Improving Class Performance in STEM Using Pareto Technique

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Abstract

This paper is a report on the application of a quality improvement technique commonly used in industries to the teaching and learning process in an engineering technology program. An instrument for assessing learning outcomes was designed to determine specific problems that inhibit learning in the program, and their frequencies of occurrence. Based on the data collected, Pareto method was used to determine the vital few, i.e., the few errors committed 80 percent of the time so that class overall performance can be greatly improved by giving deference to these few but most important problems, within limited time and resources. The study cited in this correspondence shows that when Pareto technique is well applied in a teaching/learning process, it results in an improvement of individual performances for an overwhelming majority of the class. This technique is suitable for all science, technology, engineering and mathematics (STEM) disciplines.

1. Introduction

Assessment of instructional effectiveness is a vital component of any education delivery program. For a given course or sequence of courses, assessment is typically weighted towards evaluation of students' performances in tests and examinations. Examinations should not be used only to determine students' grades or rewards but, perhaps, most importantly to assess the effectiveness of instruction delivery and apparatus. Since the central purpose of teaching is to maximize learning, clearly, students' performances should be the dominant index for measuring teaching effectiveness. It is therefore critical to take a closer look at the parameters that inhibit the student's ability to learn thus dampening the effectiveness of instruction in the teaching- learning enterprise.

It has been customary for college instructors to judge class performance and thus their teaching effectiveness in a particular class by students' mean scores in examinations. A high class average score is generally assumed to be indicative of effective teaching. Some instructors assume that more thorough and meaningful assessment of teaching effectiveness is accomplished by an extended and perhaps more rigorous statistical analysis of students' grade distribution. In addition to the mean, they would go at length to compute other measures of central tendency and measures of dispersion for the grade distribution, in a bid to analyze class aggregate performance more accurately. The important question remains: what is the usefulness of the information obtained from this long-standing tradition? How does knowledge of the grade distribution from examinations help in improving instructional delivery? To our knowledge there is no claim that this information in any way illuminates the reasons for good performance or lack thereof. We expect no dissention from the fact that a talented student's innate ability leavened with hard work can produce good performance. On the other hand a less gifted student, though taught by the same instructor, may not do as well particularly if he or she is also less conscientious. Above all, the entry behavior of a student, i.e., the level of his or her preparedness or academic background is a critical determinant of the student's potential level of benefit from a course.

To be a more effective teacher one must know what needs to be improved in the learner and how to improve it so that learning ability can be enhanced. In this correspondence we report a case study in which a new paradigm for evaluating class performance as a means of improving teaching effectiveness was used. The new approach improved the overall class performance, which resulted in improved individual performances for an overwhelming majority of the class. The methodology used is based on the quality improvement techniques of Pareto and Grier [1]. Instead of finding average class performance or studying grade distributions, an aggregate of errors in tests were compiled to determine the most frequently committed errors or the vital few, and the less frequently committed errors or the useful many, to borrow the phrases coined by Joseph Juran [2]. With limited resources and time, the process and thus the group of students (batch of products) were greatly improved by given difference to the most important but few problems – the vital few. A Pareto diagram was used to identify the vital few.

2. Philosophical background

Alfred Pareto conducted a study, in the last century, in which he found that there were a few people with a lot of money and many people with very little money. This phenomenon has been found to be applicable to many situations, particularly in product failures and other quality analysis situations, viz. Certain parts of an automobile fail more frequently than others; many students commit a given error more than other errors; etc. An orderly representation of items in order to identify the most important problems so that the process can be improved more economically has become an important quality improvement technique named for Alfred Pareto.

A Pareto diagram is a graph that ranks data classifications in descending order from left to right as shown in Figure 1. The vertical scale represents frequencies of occurrences (events) while the horizontal axis represents types of occurrences or events. Two fundamental differences between Pareto diagram and histogram are: (1) Pareto presents events in descending order of frequencies whereas the histogram presents events in ascending order of their numeric values. (2) The horizontal scale of Pareto is categorical while the horizontal scale of the histogram is numerical.

As a quality improvement technique, Pareto diagrams are used to easily identify the most important problems, i.e., the most frequently occurring problems. Usually 80% of the total results from 20% of the problem types. This 20% is what Juran [2] referred to as the vital few and the other types of problems constituting 80% of the total types (categories) of problems, he called the useful many or trivial many. We shall bear in mind that for the application of the Pareto concept to improving instructional delivery, our data classifications will be types of errors committed by students in tests and examinations.

