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Redesigning the Introductory Statistics Course

Roger W. Hoerl and Ronald D. Snee

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Roger W. Hoerl
General Electric
Schenectady, New York

Ronald D. Snee
Joiner Associates Inc.
Madison, Wisconsin

ABSTRACT

There is general agreement that the traditional introductory statistics course does not meet the needs of customer groups such as students and their future employers. While positive reform efforts are under way, many appear to be based on the belief that the course is fundamentally sound and just needs some modernizing. While we support these efforts, we argue that the traditional introductory course must be completely overhauled - not incrementally improved - if statistics is to have broad impact. Principles to guide this redesign are presented and then applied to the design of the introductory statistics course for business students. It is emphasized that both the content and delivery of the introductory statistics course must be changed. The proposed changes are supported by learning theories developed by educational and behavioral scientists.

KEYWORDS: Statistical education; Statistical thinking; Learning; Improvement; Behavior change; Cultural change.
Redesigning the Introductory Statistics Course

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There is general agreement that the traditional introductory statistics course does not meet the needs of customer groups such as students and their future employers. While positive reform efforts are under way, many appear to be based on the belief that the course is fundamentally sound and just needs some modernizing. While we support these efforts, we argue that the traditional introductory course must be completely overhauled - not incrementally improved - if statistics is to have broad impact. Principles to guide this redesign are presented and then applied to the design of the introductory statistics course for business students. It is emphasized that both the content and delivery of the introductory statistics course must be changed. The proposed changes are supported by learning theories developed by educational and behavioral scientists.

I. INTRODUCTION

We live in a highly competitive, rapidly changing world. We all need to do better if our society is to compete effectively in our new world. This includes all aspects of our society: business, government and education. In the case of statistical education it has long been recognized that statistics is not a favorite subject of students (of all ages) and that there is a huge gap between the actual and potential use of statistical thinking and methods. There is a clear need to improve the content and delivery of statistical education.

We believe a total redesign of statistics courses is required to address this need, particularly at the introductory level. Redesign of advanced courses will likely follow. This is not to say that all of what is being done is bad or wrong. Rather, what is needed is a new focus and emphasis with particular attention paid to teaching content that satisfies students' learning needs and delivering the content in such a way that connects to students' varied learning styles and backgrounds of study and work.

We present some generic guidelines that are useful in designing courses with particular learning objectives for a given group of learners. Our goal is to develop a process that will present statistical thinking and methods in such a way that learners of all ages and backgrounds will want to learn and use statistical thinking and methods.

The use of the generic guidelines will be applied to the design of an introductory course for business students which we call "Statistical Thinking for Business Improvement." This design is based on our experience and that of others teaching statistical thinking to adult learners in both university and business environments.

Our experience is primarily in the fields of business including manufacturing and service, engineering, research and development. Discussion with workers (professors, students, and professionals) in other fields suggest that our experiences are not unique to the application areas in which we work. We recognize that some people may find these ideas to be controversial; we believe however that it is worthwhile to consider what implications the ideas and experiences described here have for how introductory statistics is taught in various fields of application.

This article is organized as follows. We begin by identifying the root causes of the problem. This analysis is followed by the presentation of four generic principles needed to guide the design of an introductory course that will address the root causes. We then apply our principles for course design to the introductory course for business students. The article concludes with a comparison of our proposed approach and other currently used approaches to course design.

II. ROOT CAUSES OF THE PROBLEMS

One thing we have learned from the quality movement is that permanent, useful solutions to problems can only be obtained by attacking the root causes of the problems. Briefly stated, we believe that
there are four root causes which must be addressed simultaneously if the introductory statistics course is to ever achieve its potential.

First, our experience suggests that the goals for most courses are either not stated or do not meet the needs of the students. As a result, students typically don’t know why they are studying the subject (except that it may be a required course), what specific skills they will develop, or how it will help them do their jobs better.

