

Curricular Change to Improve Student Learning in Undergraduate Statistics

Jill L. Lane
Pennsylvania State University

Maja Aleksic
Arizona Department of Education

Abstract

Undergraduate students often leave statistics courses not fully understanding how to apply statistical concepts. In order to enhance student learning and improve the understanding and application of statistical concepts, an elementary statistics course was transformed from a lecture-based course into one that integrates technology with active and collaborative learning methods. The effect of these changes was evaluated using a combination of pre- and post-content knowledge tests. The overall results of these changes showed that student performance on the content test was higher in the redesigned classes compared to the traditional course.

Statistics is predominantly viewed by students as a course filled with abstract concepts and memorization of facts and formulas. Traditionally, it has been taught using lectures where conceptual information is transmitted to students in a large lecture hall with little or no opportunity for discussion of those concepts. Faculty members in these types of courses are commonly referred to as the “sage on the stage” and students typically sit passively in their seats and take notes. While this could be considered an efficient method of teaching to a large number of students (Schaeffer et al., 2001), it does little to enhance student learning (Boyer Commission, 1998). As a result, students often leave the course still not fully understanding how to apply statistical concepts in both life and in subsequent courses where an introductory statistics course is a prerequisite (Bonsangue, 1994). In this paper, we will describe the transformation of elementary statistics (Stat 200) at the University Park campus of Pennsylvania State University, from a lecture-based course similar to the one described above into a course that effectively integrates technology with active and collaborative learning methods.

The Traditional Course

Elementary Statistics in its traditional form was a lecture-based course taught in the fall, spring, and summer semesters to approximately 2,200 students annually. During the fall and spring semesters, each of the four lecture sections enrolled 240 students who were taught by full-time faculty. Twelve graduate teaching assistants each taught two recitation sections¹ per week that had an average enrollment of 40 students. In the traditional model, each lecture section met three times per week and each recitation

section met twice a week. The students enrolled in the course were predominantly freshmen and sophomores from the fields of education, communications, health and human development, and the liberal arts. These students were required to take the course as part of their major. Additionally, since the course fulfills a general education requirement at Penn State, other students at the university who needed credits in quantification also took it.

Faculty members teaching Stat 200 often complained that due to the large class size there was little opportunity for student-to-faculty or student-to-student interaction. As a result, students rarely applied course principles and concepts in a meaningful way (Cross, 1987; Chickering & Gamson, 1987). The only opportunity for interaction took place in the recitation meetings and when these interactions occurred, they were minimal at best. In these recitation meetings, teaching assistants would primarily review homework problems and administer quizzes. While this traditional course delivery model seemed to work because of the learning style of a few of the students, the majority of the students finished the course with only a cursory understanding of the basic statistical concepts (Miller, Groccia, & Wilkes, 1996).

The Redesigned Course

In 1998, the faculty members who taught Stat 200 approached Penn State's Schreyer Institute for Innovation in Learning and the Center for Academic Computing in search of ways to improve student learning in the course. Specifically, they were looking to find a way to solve five specific academic problems:

1. The traditional format did not address the broad range of quantitative skills possessed by students in the course.
2. The original course format did not provide students with opportunities for hands-on experience analyzing and collecting data.
3. It was difficult to find qualified graduate teaching assistants to teach the recitation sections since most of the graduate students in the department had undergraduate degrees in other scientific disciplines.
4. The course did not provide opportunities for individual tutoring of students since office hour availability was limited.
5. The current course structure allowed little opportunity for interactions between students and faculty.

After several consultations between instructional designers and the faculty members, it became clear that in order to solve these perceived problems a solution was needed that would not only restructure the way the course was taught, but also incorporate alternative teaching and learning methods.

In the spring of 1999, the first author of this paper proposed a new delivery model for the course. The goals for the redesigned course were to increase students' ability to understand and apply basic concepts of statistics, to actively participate in data analysis and design, to critically evaluate reports containing statistical analyses of surveys and experiments, to actively engage with course materials and other students, and to provide more opportunity for one-to-one interaction with faculty. The new model not only

addressed these goals, but also capitalized on available technology as a means of giving students the opportunity to apply statistical concepts (Chrisman & Harvey, 1998). The redesigned model was proposed to and ultimately received implementation support from the Center for Academic Transformation's Learning and Technology Program, sponsored by the Pew Charitable Trusts.

