1. MYTH-CONCEPTIONS!

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INTRODUCTION

Twenty-five years ago, the term "technology" had a rather different meaning than it does today. Anything other than chalk-and-talk or paper-and-pencil was considered technology for teaching. This might have included anything from fuzzy-felt boards to mechanical gadgets, as well as the multimedia of that period (i.e., television, tape recordings, films, and 35mm slides). The title of this Round Table talk refers to "technology"; however, the papers are concerned mainly with computers and software. The occasional reference to calculators is really only a variation on this theme, because they are essentially hand-held computers. This is merely an observation--not a criticism. The re-invention of the meaning of the term 'technology' is something to which we have all been a party.

The developments in computers and computing during the past quarter of a century have been so profound that it is not surprising that they replaced other technological teaching aids. This does not mean that we should forget such alternative aids altogether, nor the need to research their effective use. However, it is obvious that computers have significantly increased the range, sophistication, and complexity of possible classroom activities. Computer-based technology has also brought with it many new challenges for the teacher who seeks to determine what it has to offer and how that should be delivered to students.

Innovations in this area tend to be accompanied by a number of myths that have crept into our folklore and belief systems. Myths are not necessarily totally incorrect: They often have some valid foundation. However, if allowed to go unchallenged, a myth may influence our strategies in inappropriate ways. This Round Table conference provides a timely opportunity to recognize and examine the myths that govern innovations and implementations of technology in the classroom, and to establish the extent to which our approaches are justified.

Myth 1: Technology enhances the teaching and learning of statistics

Having the vision to see what technology can, or might, do is not synonymous with knowing how to take advantage of this in a teaching context. The reality is that we still have much to learn about the use of technology. Technology-based teaching may be less than optimal because (1) either the hardware, the software, or both, may be inadequate; (2) our use of the technology may be inappropriate; or (3) the students may not experience what we think they do.

Some statistical packages are particularly dangerous with respect to their graphics capabilities. For example, the same command may be used for producing histograms and bar-charts. This does not help learners who are already confused by the superficial similarities between these two diagrams. Labeling on diagrams may be minimal or simply incorrect, and there are obviously problems with packages that emphasize pretty or impressive, rather than accurate, graphs (e.g., auto-scaling may preclude realistic perceptions of magnitudes).

Most packages, of course, will do what is requested, regardless of whether it makes sense. Packages cannot think, but there is a worrying trend toward software that by default (rather than by invitation) pretends to do just that. We should be training our students how to think for themselves and to know that they must do it. The situation is exacerbated by the ready access that many lay-users now have to freeware and shareware, even though they do not have the skills, or inclination, to evaluate this software and decide on its appropriateness for the intended use. Some freeware and shareware is reputable and highly reliable. Indeed, such software may be more appropriate than a commercial counterpart because it has been produced by a specialist in the field, rather than by a commercial programmer. The danger lies in the fact that much of the available freeware and shareware has unknown characteristics and quality. Indeed, software that will later be marketed commercially is often put out as freeware at the alpha- and beta-testing stages so that users may provide feedback about problems to the producers for amendment in the final version. The snag is that such feedback tends to be private rather than public, and the trial users are a self-selecting group who may not have the relevant specialist knowledge to recognize statistical errors when they occur.

In fact, such problems are not confined to freeware and shareware. Early versions of the EXCEL spreadsheet software, for example, were flawed in terms of some statistics (e.g., negative R^2 values and moving average models that were displaced horizontally, thereby missing all the contributing data points). Although some of the errors have been corrected in later versions, schools may not yet have the necessary hardware to support these later versions.

Technology *can* enhance the processes of teaching and learning statistics. However, not all technology is fit for this purpose, and the use we make of this technology is not always appropriate.

Myth 2: Computers have changed the way we do statistics

It is certainly the case that computers have changed the way that some students do statistics. Now, if unchecked, students have the resources to collect too much data, with little thought as to why it has been collected, and to produce vast numbers of meaningless analyses!

It is also fair to say that computers have expanded the range of processes that *statisticians* can use to collect, explore, and interpret data. Clearly, technological developments since the late 1970's have been significant, and they have had an impact on what students will experience as "statistics." The evolution of more powerful computers has resulted in the development of new methods of statistical analysis and has made the implementation of some previously suggested techniques a reality, particularly in the realms of graphical displays and multivariate analysis.