Secondly, as noted by Hogg (1990, 1991) the course content is generally not based on the requirements of current or future employers. There is too much emphasis on probability and hypothesis testing in many courses, particularly at the introductory level. There are many other subjects (e.g., variation, data, graphics, processes) that students must understand deeply before they are ready to effectively understand hypothesis testing.

The third problem is the organization of the course. The approach most frequently used is to present a series of tools in isolation from each other and expect students to figure out how to integrate the tools into a problem-solving strategy. Many students have told us that this “bottom-up” approach leaves them confused about how to apply what they have learned to real problems.

Educational and behavioral science research has shown that the “top-down” approach is more effective for learners of all ages (see Forester, 1990). In this approach you teach the “whole” first and then discuss the “parts” of the whole. You begin with a complete, tangible example and then move to abstract theory of the individual techniques. You begin with gross understanding (the concept of what you are trying to do) and then move to fine understanding (competency to apply it to real problems).

The fourth root cause is our overuse of lecture as a method for delivering courses. This left-brain method is only one approach. Students learn in many ways (see Herrmann, 1989). In particular, we need to use more right-brain learning methods (see Snee, 1993). We will discuss this point in greater detail later in this article.

The result of these four root causes is confused, unmotivated students. They appear bored with the subject. They avoid the subject and don’t use it; worse yet, they resist others who want to use statistical thinking and methods. This is the exact opposite of what we want to happen.

III. A TOTAL REDESIGN IS NEEDED

Many have recognized the problems with introductory statistics courses and have made some changes. Some have added exploratory data analysis, statistical process control, and quality concepts; others have added hands-on demonstrations, individual projects, and team projects. There has also been a move to reduce the emphasis on hypothesis testing and probability. These reform efforts are useful but don’t attack, in a systematic way, the four root causes discussed in the previous section. We need to fix the whole system, not make more minor adjustments.

For an introductory statistics course to come anywhere near its potential, we must wipe the slate clean and design the course from scratch. We must change both the content and delivery of statistical education. We must put a greater emphasis on statistical thinking and experiential learning. Nothing short of a total transformation is required.

The following principles, summarized in Table 1, address the four root causes discussed earlier and provide guidance for the redesign of statistical education. The first two principles relate to the content of the course and the next two relate to the delivery.

<table>
<thead>
<tr>
<th>Table 1. Principles for redesigning statistical education.</th>
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<tbody>
<tr>
<td>1. Design programs and courses for specific needs:</td>
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<tr>
<td>- Competency based</td>
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<tr>
<td>- Desired knowledge, skills and attitude</td>
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<tr>
<td>2. Focus content on statistical thinking</td>
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<tr>
<td>3. Organize using “top-down” learning:</td>
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<tr>
<td>- Current “bottom-up” approach loses participants in the</td>
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<td>details</td>
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<tr>
<td>4. Deliver using a mixture of presentations,</td>
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<td>lectures, and experimental learning techniques, including:</td>
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<tr>
<td>- Experiments</td>
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<tr>
<td>- Discussions</td>
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<td>- Metaphors</td>
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<td>- Examples</td>
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<td>- Team Projects</td>
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</table>
1. DESIGN PROGRAMS AND COURSES FOR SPECIFIC NEEDS

There does not appear to be a consensus within the statistical community as to the purpose and objectives of statistics courses, especially the introductory course. We believe programs and courses should be competency-based with specific learning objectives in mind. These objectives should include the knowledge, skills, and attitudes the course wants to develop. The objectives should focus on what students need to know, not what it would be nice to know or what the instructor would like to talk about. It is also important that the objectives include tangible competencies (skills) and attitude development.

The competencies are specific tasks we expect the students to perform after the course. These tasks may be new to the students or enhancements of existing skills. Developing the proper attitude enhances the learning process and helps students develop value for the subject. With the objectives clearly in mind, both the instructor (or session leader) and the students know where the course is headed and what skills the students are expected to learn.