The new model allows for a more student-centered rather than instructor-centered classroom. Students spend one session per week in a large group meeting (lecture with an enrollment of 240 students) and two sessions in a computer studio lab (enrollment of 40-60 students). The faculty members in the course each teach all three sessions and a graduate teaching assistant is present in the computer studio lab classes as well. The large group meeting time provides the faculty members with the opportunity to provide students with an overview of the week's topics. The time in the labs is divided between assessments of student progress and applications and simulations of statistical concepts. The organizing center for the new course is a website developed by the Center for Academic Computing.

The Course Website

The course website serves as the technology gateway for the students in the course. By simply logging onto the site, students gain access to up-to-date administrative and assignment information. The site acts as a learning-centered syllabus (Diamond, 1998) by providing information and links to the web-based textbook, datasets, study guides, online quizzes, and additional resources. At the beginning of each week, students log on to the website and receive their weekly assignments which include readings and assignments (Figure 1). Students are responsible for completing any required readings before attending their large group meeting.

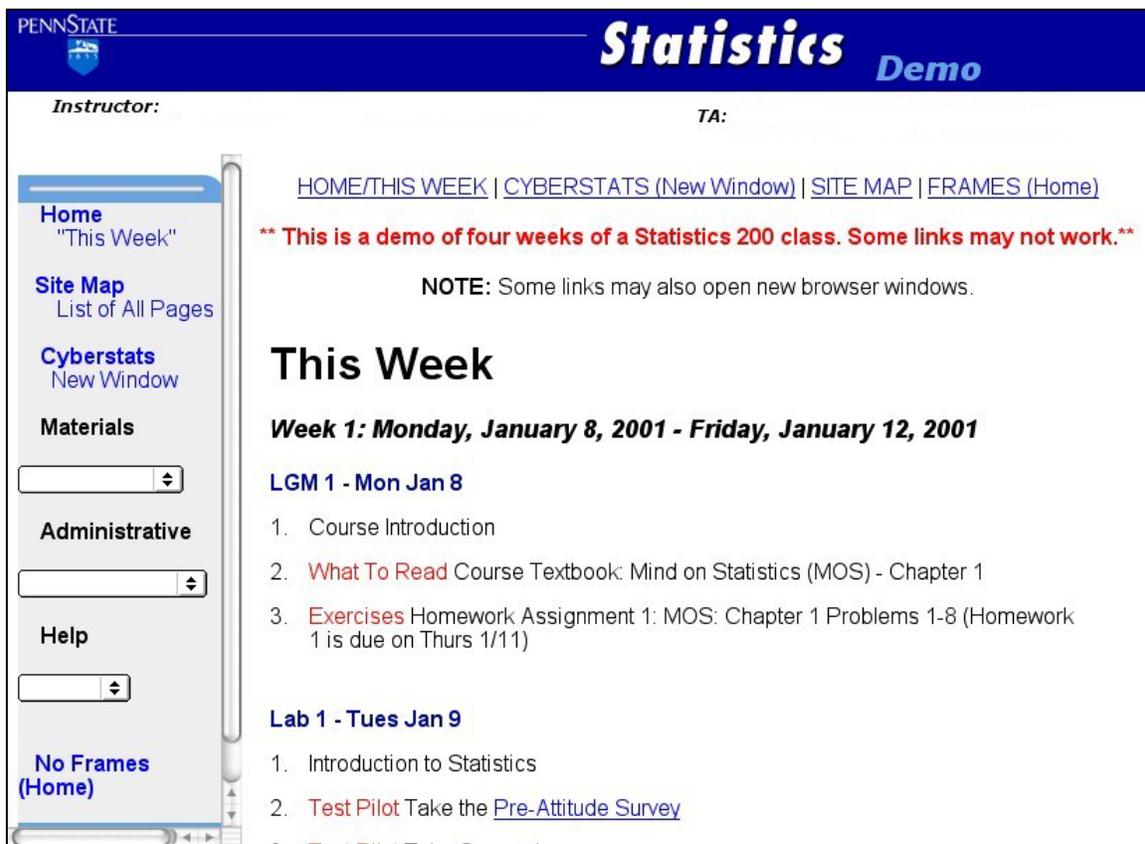


Figure 1. Online course syllabus, Penn State Statistics Department, 2001, <https://stat200.stat.psu.edu/about/publicdemo/index.html>.