Many people in the "user"-disciplines have always merely fed data into statistical packages without understanding the processes involved, and many are still doing just that. What is worse, however, is that now large numbers of people in the general population, many of whom are statistically illiterate, are doing the same (i.e., regularly relying on a package or a computer to sort things out for them). The ability to process data with a piece of software is only one aspect of using a statistical package. Selecting the appropriate analysis and being able to interpret the output are what matter. These skills must be taught if the way we do statistics is to change. They do not just emerge of their own accord.

Technology *can* change the way in which we do statistics. It does not necessarily do so, however, and the changes are not guaranteed to be beneficial.

Myth 3: Computers have changed the way we teach statistics

Computers have saved many hours of computation time, enabling the study of larger datasets than was previously possible. New topics have been added to statistics syllabi, and some techniques that were mainly ways of coping with awkward or time-consuming computations have been dropped. Statistics, of course, is a living subject; thus, the process is on-going.

It has not, however, been computers per se that have changed the way we teach statistics. More particularly, it was (1) the micro-revolution (Mangles, 1984) that made computers *physically* available to a wider range of users, and (2) the development of natural language and Graphic User Interface software that made their use accessible.

The advantages of computers include their dynamic nature, their speed, and the increasingly comprehensive range of software that they support. These, together with their increased storage capacity and processing power, enable students to experience and explore *all* aspects of the statistical process--from planning the sampling or experimental design, through data collection, database management, modeling, and analysis, to interpreting and communicating findings. Technology can now provide students the opportunity to conduct real investigations of real questions of real interest.

In teaching statistics, it is no longer necessary to spend time on ways to make manual computations easier, or on practicing such computations. There are, however, a number of dangers into which statistical educators can fall. Preece (1986) warned against filling the time made available by the use of computers with opportunities “for students to ‘try out’ a whole host of packages whose merits or failings they are not yet competent to assess” (p. 43). Computers assist us: It is statistics that we are teaching--not computing.

Taylor (1980) defined three types of computer software for use in teaching statistics:

- ***Tool*** software for *doing* statistics: statistics/graphics packages.
- ***Tutor*** software for *showing* statistics: concept simulations, and so forth.
- ***Tutee*** software: programming languages and software that allow the student to learn about statistics by “instructing” a computer.

Not everyone has access to these types of software (or the necessary hardware). Also, not all teachers understand or are trained in the uses to which software can be put. The result is that the way in which statistics is taught has not changed to the extent that we might imagine, and students’ experiences of statistics and of statistical education have become worryingly diverse. Particularly with respect to developing and transition countries, access to technology is often most limited where alternative teaching approaches are also most restricted. The use of technology to supplement available provisions (e.g., to deliver distance learning program) is therefore precluded where it is most needed.

Tutor software

Originally, Taylor’s second category (*tutor* software) was concerned mainly with teaching aspects of probability, by providing simulations of sampling distributions. Now, however, the scope of tutor software is much broader, and includes certain developments in the areas of expert system and multimedia software. In the United Kingdom, the Teaching and Learning through Technology Project (TLTP) recently funded the development of Statistical Teaching through Problem Solving software (STEPS). [See also Chapter 8.] This software provides a series of applied problem areas where the student can interact with the software to discover solutions. The more innovative modules include tutor software aimed at shaping statistical reasoning and behavior. They use a more open, interactive structure than the rigid "carrot and stick" approach of earlier programmed learning materials.

Tool software

Many statistics packages (i.e., tool software) are available (e.g., SPSS, MINITAB, DataDesk). These vary considerably in their scope, power, and ease of use. More particularly, they differ in the balances struck between statistical analyses and graphical displays, and between traditional statistical techniques and exploratory data analysis (EDA) approaches.

If a package for "doing statistics" is going to be useful in the statistical education process (i.e., as a teaching and learning tool), rather than merely providing bigger and better opportunities for doing statistical analyses, it should be highly interactive and possess dynamic graphical capabilities. Students can then use it to examine the effect of scale on the appearance of a scatter-graph, study the effect of changing the bin widths on the impression of a histogram, identify the effect of influential points or outliers, study the effect of transformations on linearity or normality, or rotate a three-dimensional plot to examine the relationship between subgroups. It is particularly useful for students to be able to use "brushing" to select data points in a two- or three-dimensional display that will then be highlighted in other displays. This can extend students' perceptions of the world from a series of one- or two-dimensional snapshots to a more complex multidimensional understanding.