2. FOCUS THE CONTENT ON STATISTICAL THINKING, PARTICULARLY AT THE INTRODUCTORY LEVEL

The goal is to help students develop the thought processes that utilize statistical concepts and methods in the solution of real-life problems. Once the statistical thinking mindset is in place, it is easier for students to understand, to integrate, and to use statistical tools and methods. Statistical thinking is defined as a philosophy of learning and action based on the following fundamental principles:

- All work occurs in a system of interconnected processes;
- Variation exists in all processes; and
- Understanding and reducing variation are keys to success.

This definition which appears in the *Glossary of Statistical Terms* (see Quality Press, 1995) is similar to that proposed by Snee (1990).

We believe that the potential benefit of widespread application of statistical thinking exceeds that of any statistical technique. In fact, if no other objective were accomplished besides developing a solid understanding of, and ability to apply, statistical thinking, we believe the course would be a tremendous improvement. For example, students would understand that purchasing from multiple suppliers will increase process and product variation, which in turn will increase waste and decrease customer satisfaction. Understanding statistical thinking also requires a firm grasp of the concept of special and common cause variation and why the approach to dealing with each must be very different from the other.

3. ORGANIZE COURSES USING TOP-DOWN LEARNING PROCESSES

We should begin by setting the purpose and context for the course and then use real problems to motivate the broad model (the “whole”) for what will be discussed. The details of individual techniques are then developed and connected to the broad model. This concept reflects the fact that students need to learn how to integrate several statistical techniques into overall approaches to solving problems or improving processes.

Current research (see Forester, 1990) and common sense indicate that it is easier to learn the details of a statistical technique after understanding how this fits into the bigger picture. This approach also allows students to see where they are going. Consider experimental design as an example. Tradition would suggest that one can discuss uses of experimental design and see applications only after learning the details of sample statistics, probability rules, the normal distribution, sampling distributions, and hypothesis testing. Unfortunately, by that time the students are typically lost, confused, disinterested, and don’t understand why they needed to learn any of this.

A top-down approach would begin with a discussion of overall approaches to process improvement and where experimental designs fit. Several examples would be reviewed, noting the purpose for the design and how it is interpreted. The instructor would then point out that in order to understand how this actually works, the class needs to learn a few statistical details. Obviously, only those details needed to apply experimental design would be taught. Each of these would be introduced by referring back to the applications, and noting how this detail fits. In this way, students always understand where they are going, why this is needed, what they can do with it, and how it all fits together. The sequence is why they should apply it, what they are trying to do, and then how to do it.

4. INCLUDE A MIX OF DELIVERY METHODS

The final principle states that the course delivery
should include a mixture of delivery methods which represent a blend of right-brain and left-brain learning modes (see Table 1 for examples). This concept will reduce, but not eliminate, the amount of time spent on the instructor lecturing and presenting material.

The use of projects and examples is needed to develop understanding of the iterative nature of statistical investigations. Effective application requires sequential use of subject matter theory (deductive thinking) and data-based empiricism (inductive thinking). Typical textbook problems emphasize calculating a correct answer and therefore do not provide an opportunity for students to think independently about what they have learned from the data and how they might need to revise their theories.

Experiential learning, one of the alternative delivery methods, deserves further comment. By experiential learning, we mean learning that links formal education to how we solve problems and do our work. This powerful method of learning includes experiments, class exercises, group projects, plotting data by hand, use of subject matter theory, and independent thinking (see Kolb, 1984). Experiential learning works because it utilizes right-brain thought processes such as exploration and discovery by asking students to use their intuition, synthesize content, listen, share, feel and be involved. These techniques allow students to experience and internalize the iterative nature of statistical investigations, employing both subject matter theory and data.

Experiential learning recognizes that different people take in and process information in different ways. People have different preferred thinking processes, learning styles, and learning methods (see Herrmann, 1989; Markova, 1991).