Large Group Meetings

As mentioned above, the large group meeting takes place once a week. The main purpose of this session is to provide faculty with the opportunity to give an overview of the concepts covered in the assigned readings and to answer student items. Despite the large enrollment, these sessions are mostly discussion-based and often include the use of short activities to further illustrate difficult concepts.

Computer Studio Labs

In the computer studio labs, students are divided into collaborative learning groups to enable more student-to-student interaction. In these labs, students are either assessed on the understanding of the pre-readings and assignments or they spend class time applying statistical concepts to real-world problems. The method employed to assess student preparedness and understanding of conceptual information is Readiness Assessment Tests (Michaelson, Black, & Fink, 1996). Students are expected to prepare outside of class by completing readings and homework assignments. Upon entering the

lab session students individually take a Readiness Assessment Test (RAT). Immediately following the individual test, the students retake the test in their groups. The grades on the test are weighted with two thirds of the final grade taken from the individual score and one third of the final grade taken from the group score. The purpose of the RATs is to provide valuable formative feedback to both the students and the faculty member. Analysis of student answers can help faculty target their lectures and course assignments to clarify misconceptions and give additional practice.

As mentioned previously, the other function of the computer studio labs is to provide students with the opportunity to work on collaborative activities that enable them to apply statistical concepts to real-world problems. These activities (Figure 2) make use of either real-time data collected through the administration of surveys in the course or through pre-designed activities that make use of existing datasets (Figure 3).

Activity #009: Moneybags

You are presented two bags that contain paper money (bills of varying denominations). Both bags contain 20 bills. The composition of each of the two bags--A and B-- is as follows:

Bag A	Denomination (x)	\$1	\$2	\$5	\$10	\$20	\$50
	Count of Bills		9	6	2	1	1

Bag B	Denomination (x)	\$1	\$2	\$5	\$10	\$20	\$50
	Count of Bills		1	1	1	4	6

Problem: One bill will be randomly picked from one of the bags. The identity of the bag is unknown to the person who draws. The person drawing the bill will receive \$100 if he or she correctly identifies the bag from which it was picked; otherwise, receives nothing. The problem is to devise a strategy for guessing the bag.

First, let's rearrange the format of the denominations and counts for the two bags, as follows:

	Bag A		Bag B	
Denomination	Count	Proportion	Count	Proportion
\$1	9	.45	1	.05
\$2	6	.30	1	.05
\$5	2	.10	1	.05
\$10	1	.05	4	.20
\$20	1	.05	6	.30
\$50	1	.05	7	.35

Figure 2. Sample activity, Penn State Statistics Department, 2001, <https://stat200.stat.psu.edu/eternal/activities/009/Act009-rho.html>.

While students are at work on these activities, faculty members and teaching assistants will interact with the groups and answer specific items. If it appears that a majority of the class is having trouble applying a particular statistical concept, the faculty member will stop the entire class and conduct a mini-lesson to clarify student misconceptions.

Datasets Listing

This is listed in reverse chronological order from the most recent week to the first week.

Week 4

1. Data for Activity 12 [Survey 1](#)

Week 3

No Items Found

Week 2

1. Data for Activity 10 [Survey 1](#)

Week 1

1. Data for Activity 1 [Survey 1](#)

Figure 3. Links to existing datasets, Penn State Statistics Department, 2001, <https://stat200.stat.psu.edu/about/publicdemo/datasets.html>.

Benefits of the Model

The new model capitalizes on the research showing the positive effects of active and collaborative learning strategies on student learning (Brandon & Hollingshead, 1999; Bonwell, 1996). Various active and collaborative learning methods have been shown to increase student mastery of material and their ability to transfer and apply new knowledge (Felder & Brent, 1996; Haller, Gallagher, Weldon, & Felder, 2000; Springer, Stanne, & Donovan, 1999). By restructuring the class to allow for increased interaction between students and faculty and to give students the opportunity to become engaged in real-world problems and situations, it was hoped that the amount of student learning would increase. What follows is an explanation of the methods used to evaluate the project and the findings of the study.

