students to see the data values “hidden” in boxplots, as shown in Figure 5.

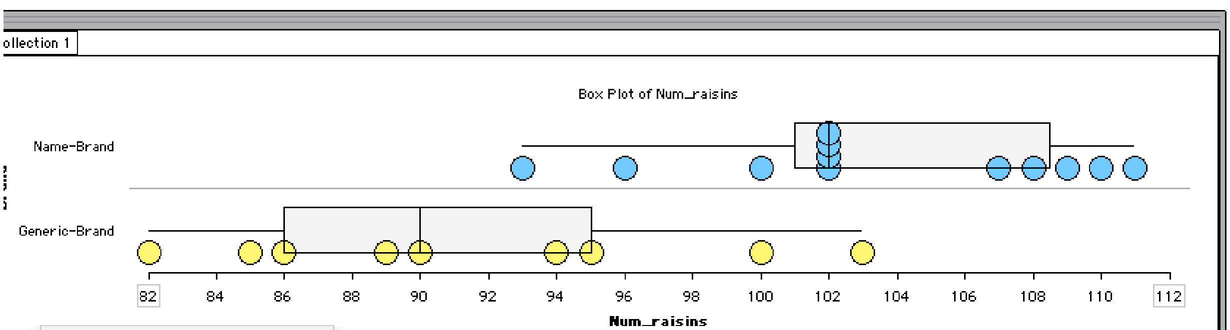

Figure 5. Comparing the number of raisins between two brands using boxplots with visible case icons in *TinkerPlots*.

Simulations as a Pedagogical Tool. Technology can also play a significant role in enhancing students’ ability to study random processes and statistical concepts by giving them easy access to viewing and designing simulations (e.g., Chance & Rossman 2006; Lane & Peres 2006; Lane & Tang 2000; Mills 2004). These tools allow them to answer ‘what happens if this is repeated a large number of times’ through direct observation. With such simulations, abstract concepts such as sampling distribution (Figure 6) and confidence intervals (Figure 7) become more concrete. Students’ understanding is developed by carrying out these repetitions, controlling parameters (such as sample size, number of repetitions), and describing and explaining the behavior they observe rather than on relying exclusively on theoretical probability discussions, which can often be counterintuitive to students (delMas, Garfield, & Chance 1999).

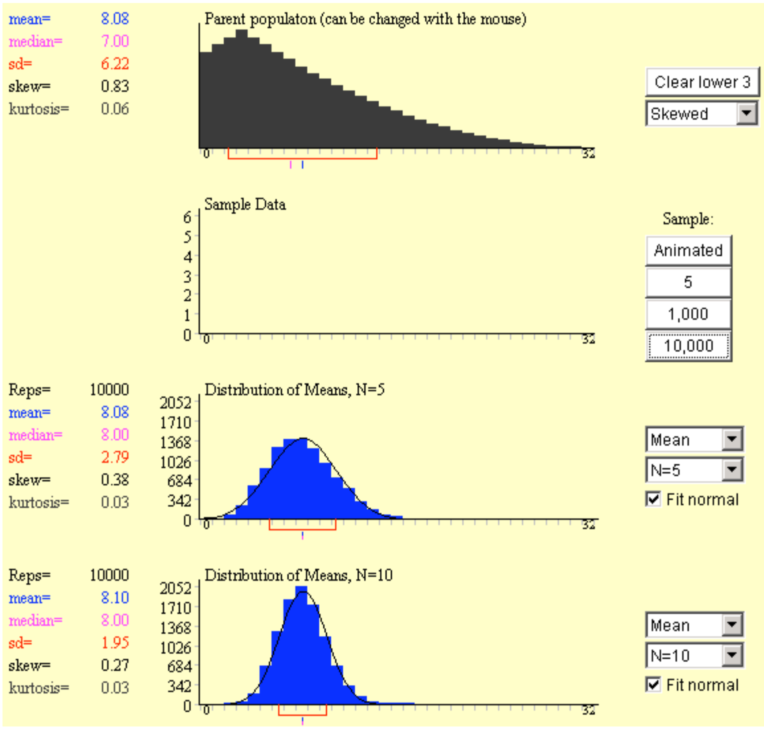

Figure 6. Illustration of the Sampling Distributions applet (http://onlinestatbook.com/stat_sim/sampling_dist/), from the "Rice Virtual Lab in Statistics" which allows students to specify a population shape (e.g., skewed), different sample statistics (e.g., mean), and sample sizes (e.g., n=5 and n=10). The above numerical and graphical displays results for 10,000 repetitions.