For a variety of reasons, some academic, some economic, and some pragmatic, teachers may prefer to adopt software that provides an *integrated environment* for statistical computing (e.g., the office suites that are now often bundled with purchased hardware). With access to this variety of tools, students' statistical training can be expanded to include data-base management and more sophisticated presentation and communication skills using word-processing and graphic/art-work applications. However, such software has been designed to be all things to all people, which means that everybody gets something that they do not want, and everybody loses something that they really need. Using such software also encourages an over-dependence on the publishers' ideas of what the practitioner needs, whereas publishers *should* be made to produce affordable and usable software that actually reliably computes the statistics needed.

There is still a belief that all demonstrations tend to be more dramatic and interesting when done by a computer than by the chalk-and-talk method. Computer demonstrations certainly come nearer to the expectations that students (experienced with technology in other contexts and with the media portrayal of sci-fi technology) bring to the situation. If students' interest can be aroused, it is presumed that they will be more eager, and more likely, to learn. This has been a guiding influence for many innovations (not just those involving technology) in statistical education in recent years. Although empirical evaluation of this assumption has not kept pace with the developments that are based on it, it is reasonable to suppose that, if students' interest is not engaged, then their learning will be impeded. However, we must guard against turning a belief about a *necessary* condition for learning into an assumption (myth) that it is a *sufficient* condition.

1. MYTH-CONCEPTIONS!

Tutee software

Sometimes *tutee* software is used to replicate the way we used to teach statistics, before computers (i.e., technology is used to perpetuate, rather than change, the way we do statistics). Students are taught how to program, and then to write their own programs for deriving various statistical concepts, such as the mean and variance. The argument is that if the student can make a machine do the computation, that student should have gained insight into the nature of the concept. This encourages an overemphasis on the algorithmic and computational aspects of statistical concepts.

However, this does not seem to be an efficient way of using students' time. It is possible that *some* students might benefit, but probably not as much as they would, for example, by experimenting with deriving the mean of a variety of different distribution shapes, using software that is already available. In this way, students can explore the *functional* characteristics of the mean as a representative value, discovering, for example, the influence of distributional characteristics on its robustness and usefulness. Certainly, for the vast majority of students who study statistics, expecting them to learn first to program is merely erecting yet another obstacle to their acquiring any understanding of the processes and reasoning involved in statistics. It is important to realize that this tutee-type use of software, to replicate obsolete processes, actually occurs in a variety of different, and harder to spot, guises.

One exception, which indicated that the use of programming could be a "good" way to teach statistical concepts, was Butt's (1986) innovative method of teaching the concept of random variation using the programming language LOGO to control the movements of a turtle. The students had to discover a *black-box* algorithm by alternate prediction and experimentation. Unknown to them, however, the *rule* controlling the movement of the turtle contained a *random* element. Gradually, in their efforts to discover the *rule* that would enable them to complete their navigation of a geometrical figure, the students came to appreciate the distinction between the deterministic models that they were trying to apply and the probabilistic model that would be more appropriate. This programming approach provided an interesting way for students to learn about variability, (un)predictability, random influences, bias, and so forth. It encourages the discovery of statistical concepts at a level other than algorithmic representation.

There are also some good examples of spreadsheets being used to demonstrate statistical concepts and to allow students to experiment with these concepts. However, the strong (and possibly growing) lobby for using spreadsheets to demonstrate the *computational* aspects of statistical concepts is less convincing. Proponents of this approach argue that a spreadsheet is ideal for showing the intermediate steps in statistical calculations, by keeping students close to the data and its successive transformations. The presumption is that this experience of the spreadsheet as a form of *tutee* software will help the students obtain a better understanding of the associated formulae. Students should then eventually become comfortable with a more black-box approach, and move on to statistical software packages for more serious calculations.

This begs the question of whether the approach helps students develop an understanding of the *functional* characteristics of the concepts. Another problem is the danger that an overemphasis on the use of a spreadsheet, rather than on a dedicated statistical analysis package, may actually teach people that the spreadsheet is *the* tool for computing statistics (which it is not). If so, this is likely to be a factor contributing to, and perpetuating, the inappropriate software choices observed in the workplace.