Methods

In order to assess the impact of the new delivery model on student learning, an 18-item multiple choice pre- and post-content knowledge test was developed. The purpose of this test was to measure changes in student mastery of elementary statistical

concepts. The test was administered in Stat 200 at the beginning and end of each semester that the project was funded as part of the Pew Grant. During the pilot semester (spring 2000), one instructor taught the pilot section and a different instructor taught the two traditional sections. The fourth section of the course was not included during the pilot semester because the instructor teaching that section was using a textbook that was different from the text that had been adopted for the course. The study utilized a quasi-experimental design since it was not possible for the researchers to randomly assign students to the pilot and traditional sections of the course. Cook and Campbell (1979) describe this method using untreated control group designs with a pretest and posttest as both interpretable and appropriate to use when a traditional pre- and posttest control group design is not possible (Cook & Campbell, 1979, p. 103). The primary reason for the pretest was to examine differences in statistical knowledge between groups at entry into the class. Additionally, the pretest served as a baseline measure to examine changes in statistical knowledge from entry into the class to exit from the class as well as to allow for comparisons to be made during the full implementation semesters (fall 2000 and spring 2001). No significant differences in statistical knowledge were found between groups at entry during the pilot semester suggesting that the groups approached equivalency. While potential threats to internal validity, including selection-maturation, instrumentation, differential statistical regression, and history can occur with the use of an untreated control group design (Cook & Campbell, 1979, pp. 103-105), the finding that the groups did not differ significantly in statistical ability at entry minimized all internal validity threats with the exception of history. Some of these history threats were minimized since the pilot phase of the study was conducted in a single semester and the administration of the pretest and posttest occurred at common times during the semester for both groups.

Results

Pre- and Post-Content Knowledge Test: Pilot Semester

In order to assess the potential impact of the redesign on student learning in Stat 200 and to establish a baseline for further study, a content knowledge test (Figure 4) was administered at the beginning and end of the spring 2000 semester (pilot semester).

Content area: Hypotheses testing/interpretation of results/ p-value and use of probability

A candidate running for Congress claims that 64% of adults in the U. S. favor a tax cut. Her opponent says this is much too high--it is definitely less. To see if this claim has merit, a random sample of 400 adults is polled and 46% report favoring a tax cut. The probability of obtaining that percentage found or an even lower one turns out to be .032, or a 3.2% chance, if one calculates this probability assuming the claim is true. If we test a hypothesis about the candidate's claim with a .05 significance level, based on the outcome of the polling, we should:

- a. Draw no conclusions and get a bigger sample
- b. Conclude that the percentage of adults favoring a tax cut is between 60.8% and 67.2%.
- c. Reject the candidate's claim
- d. Not reject the candidate's claim

Content area: Percentiles and variability (range, standard deviation)

Which of the following statistics is not a measure of variability?

- a. Range
- b. Standard deviation
- c. Interquartile range
- d. Percentile

Content area: Population versus Sample data

A researcher wishes to determine the proportion of adults (people 18 or older) in the U.S. who have smoked marijuana at least once. She randomly obtains a simple random sample of 400 adults and determines the proportion among the 400 who say they have smoked marijuana at least once. The result: 256 say they have.

The population of interest to the researcher is:

- a. The 400 people in her study.
- b. All people in the U.S. who are 18 or older.
- c. All adults in the U.S. who have smoked marijuana at least once
- d. The 256 people among the 400 asked who say they have smoked marijuana at least once.

Figure 4. Sample content knowledge test items.