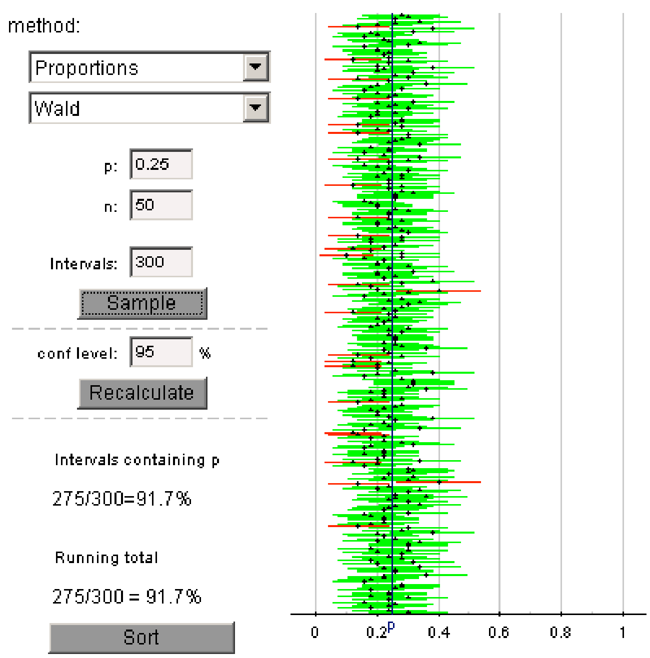

Figure 7. Illustration of Simulating Confidence Intervals applet from the Rossmanchance Applet Collection (http://www.rossmanchance.com/applets/index.html) to generate 300 different random sample proportions and resulting confidence intervals, recording the percentage of intervals that succeed in capturing the value of the population proportion.

*S*tudents can also examine nontraditional distributions (e.g., the sampling distribution of a median) while easily analyzing the effects of different parameters (e.g., sample size, population size, and number of samples) on such conceptual ideas (see Figure 8). Students can modify these parameters and initial conditions to explore and make their own conclusions.