The debate over whether spreadsheets are useful in the teaching of statistics has been fueled by peoples' differing opinions about what comprises a statistical education. The discussion has, at times, been quite heated, but has been confounded by the fact that different beliefs about thr essence of a statistical education lead to the different uses of spreadsheets. The debate periodically recurs, largely because there is little empirical evidence of the *cognitive* gains that might, or might not, be acquired by students from the proposed uses of spreadsheets in the teaching process.

Taylor's (1980) framework of tool, tutor, and tutee software is still useful in classifying types of software, although we must also consider the influence of more recent multimedia developments. The Internet is possibly the most exciting prospect yet in technology-based teaching, because it offers access to data, the possibility of consulting with experts and of collaborating with others on a world-wide basis, quicker and more widespread dissemination of outcomes, and so forth.

Actually, Moore (1993) believes that computing has not really had the impact on how we teach statistics that we might have expected. He sees it as being reminiscent of the way in which, in the 1950's, people expected television to impact, and fundamentally change, our teaching. However, he asserts that, with only a few exceptions, the use of television has been disappointingly mundane, and feels that the computer's influence on statistical education has to be extended to reach its full potential.

In reality, there are examples of exciting uses of computing technology. However, these tend to be individual, somewhat isolated projects, rather than wide-ranging developments affecting many educational institutions. One United Kingdom school, for example, is involved with an ecological research project off the coast of Florida, U.S.A., and regularly collects data using communication via the Internet to control the project's submersible. Meanwhile, many United Kingdom schools do conform with Moore's understanding of the more mundane uses of technology.

Some software is still being produced that is of the old stereotypical programmed learning type, characterized by: "Well done - you realized that …." or "Bad luck, you missed … Go back to …." This kind of software is merely transferring the style of the tutor-texts of the 1950's and 1960's to the modern-day computer, and makes no use of the very different opportunities available by the switch to a different instructional medium. Moore (1996) made the point that, in general, technology should not be thought of as operating in text-based terms, for that is not where its strength lies, especially because we already have good text-based media (i.e., books).

Surely, by now we should have moved from these banal and sterile tutor-text approaches to teaching statistics. However, there are still would-be software developers who are ignorant of, or ignore, the progress made by others. This may also be a criticism of the general level of dissemination (or lack of it) that educators are able to achieve with respect to empirical work aimed at identifying good practice in statistical education.

Myth 4: Introducing technology into the statistical teaching process is innovative

Again, this is not really the whole story. Introducing technology effectively requires exactly the same kind of planning and understanding about how students learn, and how best to teach them, that we should use to plan any other nontechnologically-based teaching. It also requires empirical evidence about the optimal materials to be used, the methods for presenting them, and how to integrate them into the overall teaching process.

Myth 5: Students learn statistics more easily with computers

There is a large selection of software available for demonstrating probability and sampling distributions. A noticeable feature of the Second International Conference on Teaching Statistics (ICOTS-2; Davidson & Swift, 1986) was the enthusiasm of many delegates for demonstrating newly developed examples of central limit theorem software. It is somewhat surprising that new examples of this are still being produced, when there is an established collection already and when the new examples add little in terms of content or pedagogy to the earlier offerings. The contributions to statistical computing sessions at the Third International Conference on Teaching Statistics (ICOTS-3; Vere-Jones, 1990) were more varied in their content, which indicates the progress in this area. This progress has, by and large, been sustained in subsequent meetings of the International Statistical Institute (ISI) and the International Association for Statistical Education (IASE). However, software to simulate statistical distribution theory is still a popular teaching resource, and this type of software may be the only reason why some teachers use the computer in teaching statistics.

Although such software undoubtedly allows the concepts to be explored quickly and efficiently under a variety of conditions, it is not safe to assume that students will grasp all the important ideas of sampling, variability, sampling distributions, and so on, unless they also have some experience with the concrete versions of the experiments that are symbolized by the software.