Students in three sections took the pretest and posttest; two sections were taught in the traditional three-lecture, two-recitation format ($n = 340$) and the other section was taught using the new delivery model of one lecture and two computer studio labs ($n = 140$). The

performance in both the pilot and traditional sections of the course improved from pretest to posttest. Using analysis of variance, this improvement in performance from pretest to posttest was found to be statistically significant for both the pilot and traditional sections. Specifically, in the pilot section students had 51% correct at pretest while their scores improved to 66% at posttest ($F[1, 319] = 76.34, p = 0.001$). In the traditional sections students had 51% correct at pretest while at posttest they had 60% correct ($F[1, 603] = 61.71, p = 0.001$). It is important to note that there was no significant difference between the two groups at the time of the pretest as results indicated that both groups had approximately equal levels of pre-existing statistical knowledge. Even though this equivalence existed on the pretest, the pilot section outperformed the traditional section on the posttest measure (66% correct in the pilot class, 60% correct in the traditional class). This difference in posttest performance between the pilot and traditional sections was found to be statistically significant, $F(1,478) = 13.56, p < .001$, with a small effect size ($f = .176$).

A multivariate analysis of variance was used to analyze differences between student performance in the traditional class and the pilot class in the posttest measure. When comparing average scores on the posttest, students in the pilot section outperformed students in the traditional section on 16 of the 18 items. Four items have been identified where the pilot classes outperformed the traditional section with an average score difference between 5%–10% (Table 1). However, these differences were not statistically significant. When analyzing the specific content areas on the test, the pilot section appears to have a larger portion of students who answered items correctly on interpreting results and proportions, as well as understanding concepts such as median, percentiles, confidence intervals and margin of error.

Table 1
Items with 5–10% Difference in Performance between the Traditional Class and the Pilot Section of Spring 2000

Item #	Concept	% Correct Traditional Class ($n = 340$) Spring 2000	% Correct Pilot Class ($n = 140$) Spring 2000
1.	Median	75.9	81.4
2.	Percentiles	85.8	90.7
7.	Interpreting Results/Proportions	86.8	91.4
8.	Confidence Intervals/margin of Error	53.4	61.9

Areas where the pilot section outperformed the traditional section with an average score difference greater than 10% included items assessing students' ability to distinguish population versus sample data, interpret percentile and variability statistics as well as understand concepts such as mean, median, mode and the normal distribution (Table 2).

Table 2

Items with More than 10% Difference in Performance between the Traditional Class and the Pilot Section of Spring 2000

Item #	Content	% Correct Traditional Class ($n = 340$) Spring 2000	% Correct Pilot Class ($n = 140$) Spring 2000
6.	Population versus sample	38.9***	61.4***
14.	Percentiles/variability (range, standard deviation)	62.5***	82.1***
16.	Distributions/Mean/Median/Mode/Histogram	18.2***	33.1***
17.	Mean/Trimmed mean/Median	50.8*	63.3*

* $p < .05$. *** $p < .001$

Additionally, one item was identified where the traditional class outperformed the pilot section with a difference of more than 5%. The traditional class had a larger proportion of students answer correctly the item assessing students' ability to read as well as utilize information from statistical tables. While 93% of the students in the traditional class answered this item correctly, only 85% of the students from the pilot class did. This difference was statistically significant, $p < .01$.

Pre- and Post-Content Test: Full Implementation

Even though the results from the pilot semester of the project indicated only a small but statistically significant increase in performance between the pilot section and the traditional, the decision was made to drop the traditional section beginning in fall 2000 and the new delivery methods were implemented across all sections of the course. This decision was based on the fact that the new delivery method did not have a negative impact on student learning of statistical concepts, it provided students with more opportunities for hands-on experience analyzing and collecting data, and it allowed for more opportunity for interactions between students and faculty. The same instructors as the pilot semester taught three of the sections in fall 2000 and spring 2001 and one additional instructor taught the remaining section of the course. Pretest and posttest results from the full implementation semesters (fall 2000 and spring 2001) were compared with the results from the spring 2000 traditional section. The purpose of the evaluations during fall 2000 and spring 2001 were to assess whether the learning gains achieved during the pilot semester would continue over subsequent semesters. If the result proved to be consistent then that would support the proposition that the results of the initial experiment could be generalized over time to future populations of students in Stat 200.

In fall 2000, all four sections of Stat 200 were taught using the new delivery model ($n = 681$). Students in all four sections of the class took the content knowledge pretest and posttest with performance in all sections improving from pretest to posttest.