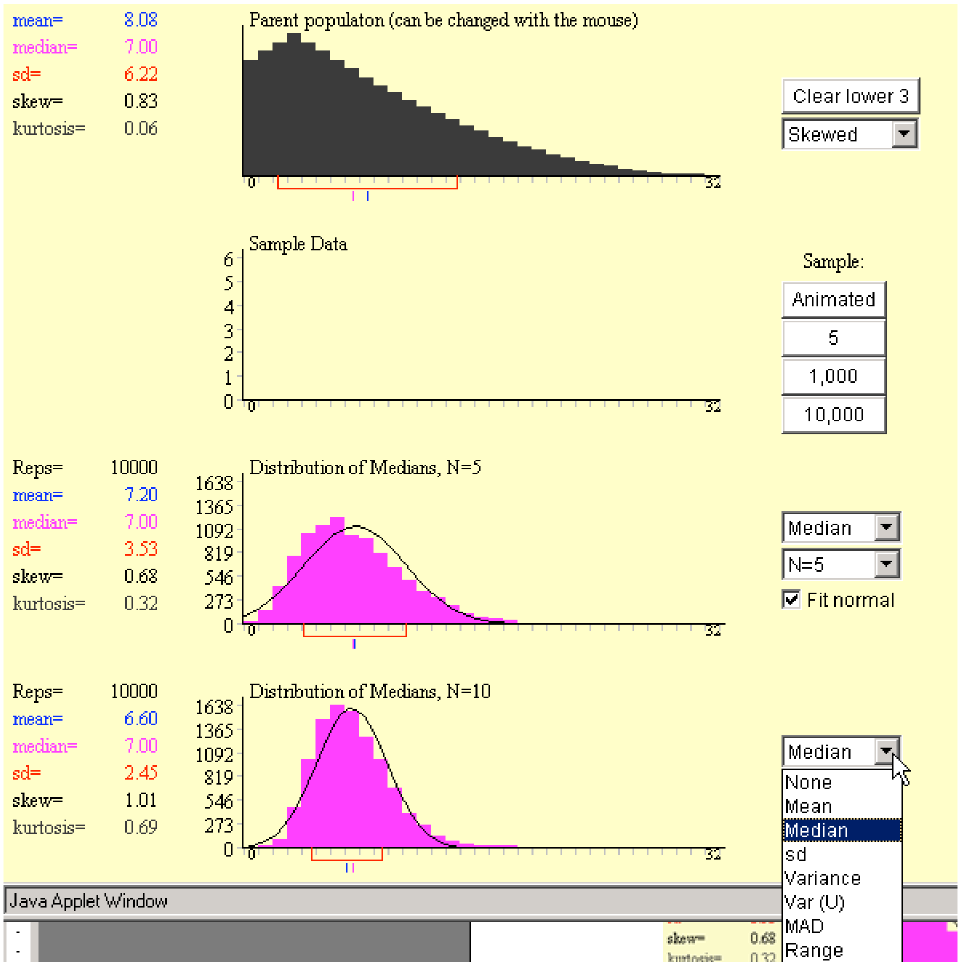

Figure 8. Illustration of change to sampling distribution of a median in the "Rice Virtual Lab in Statistics" Sampling Distributions applet (http://onlinestatbook.com/stat_sim/sampling_dist/index.html).

Investigation of Real Life Problems. One of the most important uses of technology is its capacity to create opportunities for curriculum and instruction by bringing real-world problems into the classroom for students to explore and solve (Bransford, Brown, & Cocking 2000). Technology facilitates the discussion of more interesting problems and data sets (which may be large and complicated), often accessed from the Internet. We now have the power to have students analyze real and often messy data, giving students a better idea of what statisticians do by having them go through the process of collecting, analyzing and making conclusions to investigate their own questions. Assessment can focus on giving students data sets and having them complete a full analysis on their own, which may include "cleaning" the data first (e.g., Holcomb 2004). Such exercises empower students as users of statistics and allow them to better understand and experience the practice of statistics (Ben-Zvi 2004).

Provision of Tools for Collaboration and Student Involvement. Course management systems provide communication tools (such as discussion forums, file exchange and whiteboard), productivity tools (online student guide, searching and progress review), student involvement tools (group work, self-assessment, student community building, and student portfolios) as well as administration tools. In these learning environments it becomes easier for students to collaborate with other students which can help improve the writing and communication skills needed to convey their findings. They also allow students to do more learning on their own, maybe outside of class, using Web-based or multimedia materials. This frees the instructor to minimize lecture and to spend more time on data analysis activities and group discussions.

While interest in using technology in teaching and learning statistics is great, there is not a lot of data available that provide answers to all the questions teachers may have regarding best uses of technology to support student learning. The following section provides an overview of some of the current research on using technology to teach statistics.

5. OVERVIEW OF RESEARCH ON TECHNOLOGY IN STATISTICS EDUCATION

Research on the role of technology in teaching and learning statistics has been increasing over the last decade. In 1996, a special International Association for Statistical Education (IASE) Roundtable was convened in Granada, Spain to discuss the current state of research on the role of technology in statistics education at that time. While much of the work reported at the roundtable (Garfield & Burrill 1997) was on the development of new tools to help students learn statistics, there was a clear call for more research on appropriate ways to use these tools to promote student learning. It was suggested that a new research agenda was needed to identify appropriate methodologies for future studies on this topic as well as to explore new ways to use technology in studying this topic (Hawkins 1997). Given the changes in technology in the past decade, ideas about both of these aspects of technology are still emerging. In this section, we highlight some of the more recent research questions being explored and the types of studies involved, particularly with respect to developing students' statistical reasoning. The following section will suggest some implications from the research for teaching practice.

Ben-Zvi describes how technological tools are now being designed to support statistics learning in the following ways (2000, p. 128):

1. Students' active construction of knowledge, by "doing" and "seeing" statistics.
2. Opportunities for students to reflect on observed phenomena.
3. The development of students' metacognitive capabilities, that is, knowledge about their own learning and thought processes, self-regulation, and control.

In addition, technological tools can bring exciting curricula based on real-world problems into the classroom; provide scaffolds and tools to enhance learning; and give students and teachers more opportunities for feedback, reflection, and revision (Bransford, Brown, & Cocking 2000).

The types of research studies that explore technology in statistics education can be grouped into three categories:

1. Development, use and study of particular tools (e.g., the creation and use of *Fathom* software – Biehler 2003; *Minitools* – Cobb, Gravemeijer, Bowers, & Doorman 1997).