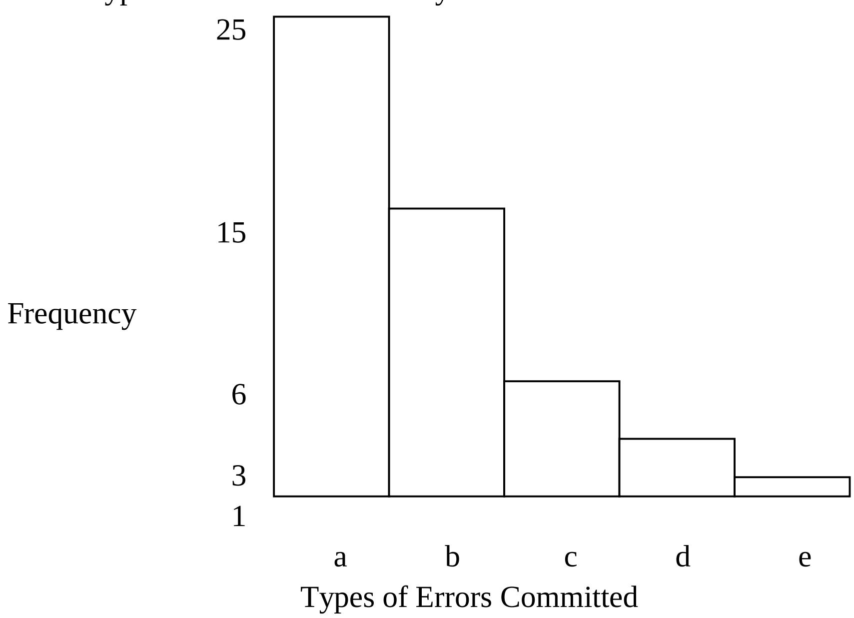

Figure 1. Pareto Diagram for Types of Error Committed by Students

The strength of this technique lies on its ability to identify the most important problems and thus the facility to correct as few of the problems as time and resources can allow with maximum impact on the batch quality improvement. Consider, for instance, a class of students susceptible to 10 categories of errors in a series of examinations. If the total number of errors committed is 50, and 40 of these errors committed belong to only two categories of errors, then a remedial program that specifically and successfully addresses the bases of these two errors will result in an 80% improvement of the class performance. The tool for identifying these vital few, two most frequently committed errors in this case, is Pareto diagram. It is obvious that a targeted correction of the sources of these two errors is the most economic means of achieving an 80% improvement on the overall students' (group's) ability to learn.

3. Application of the Pareto concept to improve teaching effectiveness.

The key to a successful application of this quality improvement technique is a well-designed assessment instrument. The instructor must determine what weaknesses he or she intends to assess and design questions that can properly assess them. In other words, the failure to answer a question correctly must be directly attributable to a specific deficiency on the part of the student. The questions must be strictly diagnostic so that the success of the student can be guaranteed if the deficiencies are made up. Examples of such deficiencies in an engineering technology class include [3], weak mathematical background; inability to transfer knowledge; inability to interpret word problems (poor language ability); and lack of understanding of the technical subject matter. These deficiencies constitute the categories or types of errors referred to in section 2.

It must be clearly stated that the objective is to improve the overall class performance by using limited resources (man-hours) to address the greatest difficulty the class has as a group. Accordingly, the process is to identify the most important problems in the class and doing something to eliminate them. Pursuant to this objective, the deficiencies that constitute the vital few (80%) of the total errors should be addressed. For easy identification of the vital few, the Pareto diagram may be drawn with a cumulative frequency line as shown in Figure 2. A successful remedial program targeting the vital few will result in the vital few commuting to the useful many in a post-remedy post-test analysis.