Using analysis of variance procedures, this improvement in performance from pretest to posttest was found to be statistically significant, $F(1, 1564) = 297.50, p = 0.001$. On the pretest students answered 55% of the items correctly with posttest scores increasing by more than 10%, to 68%. Spring 2001 results showed a similar increase from pretest to posttest. This increase in performance was found to be statistically significant, $F(1,1763) = 173.50, p = 0.001$. While on the pretest students answered 58% of the items correctly, the average score on the posttest was 68%.

When comparing the performance of students in the redesigned classes of fall 2000 and spring 2001 to those in the traditional class (spring 2000), the redesigned class outperformed the traditional class on overall posttest performance (68% correct in the redesigned classes, 60% correct in the traditional class). This difference in posttest performance was found to be statistically significant, $F(1,1019) = 56.06, p < .001$ for fall 2000 and $F(1,1114) = 57.69, p < .001$ for spring 2001. The effect size for each of these posttest performance differences was $f = .223$.

A multivariate analysis of variance was used to analyze differences between student performance in the traditional and the redesigned classes in the posttest measure. When comparing average scores on specific items on the posttest, students in the both the redesigned class of fall 2000 and the redesigned class of spring 2001 performed at or above the level of the students in the traditional class (spring 2000) on each of the 18 items. Two items were identified where one or both of the redesigned classes outperformed the traditional section with a difference of between 5%–10% (Table 3). These differences were statistically significant, $p < .001$. The redesigned sections had a large portion of students who answered items correctly on the application of percentiles as well as understanding the concept of margin of error and problems addressing the use of opinion polls.

Table 3
Items with 5-10% Difference in Performance between the Redesigned Classes of Fall 2000 and Spring 2001 and the Traditional Class of Spring 2000

Item #	Concept	% Correct Traditional Class ($n = 340$) Spring 2000	% Correct Redesigned Class ($n = 681$) Fall 2000	% Correct Redesigned Class ($n = 776$) Spring 2001
2.	Percentiles	85.8***	92.1***	94.6***
5.	Opinion polls/Margin of error	82.6***	(81.4)***	89.9***

*** $p < .001$

There were eight areas where the redesigned class showed more than a 10% increase in performance compared to the traditional class. These included items assessing students' ability to use population and sample data, construct confidence intervals and interpret margin of error information, understand the concept of dependent variables and standard error, reason about percentiles and standard deviations, conduct hypothesis testing, and interpret statistical results, as well as reason about means, trimmed means

and medians (Table 4). The difference on posttest performance on all eight items was statistically significant, $p < .001$.

Table 4
Items with More than 10% Difference in Performance between the Redesigned Classes of Fall 2000 and Spring 2001 and the Traditional Class of Spring 2000

Item #	Content	% Correct Traditional Class (n = 340) Spring 2000	% Correct Redesigned Class (n=681) Fall 2000	% Correct Redesigned Class (n = 776) Spring 2001
6.	Population versus sample	38.9***	53.5***	52.3***
8.	Confidence intervals/ Margin of error	53.4***	74.4***	70.2***
9.	Sample size/standard error/ Large sample	70.9***	88.8***	87.1***
11.	Variables (dependent)	77.0***	85.8***	88.5***
14.	Percentiles/Variability (range, standard deviation)	62.5***	73.9***	75.1***
15.	Hypothesis testing/ Interpreting results/ P-value/use of probability	45.4***	58.1***	62.1***
16.	Distributions/Mean/ Median/Mode/Histogram	18.2***	36.7***	32.2***
17.	Mean/Trimmed Mean/ Median	50.8***	63.6***	60.6***

*** $p < .001$

Discussion

Evaluation results of the new delivery model did produce significant learning gains across many statistical areas. However, there were some areas where student performance and content mastery was lower than predicted regardless of the delivery model used. These areas included the ability to read and interpret information from tables, reasoning and solving problems involving the normal distribution, and interpreting data from histograms. Apparently, regardless of the class format these areas seem to be difficult for the majority of learners. Overall, the pilot and redesigned classes outperformed the traditional class on the post-content test. Students who took statistics under the new delivery method demonstrated a greater understanding of a number of statistical concepts. From these results, it appears that the new mode of instruction allows students to better learn and master statistical concepts covered in an introductory statistics class.