2. How use of particular tools help develop students' reasoning (e.g., use of *Sampling SIM* software to develop reasoning about sampling distributions – Chance, delMas, & Garfield 2004).

3. Comparison of tools (e.g., comparing *ActivStats*, *CyberStats*, and *MM*Stat* multimedia – Alldredge & Som 2002; Symanzik &Vukasinovic 2002, 2003, 2006).

Some of the most informative studies were not designed to focus on the use of technology but on larger teaching experiments that combined innovative instructional activities and technological tools to promote student reasoning about a particular topic, such as distribution (e.g., Bakker 2004, Cobb 1999; Cobb & McClain 2004). These studies focused on the use of a set of *Minitools*, applications created to help students move along a learning trajectory. Similarly, the studies of Makar and Confrey (2005) and Rubin, Hammerman and Konold (2006) explore teachers' knowledge and reasoning as they use innovative software (*Fathom* or *TinkerPlots*).

Although few studies have been empirical in nature in the field of statistics education, such studies have provided valuable information on how technological tools can both improve student learning of particular concepts as well as raise new awareness of student misconceptions or difficulties (e.g., Batanero, Estepa, Godino, & Green 1996; Finch & Cumming 1998; Shaughnessy 1992). Cobb and McClain (2004) found that students were able to more easily make and test conjectures when using such tools to analyze data. While controlled experiments are usually not possible in educational settings, qualitative studies are increasingly helpful in focusing on the development of concepts and the use of skills that technology is intended to facilitate. Investigations by Miller (2000) and Lee (2000) are examples of qualitative studies of how instructors can integrate technological tools to support a student-centered learning environment for statistics education. Other examples are Biehler's (1998) use of videos and transcripts to explore students' thinking as they interacted with statistical software and research by delMas, Garfield, and Chance (1999) that provides a model of collaborative classroom-based research to investigate the impact of simulation software on students' understanding of sampling distributions.

One research area where empirical results have been less consistent is in the use of simulation as a pedagogical tool. Research on simulation training indicates that even a well-designed simulation is unlikely to be an effective teaching tool unless students' interaction with it is carefully structured (Lane & Peres 2006). Chance and Rossman (2006) illustrate how simulation can be a powerful tool in helping students learn statistics, particularly the ideas of long-run patterns and randomness, in a concrete, interactive environment (e.g., using a simulation of sampling Reese's Pieces or shuffling playing cards to build on a tactile simulation while allowing the user to easier adjust parameters such as sample size and immediately explore the impact). Technology is also used in involving teachers in the design of computational tools that presumably encourage them as designers to reflect upon the statistical concepts incorporated in the tools under development. Healy (2006) describes how involvement of Brazilian mathematics teachers in the collaborative simulation design process helped participants come to see distributions as statistical entities, with aggregate properties that indicate how their data are centered and spread.

Although research supports the use of technology to facilitate and improve the learning of statistical concepts, Biehler (1997) cautions that statistics educators need a system to critically evaluate existing software from the perspective of educating students and to produce future software more adequate both for learning and doing statistics in introductory courses. Thistead and Velleman (1992), in their summary of technology in teaching statistics, cite four obstacles that can cause difficulties when trying to incorporate technology into college statistics courses: equipment (e.g., adequate and updated computer labs), software (availability and costs), projection (of computer screens in classrooms), and obsolescence (of hardware, software, and projection technologies).

Nowadays, we can see increased availability of computers, access to graphing calculators and Internet, updated and more widely available software, often via CDs bundled with textbooks or on the World Wide Web, and new methods of projecting computer screens such as interactive white boards. But another obstacle is the fact that it takes time and thought to effectively incorporate new technologies. Success in the use of technology for teaching means success in placing teachers on the road to new ideas and methods of teaching, not the sudden transformation of teaching (Huffman, Goldberg, & Michlin 2003). A first step on this road can be obtaining information on how technology can be used to support and improve students' learning in statistics courses and what technology is available to accomplish this goal.