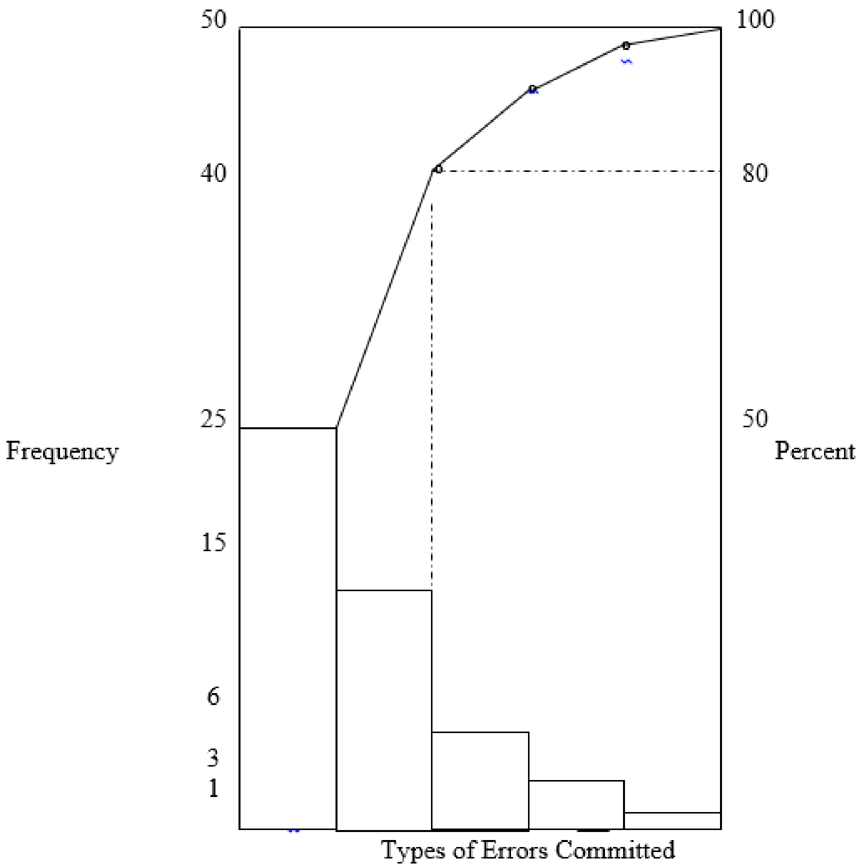

Figure 2. Cumulative Line Depicting the Vital Few

A quasi-algorithm for the application of the Pareto technique in engineering quality instruction delivery may be represented as follows:

1. Determine the difficulties that may inhibit learning in the class and thus lead to poor class performance
2. For every probable deficiency, design a question to determine its existence in the student
3. Collect and tally data from the test results
4. Draw the Pareto diagram and determine the vital few – the few difficulties that most (Say 80%) of the students have.
5. Design remedial programs to address the vital few difficulties
6. Retest the class after remedial program
7. Back to step 3.

5. The case study

The department of engineering technology at Savannah State University identified that among the greatest contributors to freshman dropouts in its programs is incoming students' weak background in mathematics and the physical sciences. To address this problem, the department had a summer bridge program designed to help incoming students make up their apparent deficiencies in these subjects. This study is part of a three – year project funded by the U. S. Department of Education. The Pareto technique described in this paper was used in the second year (for year-two cohorts), using year-one cohorts as control in the study. This study focuses on the mathematics tutorial/remedial program only.

Each year, for three consecutive years, fifteen students who have been admitted to Savannah State University engineering technology programs were selected to participate in a summer bridge program prior to their matriculation in the fall. The bridge program was a residential program designed to introduce the students to college life and to provide them a head start in engineering technology education. The students were offered remedial classes and tutorials in mathematics, among other courses in a four-week program each summer. Students were tested three times – pretest, midterm, and post-test/final test to determine class progress. Time and resource allocation to the various topics in mathematics was roughly equal, for Year-one cohorts. However, for the year-two cohort's time and resources were allocated based on need priority. Mathematics topics in which students performed poorly were allotted more time and resources within the limited time and resources available for the program. The class performances and progress made in the tests for each year provide a means for comparing the effectiveness of the two remediation plans, both of which have the same time and resource constrains. The test scores for cohort 1 and cohort 2 are given in tables 4 and 5, respectively.

Following the method suggested by Kalu and Chukwukere [4], and using 10 mathematics topics as categories, the vital few were determined after the Midterm test and the algorithm followed beginning with the mid-term test. The results of the class aggregate performances in each category are shown in tables 1 and 2. The results of the final/posttest show that a significant improvement was achieved from focusing resources and time on the vital few.

5.1. Study methodology

In a three-year program, 15 students who have been admitted to engineering technology programs at SSU were selected for a summer bridge program each year. These students' mathematics backgrounds were assumed to be generally weak. In year one, the students were offered remedial classes and tutorials in Mathematics for four weeks. A pretest, a midterm and a final posttest were administered to determine the class improvement in mathematics. The college algebra topics covered in the bridge program were Coordinate Systems, Exponents and Logarithms, Functions and Graphs, Inequalities, Linear Equations, Operations in Expressions, Quadratic Equations, Real and Complex Numbers, Sets, and System of Equations. Results of the three tests are shown in table 4. As observed by Tessema, et al, [5], The mean scores in the pre-test, mid-term, and post-tests for each subtest was low, perhaps, indicating unreadiness of the participants for college algebra course.