IV. AN EXAMPLE OF COURSE REDESIGN

We will illustrate the use of course redesign principles using an introductory business statistics course which we’ve entitled “Statistical Thinking for Business Improvement.” The overall model for this course, shown in Figure 1 (discussed further below), was used in the design of a continuous improvement curriculum for the Du Pont Company (see Snee, 1993) and an introductory MBA level course at the University of Delaware. Informal feedback, as well as tangible results, have been very positive.

The overall purpose of this course is “to prepare students to be business leaders by developing their capabilities to use statistical thinking to improve business processes.”

The importance of linking business processes (targeted at the customer) and improvement activity is shown by the relationship between the boxes in Figure 1. This model sets the context for material being taught. All tools, techniques, methods, etc., are presented and discussed relative to this link between business processes and improvement.

As Figure 1 illustrates, students will see that:

- We have two jobs:
  - Do our work of serving our customers, as illustrated by the business process; and,
  - Improve on how we do our work, as illustrated by the improvement activity.

- Data and the data collection process are the link between the business process and the improvement activity.

- The improvement activity is made up of at least two processes: problem solving and process improvement.

Understanding and using an improvement system to improve business processes is what the course is about. All tools, techniques, methods, etc., are presented and discussed in relation to Figure 1.

Specific objectives of the course are summarized in Table 2. Desired outcomes in the areas of

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Figure 1. Model for business improvement.
Redesigning the Introductory Statistics Course

Table 2.
Objectives of statistical thinking for business improvement.

Objectives for the course encompass the knowledge, skills, and attitudes that students will gain. Each of the objectives is written as something the students should be able to do by the end of the course.

Knowledge:

- Describe the role within business of:
  - Statistical thinking and methods for problem solving and process improvement.
  - Understanding and quantifying variation.

Skills:

- Collect data appropriate to a specified purpose, and recognize limitations in existing data.
- Graphically analyze data using basic tools.
- Derive appropriate, actionable conclusions from data analyses.
- Solve real problems, improve real processes.
- Handle more advanced material in future statistics courses.

Attitude:

- Believe that statistical thinking and methods can help you do a better job in your chosen career.

knowledge, skills, and attitude are addressed. The desired knowledge and skills state the desired competency. These skills are included among the top nine items identified as desirable for introductory statistics courses by the Hogg Conference II (see Hogg, 1990, 1991). The purpose of the attitude objective is to create a mindset that will create an appreciation for statistical thinking and methods among students, and enable them to utilize the material and pursue further learning in the area.

The content of the course emphasizes statistical thinking. The understanding of and skills needed to apply statistical thinking would be developed by reviewing the three main concepts of the statistical thinking discussed earlier (i.e., process thinking, understanding variation, and reducing variation), and teaching the tools required to apply these concepts to real problems. These include both quantitative tools, such as experiment and survey design, and "soft" tools, such as flowcharting, brainstorming, and affinity diagrams.

The delivery of the course would employ the top-down approach. The pyramid in Figure 2 illustrates how this could apply to the introductory course. It begins with discussion of tangible, relevant data on the need to make our businesses more competitive. This forms the context, or why the material is important. It also includes understanding the objectives, the concept of statistical thinking, and the overall model in Figure 1.

An outline of the course described in Table 2 and Figure 2 is shown in Table 3. The topics in this outline include eight of the nine highest priority items recommended by the 1990 Hogg conference for inclusion in the introductory statistics course (see Hogg, 1990, 1991). We note that the sequence of topics in Table 3 is virtually the exact opposite of the traditional introductory course. This sequence utilizes a "pull" approach where the material is pulled in as it is needed to develop deeper understanding of the current topic.

The Statistical Thinking model in Figure 3 provides the next level of detail in terms of what we are actually doing. This is a more detailed depiction of the linkage between the Business Process and the Improvement Activity (shown in Figure 1). Based on similar models in Box, Hunter, and Hunter (1978) and other sources, it emphasizes the iterative role of deduction (theory to data) and induction (data to theory). These concepts would be illustrated with several real case studies. Students should now have a good understanding of where the course is going and how they could actually apply the material to real problems.