6. RECOMMENDATIONS FOR USING TECHNOLOGY TO TEACH STATISTICS AND PROBABILITY

Research studies on technology in statistics education have pointed to several effective ways to use technology in the statistics classroom. Below we provide a summary of what we believe to be the most important issues to consider:

- Too often in statistics courses, students become focused on the numerical calculations. This tendency can be exacerbated in a computer-rich environment, especially in using statistical packages that easily produce large amounts of (often unclear) output – students focus on the output instead of the process. Many teachers also have such expectations and may rely on drill-and-practice uses of technology rather than the student-centered, rich tasks that offer the greatest value added for the use of technology (Means, Penuel, & Padilla 2001). Rather than let the output be the end result, we believe it is important to discuss the output and results with students and require them to provide explanations and justifications for the conclusions they draw from the output and to be able to communicate their conclusions effectively. Although students can spend time entering data (with an emphasis on ways to organize data, types of variables, etc.) it is more useful to have them do only small amounts of data entry and spend more time exploring, analyzing and interpreting data.

- While technology allows for more student-driven and open-ended explorations, this may not happen right away, as students first need to become familiar with the tool and how to use it. Sometimes students become overwhelmed or lost in the details of the instructions or programming commands and do not see the bigger statistical ideas being developed. For example, in exploring sampling distributions, they focus on how many trials to include in the simulation rather than how the sample size affects the resulting empirical distribution. Teachers therefore need to carefully structure explorations so that even while learning to use the software, students are able to focus on the concepts rather only paying attention to the technology or blindly following a list of commands. In this way, students may discover and construct meanings for the big ideas of statistics as they are guided through a series of investigations. Without this careful structuring and guidance, students may only be paying attention to the software and not to the statistical problem or content (Collins, Brown, & Newman 1989). The student activities that include use of technology should embed questions that guide students in an investigation of statistical problems and encourage the students to discuss and summarize the big concepts of the lesson before they are summarized by the instructor. In this way, students should learn to conduct their own explorations with less and less structure and support from teachers. Both these points underscore that the accompanying instructions are often more crucial in impacting student learning than the specific choice of technological tool.

- Collaborative learning is often particularly helpful in statistics education and technology can be used to facilitate and promote collaborative exploration and inquiry, allowing students to generate their own knowledge of a concept or new method in a constructivist learning environment (Huffman, Goldberg, & Michlin 2003; Miller 2000). Interactions within the groups have an important role with questioning and critiquing individual perspectives in a mutually supportive fashion so that a clearer understanding of statistical concepts emerge and knowledge of statistical ideas develops (Ben-Zvi 2006). This type of iterative exploration of data also mirrors statistical practice and helps students develop a "habit of inquiry" (Wild and Pfannkuch 1999).

- Statistics education is also characterized by the deep rooted misconceptions that students often hold entering the course. Technology greatly facilitates employment of a "predict-and-test" strategy that has shown to be effective in establishing the cognitive dissonance necessary for students to change their ways of thinking about a concept (e.g., Posner, Strike, Hewson, & Gertzog 1982). Students can be required to predict what they will observe (e.g., expected shape of a distribution, effect of increasing number of observations) and then use the technology to obtain immediate feedback on their understanding. This is especially useful when the feedback is directly observable without the need for a lot of inference by the students, especially from numerical results that may not yet make sense to students.

We also offer the following more general reminders to consider when planning to use technology:

- Technology does not replace the teacher, but teachers need to actively observe the students, identify their difficulties, probe their thought processes and the conclusions they are forming, quickly curb any problems they are having with the technology, keep students on task, and answer questions (Feenberg 1999). Teachers don't have downtime while students are interacting with technology.

- Technology should be chosen to facilitate student interaction and accessibility, maintaining the focus on the statistical concept rather than on the technology (Moore 1997). This choice can depend on the learning curve, portability, and flexibility of the tool (e.g., whether the technological tool can be utilized in other places in the course such as using the same software to carry out other data analysis or simulation tasks). It is important to consider the background of the students and the goals of the course as well as the instructor's comfort level and knowledge.

- A supportive learning environment is needed that is rich in resources, aids exploration, creates an atmosphere in which ideas can be expressed freely, provides encouragement when students make an effort to understand, and allows students (and teachers) the freedom to make mistakes in order to learn (e.g., Brown & Campione 1994; Cobb, Yackel, & Wood 1992).

6.1 Possible Obstacles to Incorporating Technology in the Statistics Classroom

Integrating technology in the classroom has great potential to enhance teaching and learning, turning that potential into a reality can be a complex and multifaceted task. Some of the key factors for successfully integrating technology in the classroom are well-defined educational visions, curriculum design, and teacher preparation and support (Kleiman 2004). This success comes with some "costs" and instructors and administrators need to think carefully about how to best integrate the tools into the classroom. This section presents some of the common obstacles teachers must face to create rich learning environments with the use of technology and the necessary support mechanisms to overcome them.