Concluding Remarks

The transformation of elementary statistics to enhance student learning has proven to be a successful example for integrating technology with active and collaborative learning methods in postsecondary education. The gains in student learning demonstrated by the new delivery model have had a tremendous impact on the statistics department at Penn State. Because of the success of this project, two additional introductory statistics courses are currently undergoing similar revisions. It is hoped that a replication of this study on those classes will show similar gains in student learning.

Notes

¹Classes containing a subset of students from a large lecture section.

References

- Bonsangue, M. V. (1994). Symbiotic effects of collaboration, verbalization, and cognition in elementary statistics. In J. J. Kaput & E. Dubinsky (Eds.), *Research issues in undergraduate mathematics learning: Preliminary analyses and results* (MAA Notes No. 3, pp. 109-117). Washington, DC: Mathematical Association of America.
- Bonwell, C. C. (1996). Enhancing the lecture: Revitalizing a traditional format. In T. E. Sutherland & C. C. Bonwell (Eds.), *New directions for teaching and learning: Vol. 67. Using active learning in college classes: A full range of options for faculty*. (pp. 31-44). San Francisco: Jossey-Bass.
- Boyer Commission on Educating Undergraduates in the Research University (1998). *Reinventing undergraduate education: A blueprint for America's research universities*. Princeton, NJ: Carnegie Foundation for the Advancement of Teaching.
- Brandon, D. P., & Hollingshead, A. B. (1999). Collaborative learning and computer-supported groups. *Communication Education*, 48, 109-126.
- Cook, T. D., & Campbell, D. T. (1979). *Quasi-experimentation: Design & analysis issues for field settings*. Boston: Houghton Mifflin.
- Chickering, A. W., & Gamson, Z. F. (1987). Seven principles for good practice. *AAHE Bulletin*, 39(7), 3-7.
- Chrisman, N. R., & Harvey, F. J. (1998). Extending the classroom: Hypermedia-supported learning. *Journal of Geography in Higher Education*, 22(1), 11-18.
- Cross, K. P. (1987). Teaching for learning. *AAHE Bulletin*, 39(7), 3-7.
- Diamond, R. M. (1998). *Designing and assessing courses and curricula: A practical guide*. San Francisco: Jossey-Bass.
- Felder, R. M., & Brent, R. (1996). Navigating the bumpy road to student-centered instruction. *College Teaching*, 44(2), 43-47.
- Haller, C. R., Gallagher, V. J., Weldon, T. L., & Felder, R. M. (2000). Dynamics of peer education in cooperative learning workgroups. *Journal of Engineering Education*, 89(3), 285-293.

- Michaelson, L. K., Black, R. H., & Fink, L. D. (1996). What every faculty developer needs to know about learning groups. In L. Richlin (Ed.), *To improve the academy: Resources for faculty, instructional and organizational development* (Vol. 15, pp. 31-57). Stillwater, OK: New Forums Press.
- Miller, J.E., Groccia, J.E., & Wilkes, J.M. (1996). Providing structure: The critical element. In T. E. Sutherland & C. C. Bonwell (Eds.), *New directions for teaching and learning: Vol. 67. Using active learning in college classes: A full range of options for faculty.* (pp. 17-30). San Francisco: Jossey-Bass.
- Penn State Statistics Department (2001). Online course syllabus. Retrieved February 22, 2002, from <https://stat200.stat.psu.edu/about/publicdemo/index.html>
- Penn State Statistics Department (2001). Activity #009: Moneybags. Retrieved February 22, 2002, from <https://stat200.stat.psu.edu/eternal/activities/009/Act009-rho.html>
- Penn State Statistics Department (2001). Datasets listing. Retrieved February 22, 2002, from <https://stat200.stat.psu.edu/about/publicdemo/datasets.html>
- Schaeffer, E., Bhargava, T., Nash, J., Kerns, C., & Stocker, S. (2001, April). *Innovation from within the box: Evaluation of online problem sets in a series of large lecture undergraduate science courses.* Paper presented at the annual meeting of the American Educational Research Association, Seattle, WA. (ERIC Document Reproduction Service No. ED453239)
- Springer, L., Stanne, M. E., & Donovan, S. S. (1999). Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology. *Review of Educational Research*, 69(1), 21-51.