For example, Green (1990) reported the classroom experiences of using *Microcosm Software* (Green, Knott, Lewis, & Roberts, 1986), which has a game format (plus worksheets) to teach students concepts associated with probability distributions. He concluded that

> ...the misconceptions which are common in the field of probability (and about computers) must give cause for doubt as to whether the pupils get from computer simulations what the teachers or software writers assume. There seems to be a built-in assumption that the basis of the simulation is understood and accepted and the role of the computer (especially the random number generator) is appreciated. (p. 62)

In the past, probably the one characteristic that distinguished better from worse or merely adequate software was the speed at which the distributions could be generated. Unlike later versions, earlier software often relied on students recording successive sample statistics and then generating their own sampling distribution manually. The software was merely a sampling device. Increased speed and computing power have led to the abandonment of this approach. Ironically, however, this intermediate level of technology might have provided an important half-way point between the hours that students spent tossing coins and dice in precomputer days, and the all too remote and automatic derivation of sampling distributions that are now available.

Myth 6: Research is guiding our progress

This is not strictly true. The published research is still predominantly a collection of reports of positive outcomes. It does not tell us about things that did not work, and, therefore, about what things we should avoid. Although there is far more empirical evidence available now, it is still rather development-oriented. Research into why a particular teaching approach is effective is still relatively rare (this is true for both technological and nontechnological teaching methods). This Round Table discussion provides an opportunity to feature examples of cognitive research into students' interaction with computers, and their understanding of some of the more fundamental statistical concepts, as well as looking at studies (some classroom-oriented) that evaluate the usefulness of particular technological approaches, hopefully on a more comparative basis.

To move forward requires an amalgam of these differing perspectives. We will also need clearer ideas about the appropriate empirical methodologies to apply in order to resolve our research questions. This gathering has the potential for being a landmark event in the field of statistical education. In 1984, the Education Committee of the International Statistical Institute convened a Round Table conference on *The Impact of Calculators and Computers on Teaching Statistics* (Råde & Speed, 1985). Among the recommendations put forward were the following;

> *Educational research into teaching methods* was needed to determine at what age and through what methods statistical concepts can be effectively learned by children; the stage at which calculators and computers can best be introduced in the teaching of statistics; for what statistical purposes calculators and computers are best suited; and how developments in computers can affect statistical courses and syllabuses.
>
> *Educational research into programming methods* was needed to determine the educational value of programming; the extent to which program writing develops the logical and quantitative skills of children and students; and how statistical packages can be developed, adapted and improved for school use.

It has been 12 years since this 1984 Round Table. We can now consider how much of this research agenda still has to be met and set a new agenda for the next millennium.

One of the difficulties is that, compared to other pedagogies [e.g., mathematics education, notwithstanding Hart's (1996) comments at ICME-8 about the paucity of research in this field], statistical education is in a relatively early stage of its development. Even when relevant research has been conducted, statistical education specialists are only just beginning to be able to build on existing studies. The scope for research has been so broad that we tend to expect a study to be a relatively one-off investigation. Gradually, we need to build a tradition of a more synthesized body of literature, which will safeguard researchers and practitioners from trying too many square wheels, or reinventing too many round (or square) ones!

Myth 7: People intuitively understand statistics and probability concepts

Although some people do seem to have a natural flare for statistics and probability, others find the concepts to be illusive and counter-intuitive. There may be many reasons for this--some being more within our control than others. It is worthwhile to remind ourselves of the types of misconceptions that prevail, as well as to consider areas in which technology-based teaching seems to offer useful prospects. Biehler (1995) has written more formally about the requirements of statistical education software from a teaching point of view.

1. MYTH-CONCEPTIONS!

Misconceptions in the area of descriptive statistics

Rubin, Rosebery, and Bruce (1990) observe that students have difficulties understanding what it means for something to *represent* another thing. She draws a distinction between how a histogram is meant to represent a sample *accurately*, and how a sample is meant to represent a population *probabilistically*. Students who do not distinguish between these two types of representation expect *sample* = *population*. If this turns out not to be the case, they believe that the experimenter made a mistake. This misconception also leads students to assume that there should be no sampling error (i.e., no variability). Software is available that provides visual evidence of sampling variability to counter this misconception.

Students' personal beliefs about types of data may be a matter of judgment from situation to situation. Sometimes, for example, their decisions to treat a particular variable as qualitative rather than quantitative, or discrete rather than continuous, may be influenced more by the way in which the data have been collected and recorded than by conventional views of the underlying distribution of possible data values. Clearly, some variables provide for less uncertainty than do others, but age and income, for example, can be difficult. Dynamic graphics allow students to compare representations and summaries obtained when they adopt different assumptions. This may also encourage a more critical approach to statistical presentations.