Need to Re-examine Student Learning Goals. While technology allows changes in instructional focus, these changes need to be reflected in the course goals and corresponding student assessments. At the high school level in particular, if standardized testing will be used as the one measure of students' success, this will impact how technology should be incorporated. For technology to gain the most impact on student learning, other course goals will be necessary. At the college level, changes in learning outcomes due to use of technology (e.g., doing away with the use of statistical tables and instead relying on software to compute *P*-values) may require buy-in from colleagues and administrators. At any level, changes resulting from incorporating technology may require endorsement from instructors, parents, and students.

Lack of Awareness of and Comfort with New Technologies. Probability and statistics are specialized subjects, and many schools may not have a faculty member whose expertise is in these areas. Since teachers' schedules are very demanding, little time is available to learn about new technologies and their capabilities. Teachers who have learned statistics decades earlier may not be comfortable using the new tools and may not believe in the value of their use. In some cases, teachers may be able to attend conferences and hear about new technologies, but this is usually not enough time for them to appreciate the benefits of the technology and fully learn how to effectively use it in the classroom. Unless teachers are provided with a long-term support for learning to use and implement technology, they are unlikely to use it in their classrooms. Internet-based communities of teachers are becoming an increasingly important tool for overcoming teacher's isolation and need for support (e.g., Levin & Waugh 1998).

Lack of Support for Teachers. According to Ritchie (1996), schools are not yet effectively implementing instructional technologies in spite of the increase in the capacity of available educational technology. This study identified lack of administrative support as one of the most critical impediments for the integration of instructional technology. Administrative support is needed in order to provide funding for computer labs, consistent technical support for teachers, and on-going professional development for teachers to have the opportunity to learn new technologies and their uses in classrooms. Even when the technology is in place and the technical support is available, teachers need much more support and professional development in learning how to implement a new pedagogy with technology since technology alone does not make for effective teaching. To maximize the benefits of technology for students, teachers need to spend time modifying what they will teach, how they will teach it, and how they will assess it using technology (U.S. Congress, Office of Technology Assessment, 1995).

Class Time Required for Exploration. One of the largest benefits of using technology is allowing student exploration of concepts and deeper probing into large messy data sets, but such investigations can be time consuming. However, time can be saved by eliminating other components of the course such as hand calculations and replacing them with better questions or richer discussions for the benefit of more meaningful understanding by the students. Students' education will also benefit by more of these explorations occurring at lower grade levels, increasing student comfort with such explorations and perhaps leading to a less impacted curriculum at the college level.

The Fact that Technology Can Fail. It is important to realize that computers can crash, Internet sites may not be available, and so on. Therefore, teaching with technology means having a plan in case the technology fails during class. Contingency plans include making handouts of the planned lessons or transparencies revealing the expected outcomes. In fact, in probability and statistics, even working technology can lead to unexpected results. It is important for both the teacher and student to be comfortable with randomness and approximations rather than clean proofs. When technology does fail, the process of constructing the lesson often prepares teachers to pose questions that can lead students to have a discussion that can serve as pre-amble to the next class meeting when the technology will function (Cardenas 1998).

Time Needed to Implement Changes. Teachers should not expect inclusion of technology in their classroom to show immediate improvements in student achievement or to be a solution to all teaching difficulties (U.S. Congress, Office of Technology Assessment, 1995, p.159). It is usually the case that effective use of technology takes refinement, trial and error, and continual improvement. Teachers should not be afraid to try something and fail; that does not mean the new teaching method is a failure but may indicate modifications that need to occur for the implementation to be successful in an individual classroom. Educators cannot forget that part of educating students is preparing them for life outside the classroom, so even if the use of technology does not provide immediate success in the teaching and learning of mathematics or statistics concepts, students are learning how to use technologies that they may encounter in their future jobs.

Unclear Role of Distance Learning. The methods being developed for distance learning, which incorporate many innovative uses of technology, may allow schools to share resources and make a high quality probability or statistics class at one school available to others. However, with increased distance learning courses, it is also unclear as to how much of a course can be taught exclusively using technology, what the appropriate roles of an instructor should be, and how much emphasis should still be placed on students generating calculations and graphs by hand. "Hybrid courses" that combine a distance component with less frequent face to face meetings are also being used with greater frequency (e.g., Utts, et al 2003; Ward 2004). Smith, Clark, and Blomeyer (2005) provide a synthesis of new research in K-12 online learning and Mayer (2001) provides recommendations on effective multimedia presentations.

