clock, and conclude "I would like to have a job like that." The realities of life of faculty in both smaller colleges and large research universities should be laid out clearly and candidly.

Descriptions of workplace realities for statisticians employed as practitioners in the private and public sectors are best given by statisticians currently (or recently) employed full time in those settings. In our experience, many practitioner alumni welcome an invitation to describe life in their organizations and have instant credibility with the students. It is helpful to have a faculty member in the classroom during the alumni practitioner's discussion with the students in order to ensure that all student questions regarding life in practitioner workplaces are addressed.

In addition to the proposed formal presentations of workplace realities by faculty and alumni practitioners, there already exist other practice-setting opportunities within statistics departments that have been utilized for many years. These are the teaching and research assistantships. A teaching assistantship in which the graduate student grades papers, delivers lectures, tutors students in elementary courses, and participates in the grade negotiations with disgruntled students gives some taste of the teaching role of faculty. The tension between the nurturing aspect of teaching and the evaluative aspect of grading needs to be experienced to be appreciated. A research assistantship can serve an important experiential role, the kind and extent depending on the department's involvement in research projects and the consultations of its faculty. The more a student can observe closely the negotiations of budgets and relationships, or even assume responsibility in such matters, the better a student can assess her or his psychosocial ability to handle awkward relationships and ill-defined problems of content or process. It is, however, the exception rather than the rule that graduate students are required to be both teaching and research assistants and few such departments would have "full menu" experiences for all students.

For the orientation process to be effective, not only must students be aware of the different workplace reward systems and cultures, but they also need to initiate a self-assessment of appropriateness for the various workplaces. The relevance of such self-awareness has been discussed previously by Boen and Zahn (1982, p. 175) in the context of consulting. Discussion with fellow graduate students holding differing views is an important and useful ingredient in such a self-assessment; to facilitate this, time could be set aside for initiating targeted discussion during one or more of the proposed classroom sessions. Some graduate students who excel in the classroom and thesis roles are very uncomfortable with ill-defined scientific problems and awkward or hostile personal relationships, and would be well-advised to discover those facts about themselves before they leave the relatively sheltered environment of their graduate department to seek employment. It is quite an adjustment to go from the sanitized problems appearing in statistics texts that illustrate applications of methodology with clean data to working with researchers who haven't defined their goals, let alone their outcome variables. Some students are tempermentally suited to making order out of chaos, while others simply aren't and don't know that they aren't. Helping determine the amount of structure in which they work most effectively, or may require, is one of the most useful things a faculty can do for students deciding on their workplace setting.

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What's Missing in Statistical Education?

RONALD D. SNEE*

There is a growing feeling in the statistical community that significant changes must be made in statistical education. Statistical education has traditionally focused on developing knowledge and skills and assumed that students would create value for the subject in the process. This approach hasn't worked. It is argued that we can help students better learn statistical thinking and methods and create value for its use by focusing both the content and delivery of statistical education on how people use statistical thinking and methods to learn, solve problems, and improve processes. Learning from your experiences, by using statistical thinking in real-life situations, is an effective way to create value for a subject and build knowledge and skills at both the graduate and undergraduate levels. The learnings from psychology and behavioral science are also shown to be helpful in improving the delivery of statistical education.

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Articles in recent issues of *The American Statistician* (Bisgaard 1991; Hogg 1991; Khamis 1991; Kopas and McAllister 1992; Watts 1991) and *Amstat News* (Cobb 1991) highlight the growing feeling that statistical education is in serious trouble and that changes must be made. These changes are necessary because, in general, people don't understand statistical thinking and as a result don't value its use. People can't value what they don't understand.

In order to develop this understanding and create value we need to deepen our understanding of how people learn. This will require statisticians to learn about psychology and behavioral science which Deming pointed out is part of the profound knowledge we need to make significant change (Scherkenbach 1991). Significant change will require the involvement of American Statistical Association (ASA) leadership, individuals, groups, university departments, and so forth. The learnings apply equally well in academic, industry, and government environments.

The need to change statistical education is not a new thought. The current thrust began in 1979 when the ASA Section on Statistical Education formed the Committee on Preparing Statisticians for Careers in Industry (ASA 1980) and continued through the 1980s and into the 1990s with committee reports and events such as ASA Committee of Preparing Statisticians for Careers in Federal Government (ASA 1982), Statistical Education of Engineers (Hogg et al. 1985), Statistical Education of Business Students (Easton, Roberts, and Tiao 1988), Iowa Workshop on Statistical Education (Hogg 1991), Michigan Conference on Teaching and Use of Statistical Theory and Methods (October 1990), and the ASA 1992 Winter Conference on Statistical Education.