The third layer of the pyramid includes actual examples of the Process Improvement and Problem Solving strategies depicted in Figures 4 and 5, respectively. These illustrate how the individual techniques integrate to form overall strategies for improvement and can be viewed as special cases of the Statistical Thinking model. Our experience has been that, at this point, students are very curious about the details of the tools and are anxious to learn more. We note that the strategies shown in Figures 4 and 5 are typical of process improvement and problem solving strategies commonly used in practice. Other forms of these strategies are possible. For example, see those discussed in the publications by Gaudard, Coates, and Freeman (1991), The Xerox Corporation (1993), and Joiner (1994).

More detailed discussion of the individual tools

CQPI Report No. 130, July 1995
Context: Making our businesses more competitive
(Why)

![Diagram showing levels of business improvement]

**Figure 2. Statistical thinking for business improvement.**

<table>
<thead>
<tr>
<th>Table 3. Statistical thinking for business improvement.</th>
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<tbody>
<tr>
<td><strong>Course Outline - Candidate Topics</strong></td>
</tr>
<tr>
<td>• The need for business improvement</td>
</tr>
<tr>
<td>• Illustration of the statistical thinking approach</td>
</tr>
<tr>
<td>• Business processes</td>
</tr>
<tr>
<td>• Strategies for process improvement and problem solving</td>
</tr>
<tr>
<td>• Tools for process improvement and problem solving</td>
</tr>
<tr>
<td>• Understanding relationships among variables (model building)</td>
</tr>
<tr>
<td>• Concepts of statistical inference</td>
</tr>
<tr>
<td>• Tools of statistical inference</td>
</tr>
<tr>
<td>• Understanding summary statistics</td>
</tr>
<tr>
<td>• Summary and path forward</td>
</tr>
</tbody>
</table>

would occur next to develop competency to actually apply these strategies to real problems. The tools listed in Figures 4 and 5 are discussed in detail in the publications by Brassard (1989), GOAL/QPC (1988), Ishikawa (1982), and Scholtes (1988). Note that "statistical inference" in Figure 4 includes much of what is emphasized in the traditional introductory course (probability, confidence intervals, hypothesis testing, etc.), but here is covered in much less detail. The concept of inferring about processes or populations from sample data is discussed in this step.

Lastly, statistical details required by the tools, such as probability distributions or the Central Limit Theorem, would be covered. As noted earlier this sequence is virtually the exact opposite of the traditional introductory course.

The delivery of this course would include some lecture, but also make extensive use of experiential
learning. The most important application of this approach would be for each student to complete a sequential course project, perhaps in teams. The projects would be real problems of the students' choosing and involve sequential use of the methods learned, employing, for example, the Process Improvement strategy in Figure 4. Since the projects are of their own choosing, they will tend to have some knowledge (theory) about them, gather relevant data and interpret the analysis in light of known and believed theory. In addition, they will tend to be intrinsically motivated since they are projects of interest to them.

Realistic examples can also be used in classroom discussions, such as estimating the proportion of people in a given area who are HIV positive, determining if a company's market share for a given product is stable or changing, or trying to determine the major factors affecting consumer preference for automobiles. Such examples will not have unique correct answers because of practical issues such as lack of truly random sampling, non-response bias, biased questions, lack of stable populations, or special causes in the data. Live demonstrations employing a quincunx or sampling bowl and open classroom discussions are other methods of including experiential learning.