Problems of inclusion and exclusion often occur when students have to deal with, or derive, percentages in interpreting tables of data. Again, it may be helpful to have access to graphical software, or to software that allows students to highlight different subgroups using a pointer and/or simple natural language commands.

Some students find it difficult to make a distinction between *observations* on a variable and the *frequencies* of those observations; thus, the students erroneously manipulate the frequencies instead of the observations. Software that emphasizes the *derivation* of frequencies, and hence the distinction between them and the original observations, is certainly within the scope of available packages, particularly those that possess animation facilities.

In investigating understanding of the arithmetic mean, a common finding is that students mechanically use an incompletely developed algorithm that fails to deal with *weighted* as opposed to *simple* arithmetic mean problems. What is required is software that emphasizes *functional* properties rather than computation. Likewise, the traditional emphasis on algorithmic approaches to the variance frequently leads to a counterproductive focus on questions such as "Why squared deviations?" and "Why divide by '*n*-1'?".

The mean deviation and the standard deviation are merely attempts to find a *representative* statement about the typical amount of spread about the mean; the sum of deviations, ignoring their direction, and the sum of the squared deviations, are statements that are meant to represent the overall amount of spread about the mean. Software needs to emphasize these characteristics, and to show that the mean deviation and standard deviation have a *function* of representation to serve, just as the arithmetic mean has. Appropriate dynamic graphical software can be used to extend this understanding by alerting students to, and encouraging them to explore, those characteristics of data (e.g., outliers) that may make either derived statistic less than helpful, especially the standard deviation where squaring the distance from the mean can seriously distort what is meant to be a typical value.

In general, the real world has more complexity than our teaching strategies usually acknowledge, even allowing for the benefits of computers. As Gnanadesikan (1977) states:

> Most bodies of data involve observations associated with various facets of a particular background, environment, or experiment. Therefore, in a general sense, data are always multivariate in character. (p. 1)

We are not presenting students with a sensible picture of the purpose of statistics if the tools that we make them practice using so clearly fail to deal with the real world of many interacting variables. Graphical and exploratory software provide ideal ways of solving this problem, and yet curricula and syllabi still emphasize univariate and bivariate techniques.

Misconceptions in the area of probability

Many of the misunderstandings in probability occur because the language of probability is different from our usual conversational language; however, it is not only at the pedagogic level that misconceptions about probability exist. Shaughnessy (1992) and Kahneman, Slovic, and Tversky (1982) provide good introductions to the research into other psychological misconceptions, such as the negative recency effect, ignoring base-rate information, the representativeness fallacy, and so forth.

The concept of a random experiment is the fundamental notion on which probability is built. There are two important aspects to a probability experiment: (1) *formulation* and (2) *enumeration.* There is the description (formulation) of the experiment itself, and there is the identification of all possible outcomes that constitute the sample space (enumeration). The source of many misconceptions can be traced back to these two aspects of a probability experiment. If technology is going to assist with misconceptions in this area, software is needed that can emphasize formulation, because if students misinterpret the statement of the experiment they will end up working with an erroneous sample space. In general, we need more emphasis on teaching students to construct (probability) models. Traditionally, we have overemphasised their manipulation (see Green, 1982).

The equally-likely approach has conventionally been the natural starting point for the study of probability. However, research has shown that people do not necessarily believe wholeheartedly in the equal likelihood of equally-likely events. Also, the equally-likely approach is rarely adequate for modelling events in the real world. Indeed, there are risks in overemphasizing this definition of probability. As Green (1982) demonstrated, there is a danger that a student reared on an “equally-likely diet” will always attach a probability of .5 to each of two mutually exclusive and exhaustive events based on any probability experiment, irrespective of how different the events’ probabilities really are. The availability of good simulation and bootstrap software should lessen the perceived need to rely so heavily on equal-likelihood approaches, as well as offer possibilities for addressing real-life problems.