This growing trend is welcome, healthy, and much needed but progress is much too slow. The question remains, what's missing? What should we do? How can we speed up the process of improving statistical education? Why should we do it? The obvious answer to what's missing is the students! Enrollments are declining. Math, science, and statistics are not popular subjects. Why are the students missing? We need a theory to guide us. Fortunately such theories exist but we have to go to the science of human behavior to find these helpful theories.

Calling on another discipline for help in improving one's work is not a new idea for the statistics community. Statisticians have long recommended that scientists, engineers, and others utilize statistical thinking to improve their work. It's now time for statisticians to practice what they preach and utilize what's known about behavioral science and how people learn to improve the content and delivery of statistical education.

1. WE NEED TO CREATE VALUE FOR STATISTICAL THINKING

It is well known that people will engage in an activity if they see more value in it than in other competitive endeavors. The same is true of careers. People will study statistics if they see value in it. Clearly we have not helped people understand the value of statistical thinking and methods.

Why is understanding the value of something so important you ask? It has been well understood for a long time that change, learning, and growth take place in three areas: physical, logical, and emotional. More importantly learning and growth cannot take place unless *change takes place in all three areas*! Useful discussions of this important point can be found in Covey (1989) and Scherkenbach (1991).

There are many descriptors of these three areas (Scherkenbach 1991, p. 86). The descriptors I find most useful are knowledge (logical), skills (physical), and attitude or desire (emotional). We will make a change (e.g., develop a new skill or habit) when we know what to do and why (knowledge), we know how to make the change (skills), and we want to make the change (attitude or desire) because we have value for the change (Fig. 1). In this terminology it is easy to see the missing link. Statistical education has traditionally focused on the "knowledge" and "skills" components and assumed that the attitude and desire would take care of itself. Attitude and desire reflect value.

A few teachers have worked on creating value for statistics. Each of us can recall those teachers who influenced us the most. These teachers are often dynamic, colorful, charming, and charismatic. But they also loved their subject, had a deep knowledge of it, knew its place in the grand scheme of things, and were interested in you as a student. In the process, in subtle ways they communicated the value of their subject to you. You understood that value and created your own value for the subject. In the process you internally generated the

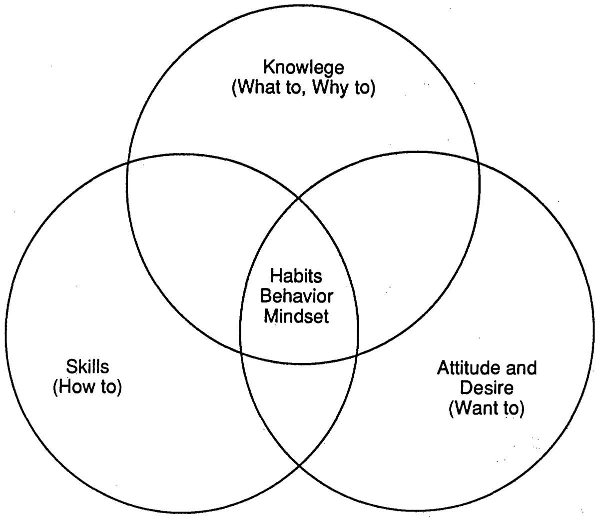

Figure 1. Effective Habits, Internalized Principles, and Patterns of Behavior (Covey 1989).

attitude and desire to deepen your understanding of the subject and put it to use. We must find a way to create this value on a broader scale.

Research on attitude and motivation has been conducted in the field of social psychology. The large body of scientific literature on the effects of attitude on memory was discussed by Aronson (1992). Mook (1987) provided a synthesis of the research on motivation and memory.

2. WE MUST CHANGE BOTH THE CONTENT AND DELIVERY OF STATISTICAL EDUCATION

The good news is that we know a lot about how to help people generate value for statistics. Many good ideas are discussed in the references at the end of this article (e.g., students collecting their own data, conducting experiments, testing paper helicopters). These ideas will generate fun, excitement, enthusiasm, and joy in learning in the process.

The bad news is that creating greater value for statistics requires a change in the *content* and *delivery* of statistical education. Change is never easy. It's often satisfying only in hindsight when you see how far you have come and how much you have accomplished. But there is no question in my mind that the statistical community must improve the statistical education process. Otherwise it will go the way of the dinosaurs.