6.2 Issues to Consider when Selecting Technology in a Statistics Class

Despite the obstacles listed above, it is still important to try to find ways to access and utilize appropriate technology to help students learn statistics. The GAISE College Report (Franklin & Garfield 2006) lists some issues to consider when selecting technological tools to use in helping students learn statistics:

- Ease of data entry, ability to import data in multiple formats
- Interactive capabilities
- Dynamic linking between data, graphical, and numerical analyses
- Ease of use for particular audiences
- Availability to students, portability

We believe that no one tool can do it all and that there are many good tools available to use, many of which are free. Therefore, rather than thinking about one technological tool for students to use, we encourage teachers to think about what sets of tools will help student best learn statistics in each unit of the course. What is used to graphically explore data in one unit may not be the best to illustrate sampling in another.

6.3 Implementation Issues

The GAISE Report advises educators to remember that technology still needs to be used carefully. As stated earlier, instructors should first remember to worry less about the specific choice of technology and instead on *why* and *how* it will be used. Careful planning of the technology implementation is crucial to having a direct impact on student learning. We list below some of the questions to consider when planning how to use a particular technology tool with students. We do not try to provide answers to these questions, because responses will vary from class to class, topic to topic, and depending on choice of technology.

- How much time will students need to explore the technology? How can the teacher make sure that videos and simulation games do not become "play time" for students and that they are learning important ideas? How much instructor demonstration should precede student use of the technology and how much debriefing afterwards?

- How can we avoid students thinking of the computer as a "black box"? How can we make sure that students understand and trust (to a reasonable extent) what technology produces? We do not want computer visualizations to just become a black box generating data. We believe that is important for educators to use a hands-on activity with devices such as dice or M&Ms to begin an activity, and then move to the computer to simulate larger sets of results. In this way students may better understand the simulation process and what the data actually represent. Follow-up assessment also needs to indicate to students that they will be responsible for understanding and synthesizing what they have learned from the technology.

- How consistently will the software be used? To what extent will students use the software? Is it only used in class and assignments or can it be used on exams? Are students assessed on how well they are able to use the software or is it optional to use it?

- How accessible will the technology be for students' use outside class? The answer to this question will determine what kind of homework assessments or group projects teachers create. Teachers should keep in mind that students value what is assessed, so assessments should be aligned with learning goals. If students are expected to use a lab outside class, what are the lab hours and are these accessible for most students?

- How many different technologies are students expected to use? For which technologies should students learn commands (i.e., software packages)? Which technologies will be demonstrations only (i.e., applets)? Incorporating many technologies can be overwhelming for students and place conceptual understanding in second place to technological skills.

7. SUMMARY

Technology has been and will continue to be a major factor in improving student learning of statistics. However, effective utilization of technology requires thoughtful and deliberate planning as well as creativity and enthusiasm. Despite the endless capabilities that technology offers, instructors should be careful about using sophisticated software packages that may result in the students spending more time learning to use the software than applying it. Even in our advanced technological society, some students are not always ready for the type of technology used in courses. Choice of a particular technology tool should be made based on ease of use, interactivity, dynamic linkages between data/graphs/analyses, and portability. Good choices if used appropriately can enhance student collaboration and student-instructor interactions, and often a combination of several different tools will be necessary.

It is also crucial to consider how best to utilize the technology (e.g., allowing predict-and-test learning situations and facilitating student interaction, not spending large amounts of time entering data). There is a need for carefully designed learning activities that guide and scaffold student interaction with technology. Set-up time should be minimal, and students often, at least initially, need to be carefully guided through the activity, with the steps building logically. As they gain more confidence with the tool and fluency with the statistical language teachers should gradually encourage students to conduct and make sense of their own explorations, with less and less guidance and structure, while focusing on the overall larger statistical concept.

What is still lacking are more studies on the most effective ways of integrating technology into statistics courses in developing students' reasoning about particular concepts, and determining appropriate ways to assess the impact on student learning in these contexts. With an increased emphasis on statistics education at all educational levels, we hope to see more high quality research projects in years to come that will provide information on appropriate uses of technology to improve student learning of statistics.

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