Subjective probability is a measure of a person’s degree of belief. Buxton (1970) emphasizes that a subjectivist assigning a probability to an event does not ask “How likely *is* this event?” but rather “How likely do I think this event is?”. Subjective intuitions do exist and may well conflict with more formal, or objective, estimates of probability. Fischbein (Fischbein & Schnarch, 1995) argues that possibly the only way of bringing subjective (mis)conceptions into line with reality is to challenge them openly with students. Presumably then, we might be looking for software that not only gives students the experience of formal or objective estimates of probability, but that also encourages them to compare and contrast such estimates with their subjective intuitions.

Typically, a student who is beginning statistics enters the study of probability after being exposed to arithmetic (and/or geometry) where ratio and proportion arguments are important. The student may therefore try to import intuitive, but inappropriate, notions of proportionality into the study of probability. Likewise, students who have taken a traditional advanced level (or high school) course in pure mathematics will have covered counting methods under the headings of permutations and combinations, which are often presented as taking order into account and “ignoring order,” respectively. However, the ideas of counting with replacement and without replacement may not receive the same attention. If technology is to help with the ensuing misconceptions, software will be needed that can alert students to their errors. However, given our awareness of such potential difficulties, it seems clear that our main objective should be prevention rather than cure. Whether this involves (or is benefited by) technological approaches is a secondary issue compared to establishing the general principles involved in prevention.

Falk (1988) identified three particularly intransigent areas of difficulty associated with conditional probabilities: (1) the interpretation of conditionality as causality, (2) people’s tendency to condition on an inferred event, and (3) the confusion of the inverse; that is, a lack of discrimination between the two directions of conditioning, P(A|B) and P(B|A).

In considering any research of this kind (certainly not just that by Falk, for there are others who have researched in this area, and adopted different descriptions for the misconceptions), we must ask whether the researcher’s descriptions are appropriate, or whether they are the products of the researcher’s expectations. If we are to establish optimal ways of overcoming misunderstandings, we need to understand them as fully as possible. Technology may now present us with new, and more effective, ways of investigating the nature of the misconceptions. Although this is not the main thrust of this Round Table, it is nevertheless relevant to it and will hopefully receive some attention during the proceedings.

The normal distribution plays a dominant role in most basic statistics courses. If mishandled, it can become the starting point for a range of misconceptions relating to probability distributions and statistical inference, including those concerned with continuity corrections and the “magic” of the number 30 for sample size. Again, knowing that there is the potential for misunderstandings suggests that to move forward, we must prevent these misunderstandings from taking root. The use of graphical and interactive software may be helpful in this respect. However, we must avoid conveying to students the idea that knowledge about the statistical distribution itself is the final product of such investigations. Ideally, the software should enable the students’ understanding of the normal distribution, for example, to be extended to its use in real world situations.

There has probably been more empirical exploration of probabilistic than statistical misconceptions, but the role of technology in resolving probabilistic misconceptions seems to be more ambiguous. There has to be more to it than merely symbolic simulations of coin-tossing, probability distributions, and derivations of the central limit theorem. Software that shows these in action in real world contexts is an exciting prospect that has yet to be fully exploited, especially for nonspecialist students.

Misconceptions in the area of statistical inference

If used properly, examples of Taylor’s tool and tutor software can remedy the misconceptions that are associated with statistical inference. Sampling can be simulated graphically to accommodate even the more abstract interpretations of population that a statistician may adopt. Alternative representations, which preferably can be viewed synchronously, allow distinctions and comparisons to be drawn between population and samples, as well as their parameters and statistics. Students need not then be exposed to (and potentially confused by) more philosophical debate about what constitutes a population or a sample.

The extension to sampling distributions can be similarly handled. Indeed, there is a plethora of software to do just that, although the design characteristics are not always as good as they might be. We must, however, still address the issues surrounding the integration of such software into the overall teaching program.

There are those who advocate that EDA methods can make the principles of statistical inference much more accessible. Some (e.g., Ogborn, 1991) argue that EDA should be given prominence over classical inference, especially for introductory or nonspecialist courses. Certainly, this could now be a viable prospect. There are more examples of software that include a reasonable range of EDA tools than there were in 1988 (see Hawkins, 1990).