3. CONTENT OF STATISTICAL EDUCATION

I believe that changing the content of statistical education is needed to help students create value for statistical thinking (Snee 1990a). The purpose of the following comments is to call attention to the need for this change in statistical education and to identify some important concepts that should be included. Detailed discussion of this subject is better done in other forums.

There is a growing consensus that the "content side" of statistical education should move away from the mathematical and probabilistic approach and place greater emphasis on data collection, understanding and modeling variation, graphical display of data, design of experiments, surveys, problem solving, and process improvement (ASA 1980, 1982; Easton et al. 1988; Hogg 1985, 1991; Snee 1988). This content relates directly to how statistical thinking is used in the solution of real-world problems. This connection to the real world helps students build value for statistical concepts and tools.

Deming had much the same view (Deming 1953, 1975, 1982; Joiner 1990). He called for greater emphasis on analytic studies which deal with planning for the future and prediction for the process which produced the data. "Process" is a generic term used to describe any sequence of events, varying from cell multiplication to management systems used to run a large corporation. Deming noted that much of statistical education is focused on enumerative studies which are concerned with estimation for the population from which the sample was drawn.

The focus on solving problems, improving processes, and predicting process performance in the future requires understanding all work as a process, that variation is present in all processes, the need for data to measure variation, and the use of statistical methods and tools to quantify and understand the variation and make predictions. These are all elements of statistical thinking (Snee 1990a).

I recognize that some prefer to view statistical studies in the context of learning about and understanding a particular phenomenon (e.g., social, biological, chemical, physical, engineering) rather than improving a process or solving a problem. I believe that these two views of using statistical thinking have a lot in common. We will better understand the commonality of these views as we work out the details of the content of statistical education.

4. DELIVERY OF STATISTICAL EDUCATION

There is less understanding of how to change the "delivery" of statistical education. A key is experiential learning. Joan Garfield pointed out that "students learn better by experiencing statistics" (Cobb 1991). This experience has at least two components: experience in working with real data (please, not computer simulations) and solving real problems and improving processes. As Cobb (1991) pointed out, experiential learning is *active learning* as compared to *passive learning* via lectures.

The goal should be to integrate the statistical thinking into the subject matter on which the student is working. Personal interest in the subject matter to which the statistical methodology is being applied and personal participation in the data collection and problem-solving processes are essential for developing value for statistical thinking.

I have taught courses both at universities and in industry that involved experiential learning. In my recent experience we taught continuous improvement and statistical thinking to teams, each of which came to the workshop with a problem to solve or a process to improve. The participants used the methodology to improve their own work as part of the workshop. The teams made real improvements to their work as well as developing new skills and knowledge. The savings realized from the improvements significantly reduced the overall cost of the training.

The improvement methodology was very popular and valued highly. Over a two-year period approximately 150 teams involving more than 1,000 persons experienced the workshop. The concept of learning by applying the methodology to problems encountered in the workplace (called just-in-time training by some) was subsequently used as the basis for the delivery of a corporate continuous improvement curriculum.

I believe that every course should contain an experiential learning component. This includes courses on statistical theory. The Chinese Proverb

I hear, I forget
I see, I remember
I do, I understand

reminds us of the importance of experiential learning—

learning by doing. Khamis (1991) pointed out that "learning is based on the conviction obtained by personal discovery, and this enhances genuine understanding (Bruner 1961; Jowett and Davies 1960)." We all learn more from what we do than from what we watch. Value comes from using statistics in one's life.

Joiner (1990) emphasized that we need to change our mindset regarding the delivery of statistical education. We must move away from "students read text, listen to professor, do homework problems" (learning from someone else's learning) to students learning by comparing data with a theory or conjecture. Collection and analysis of data is at the heart of statistical thinking. Data collection promotes learning by experience and connects the learning process to reality.

Some experiential learning techniques include individual and group projects, lab exercises, group problem solving, and workshops. Doing calculations and plotting data by hand are experiential learning techniques. Deming's red bead experiment and Bisgaard's paper helicopter experiment (Bisgaard 1991) help students discover the role and value of statistical methods and thinking as do Bill Hunter's designed experiments projects (Hunter 1977). Joiner (1990) pointed out that the quincunx can be used to convey the concepts of time-ordered data, special and common causes, the effects of tampering, and process stability. Data on personal preference for desirable room temperatures (high and low) is effective in illustrating Taguchi's loss function (Scherkenbach 1991).