V. COMPARISON WITH OTHER APPROACHES

As previously mentioned, numerous positive reform efforts for introductory statistics courses are currently being implemented. Some reformers have focused on the course content by reducing the amount of hypothesis testing, for example, and replacing it with Statistical Process Control, Exploratory Data Analysis, or Deming's philosophy. Others have focused on delivery by adding team projects, computer simulations, or in-class demonstrations. While we support these improvements, they appear to be based on the belief that the course is fundamentally sound and just needs some modernizing. In other words, the problems are believed to be special causes which can be fixed without fundamental change.

We believe that the problems are common causes, i.e., designed in and inherent to the course. Such problems can only be eliminated by understanding the true root causes and then fundamentally changing the structure of the course. The root causes we perceive were discussed in Section II. We feel that statisticians should follow their own advice by basing the entire course structure and design on clearly defined objectives, utilizing the
most up-to-date subject matter knowledge from behavior science, education, and input from employers as to their requirements. This should be done employing all relevant factors for total system optimization, rather than via one-at-a-time experimentation with individual modifications.

Table 4 depicts a summary of our approach to doing this. It compares the Traditional course, the typical Reformed course, and a recommended Transformed course on the basis of the four principles from Table 1. While there is considerable overlap between the Reformed and Transformed courses, we see little change from the Traditional to the Reformed course in the areas of purpose (objectives) and course organization. Only when transformation occurs here, and is combined with

CQPI Report No. 130, July 1995
Steps

Document the Problem

Identify Potential Root Causes

Choose Best Solutions

Implement/Test Solutions

Measure Results

No

Problem Solved?

Yes

Standardize

Sample Tools

• Checksheet
• Pareto Chart
• Control Chart

• Time Plot/Run Chart
• "Is/Is Not" Analysis

• "5 Whys"
• Cause-and-Effect Diagram
• Brainstorming

• Scatter Plot
• Stratification

• Interrelationship Digraph
• Multivoting
• Affinity Diagram

• Experimental Design

• Checksheet
• Pareto Chart
• Control Chart
• Time Plot/Run Chart

• Flowchart
• Procedures
• Training

Figure 5. Problem solving.
Table 4.
Statistical education for business students.

<table>
<thead>
<tr>
<th>Course Characteristics</th>
<th>Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Traditional</td>
</tr>
<tr>
<td>Purpose/Customer Needs:</td>
<td>Unstated, or exposure to various techniques.</td>
</tr>
<tr>
<td>Organization:</td>
<td>Focus on individual techniques, then tie them together.</td>
</tr>
<tr>
<td>Delivery Process:</td>
<td>Lecture, homework, test.</td>
</tr>
</tbody>
</table>

more fundamental change in content emphasis and delivery process, will the introductory course reach its potential.

VI. CONCLUSION

The introductory statistics course, and statistics education in general, have great potential. The introductory course could be a gateway to developing lifelong interest in and enthusiasm for statistical thinking and methods, and encourage students to take more advanced courses specific to their major fields of study. Figure 6 illustrates how the introductory course could take, as input, students meeting a minimal set of basic requirements and prepare them for a variety of future directions in statistics. Unfortunately, we are generally offered only one chance to convince them that statistics is valuable and practical. If the introductory course does not make a good impression, students will tend to avoid statistics for the remainder of their education and even in their careers.

The four root causes of Section II, which include both content and delivery, must be addressed to enable the introductory course to be successful. We believe that this requires fundamental redesign which must not only incorporate but go well beyond the current reform efforts. The proposed Transformed introductory course outlined in Section IV is only a first attempt at the desired course. Our experience is that it is a dramatic improvement to the typical Traditional or even the Reformed courses.

CQPI Report No. 130, July 1995
The Foundation for Progress

- Marketing
  - Regression
  - Conjoint Analysis
  - Survey Design
- Product Development
  - DOE
  - Multivariate
- Manufacturing
  - SPC
  - DOE
- Forecasting
  - Time Series
- Econometrics
  - Regression

Statistical Thinking for Business Improvement

Ability to Graph Data
Math Fundamentals
Basic Economics

Figure 6. Statistical thinking for business improvement.

REFERENCES