What, then, is to be the role of classical inference with its difficult philosophical basis of hypothetical or imaginary populations (the characteristics of which are first estimated and then compared, using odds reflecting conditional probabilities that are open to misunderstanding) given that modern technology and software is particularly good for exploratory and graphical approaches? Ironically, bootstrap techniques, which have become more feasible with modern hardware and software, do provide easier ways of teaching classical inference methods. Resampling experiments can be used to provide intermediate steps towards acquiring an understanding of the principles of classical inference (see Simon, 1993.) This poses a dilemma about the statistical curriculum; that is, should we stick with classical inference, but take advantage of software to ease students' learning? Or should we move to more EDA and graphical approaches?

In fact, there is a third alternative. Bayesian statisticians assert that classical approaches are not particularly useful for students of statistics and that they can be replaced instead by Bayesian software [e.g., *First Bayes* (O'Hagan, 1996)]. Furthermore, there are those who advocate this approach for both specialists and nonspecialists. Dawson (1995), for example, points out that it is unlikely that either of the axioms "social scientists need statistics" and "social scientists do not need calculus" will be abandoned. He suggests that the solution may possibly lie in the development of easy-to-use automated Bayesian inference techniques, built into a user-friendly software package, so that a less philosophically convoluted style of statistics may be taught to those who can use (but not program) a computer.

In designing a survey or an experiment, precision can, and should, be manipulated if statistical and meaningful or practical significance are to be equated. Quite apart from convincing students that such manipulation is not cheating, we encounter widespread confusion as to what *precision* means. For many students, it is often semantically indistinguishable from accuracy. Graphical software is readily available that allows students to experiment with the sampling process and to investigate the effect of biased, random, and other methods of sampling on the estimates obtained. It is not clear, however, that such software is fully exploited by all teachers who use it, because some teachers have misconceptions about the sampling process themselves.

In fact, our students generally have information available to them on the relationship between sample size and precision by the time they reach the level of Sixth Form work (age 17-18). Nevertheless, they do not appear to appreciate its practical value in the preplanning stages of their projects. Their understanding seems to be at a superficial or surface level rather than at a level where they could apply the principles they have learned. Can technology address this problem? This is another case that serves to demonstrate that resolving students' misconceptions is not necessarily sufficient for making them statisticians.

Myth 8: Technology will solve students' statistics and probability misconceptions

1. MYTH-CONCEPTIONS!

Technology may be able to help us find some solutions, but not until we have a better understanding of the origins of those misconceptions and we have found optimal ways to address them. Even then, only some of the misconceptions that students have will be particularly amenable to technology-based prevention or cures.

It is one thing to claim that more dynamic and interactive software can allow students to gain insights by exploring and experimenting with statistical concepts. It is quite another to find empirical evidence of how, why, and when these enhanced insights are gained. As statisticians, we are aware that the media, our policy-makers, members of the general public, our students, and even ourselves on occasions, are prey to many statistical and probabilistic misconceptions. Some of these misconceptions seem to be reasonably easy to address. Research shows, however, that others remain deep-seated and resistant to change. In fact, it is not only peoples' misconceptions that we need to worry about. To be statistically literate, a person must have not only reliable understanding, but also an inclination for using that understanding in everyday reasoning. It remains to be seen how much the use of technology can solve peoples' misconceptions, let alone encourage them to modify their reasoning strategies at such a fundamental level.

CONCLUDING REMARKS

Certainly, computers and related forms of technology are here to stay--at least until they are supplanted by some new form of technology. In general, software is becoming more flexible. Although there are exceptions, available software is now geared more towards skills development and understanding, with less emphasis on fact and definition teaching, or on rote practice of arithmetic computations, than was the case in the mid-1980's.

It is our task to identify priorities for a new research agenda, although the main areas outlined in the 1984 recommendations (Råde & Speed, 1985) may provide a useful starting point. Certainly, we should now be in a position to consider two additional areas of meta-enquiry: (1) What are appropriate empirical methodologies to apply in order to establish the role of technology in teaching and learning statistics? and (2) What is the role of technology in such research?

Our research should be aimed at identifying a broad range of ways in which technology can assist the teaching and learning process. Just as there is "no one right answer" to a statistical investigation nor is there "one right way" to teach statistics, there may be many "wrong" ways! A variety of methods and materials will always be a source of strength and benefit to both teachers and students, provided we have insights into how to use the available resources.

What we can afford to be optimistic about is that the myth-conceptions about the role of technology in teaching and learning statistics will cease to be misconceptions as current trends toward the amassing of more empirical evidence continue, and our understanding of the processes involved increases.

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