In short, we can speed up the learning (personal change) process by creating an environment that enables student participation and personal discovery. Experiential learning has a growing literature of which all involved in statistical education should become knowledgeable (e.g., see Kolb 1984).

5. DIFFERENCES IN THINKING AND LEARNING STYLES SHOULD BE CONSIDERED

We see the value of experiential learning when we recognize that people have different thinking processes and different learning styles (Herrmann 1989). We take in and process information in different ways (Markova 1991). Some differences in learning styles appear to be related to which side of the brain one prefers to use. Springer and Deutsch (1989) summarized and evaluated the extensive scientific literature on the different thinking processes of the left and right hemispheres of the brain.

Herrmann (1989) has expanded the right-brain–left-brain theory to include upper (cerebral) and lower (limbic) hemispheres which produces four thinking processes (Fig. 2). This in turn leads to different preferred learning styles (Fig. 3).

Cerebral-left-brain thinkers respond best when they can quantify, analyze, and theorize about things. Limbic-left-brain thinkers like to see how things are put together, organize things, and practice. Cerebral-right-brain thinkers learn best when they can explore ideas, discover on their own, and conceptualize what is happening. Limbic-right-brain thinkers learn best when the activity is personalized and they rely on their feelings.

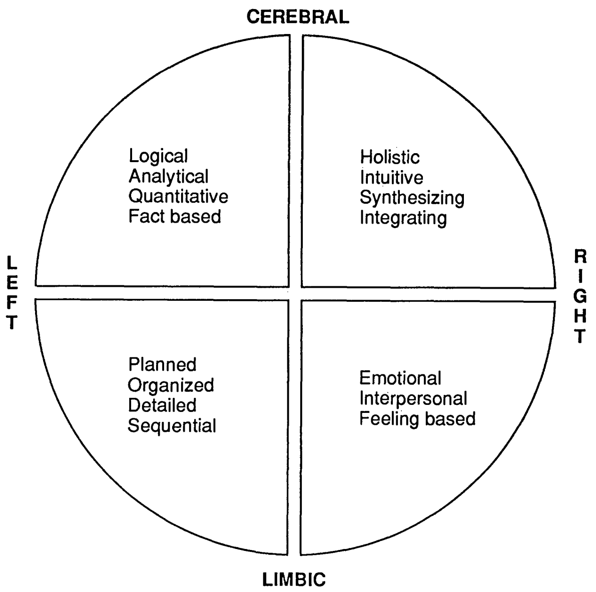

Figure 2. Whole-Brain Thinking Processes.

Different learning styles require different learning methods (Fig. 4). Some people like to read books and listen to lectures (cerebral-left brain). Others rely heavily on doing exercises, creating summaries, and reviewing the material (limbic-left brain). Cerebral-right-brain thinkers prefer visual aids, metaphors, and experiments, while the limbic-right-brain thinkers like group projects, discussions, and sharing experiences.

Statistics has traditionally been taught using left-brain learning modes: students read the text, listen to lectures, and work on problems at the end of the chapter (Joiner 1990). Some people learn this way. Others respond best to right-brain learning methods (Fig. 4). Wetzstein (1990) discussed the use of Herrmann's research in the design of statistical training.

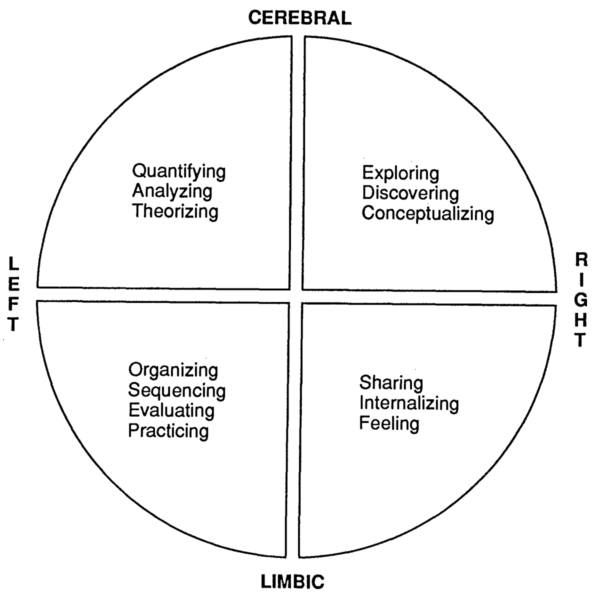

Figure 3. Preferred Learning Styles.

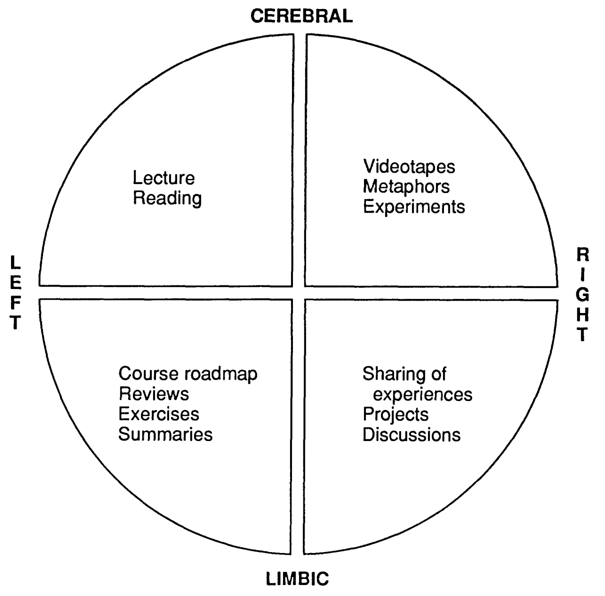

Figure 4. Learning Methods.

I've found Herrmann's thinking useful in designing and delivering quality improvement education. Different learning styles are present in each group of people. People take in and process information in different ways. We want the learning process to be robust to a variety of learning and information-processing styles.

Each educational experience, therefore, must include a variety of learning methods. Assigned readings and lectures get the attention of the left-brain thinkers. Others respond best to group exercises, experiments, games, and metaphors. The goal is to enable each person in the group to relate to the course content in some way.

Using a variety of learning methods can also help some people discover new worlds that might be closed to them because the teaching methods used are not compatible with their preferred learning styles. We should work to enable students to study in a mode that is effective for them, thereby increasing their comfort with this new subject they are studying.

Herrmann's (1989) work also shows that preferred thinking processes (Fig. 2) vary for different occupations. Recalling that preferred learning styles and methods (Figs. 3 and 4) are related to preferred thinking processes suggests that we should consider using different learning methods for different disciplines. For example, engineers and lawyers tend to be cerebral-left-brain thinkers, while many teachers, nurses, and social workers have limbic-right-brain thinking preferences.

Herrmann's work has many implications for statistical education. My purpose here is not to give a detailed analysis, but rather to highlight Herrmann's concepts which are based on extensive research and encourage the evaluation and testing of his ideas. Some may find the scientific literature on right-brain–left-brain learning (Springer and Deutsch 1989) helpful in determining the utility of Herrmann's work.

6. SO WHERE DO WE GO FROM HERE?

Many of the suggestions above can be implemented by individuals and small groups working in cooperation with each other. In culture change jargon, this would be pursuing a "bottoms-up" approach to improvement to statistical education. A "top-down" approach is also needed. Culture change moves ahead most rapidly when it is led top-down and implemented bottom-up.

A top-down approach calls for the ASA leadership (e.g., ASA president, board of directors, and staff) to identify improvement of statistical education as *the* #1 initiative and work to enable ASA to lead the necessary change process. ASA leadership should identify, prioritize, and lead initiatives critical to the improvement of statistical education. One possibility was discussed by Watts (1991).

ASA leadership can also encourage networking among those working on statistical education for engineers, business, medical, mathematics, and other disciplines. At this point it appears that there is little synergy among these groups.

The ASA leadership could also help enable the development of partnerships between statistics and other disciplines (Snee 1990b). The resulting relationship would be very beneficial in developing those experiential learning situations where statistics is taught in the context of solving the problems and improving the processes of the partnering discipline.

7. PEOPLE WILL USE STATISTICAL THINKING WHEN THEY EXPERIENCE ITS VALUE

The bottom line is that people at the university and in industry and government will study and make use of statistical thinking whey they experience its value. We must change the content and delivery of statistical education to enable students to experience the use of statistical thinking and methods in dealing with real-world problems and issues. These experiences will produce a more favorable attitude toward the discipline and greater desire to put statistical thinking to use.

Greater use of experiential learning and other right-brain learning methods can help a broader range of students discover the wonderful world of statistics. Enabling students to solve real problems from their field of interest as part of the learning experience will go a long way toward creating value for statistical thinking and methodology. There is much work to be done. Let's get on with it!

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