The program approach in year-one involved administering a standardized college algebra pretest before the college algebra tutorial was offered. Based on the tutees' pretest performances, the tutor constructed college algebra worksheet activities that cover setting up equations for given a situation, basic operations with polynomials, factoring polynomials, solving linear equations in one variable, and simultaneous equations in two variables, operation with exponents, radicals and rational expressions. This carefully crafted worksheet was distributed to the tutees. Participants were tutored four days a week for 120 minutes per day for two weeks. The tutor emphasized relational understanding instead of instrumental understanding while demonstrating the processes involved in answering the questions in each activity type. Help was offered whenever a tutee failed to perform a task correctly. Tutees were encouraged to workout additional similar activities beyond class time. At the end of the second week, a standardized test was administered and the process continued for another two weeks to further reinforce learning and a posttest was administered at the end of the second week period.

The Data from the tests lead Tessema, et al, to conclude that Vygotsky's theory of "Zone of Proximal Development" was not applicable to this tutoring situation because, a) there is evidence suggesting that prior knowledge plays a powerful role in comprehension and learning; (b) pre-conception show a remarkable resistance to traditional attempts to change this group of students; and (c) there was no incentive to warrant better performance on the post-test. They further recommended that the study be replicated after getting approval to place academic incentive such as exemption from college algebra course if a participant scores 80% or better on the post-test or provide monetary incentive commensurate with post-test performance. This recommendation was implemented in the second year. Following exactly the same approach for tutoring, in Year-two, the results of the mid-term test were similar to those of the year-one cohorts, even though participants were told that good performance in the test would earn them exemption from college algebra course; and students were also offered monetary incentive commensurate with performance in tests. In year-two therefore, a different approach to tutoring (the Pareto approach) was adopted after the mid-term test since even the generous incentives could not produce a different result from year-one in the midterm test.

5.2. Using the Pareto technique to improve class performance in year-two

Instead of looking at the students' individual performances in the mid-term test, the number of failures in each topic or category were examined and the data tallied. Each subject matter or topic was represented by the same number of questions in the test. The categories were ranked from highest to lowest by number of failures. The data showed that three categories – coordinate systems, system of equations, and exponents and logarithms, constituted 70% of the total errors committed by the students. These data are shown in table three and the Pareto Diagram of figure 3. Based on this information it was decided that more attention should be paid to these three categories as a means of improving the class performance by 70%. Thus from the midterm, 70 % of the time and resources were focused on these three categories. The results of the students' performances for year-two are shown in table 5. Also, Tables 1 and 2 show the reduction in errors for each category using the traditional method and the Pareto approach, respectively.

5.3. Data from tutoring approaches

The tables below and figure 3 show the results obtained from the use of traditional tutoring resources allocation and the Pareto technique approaches.

Table 1. Frequencies of nonconformities/number of errors before and after intervention

#	Categories/Nonconformities	Number of Errors/Frequencies		
		Pretest (PRT)	**Mid-Term (MDT)**	**Change (Δ =MDT-PRT)**
1	Coordinate Systems	65	60	05
2	Exponents and Logarithms	55	52	03
3	Functions and Graphs	20	09	11
4	Inequalities	10	10	00
5	Linear Equations	20	10	10
6	Operations in Expressions	20	11	09
7	Quadratic Equations	25	12	13
8	Real and Complex Numbers	20	10	10
9	Sets	10	10	00
10	System of Equations	59	58	01
	Total	**304**	**242**	**62**

This table shows that there is no significant change in outcome between pretest and midterm test (first two weeks of tutoring) when the year-one approach (traditional approach) in tutoring was used, despite the incentives.

Table 2. Reduction in number of errors following the application of Pareto technique

Rank# by Errors	Categories/Nonconformities	Number of Errors/Frequencies		Reduction in Number of Errors
		Mid-Term (MDT)	Posttest/Final (PST)	Change (Δ =PST-MDT)
1	Coordinate Systems*	60	05	55
2	System of Equations*	58	10	45
3	Exponents and Logarithms*	52	01	50
4	Quadratic Equations	12	07	05
5	Operations in Expressions	11	10	01
6	Linear Equations	10	03	07
7	Sets	10	10	00
8	Inequalities	10	10	00
9	Real and Complex Numbers	10	07	03
10	Functions and Graphs	09	05	04
	Total	**242**	**68**	**174**

*The Vital Few constitutes 70% of the errors (25% of the topics representing 70% of the total students' errors)

This table shows a significant improvement in outcome between Midterm test and Post/final test (second two weeks of tutoring) when Pareto method was used for resource and time distribution.

Table 3. Midterm test results, data for Pareto analysis

Mathematics Topic	Number of Students' Errors	Cumulative Frequencies	Cumulative %
Coordinate Systems*	60	60	25%
System of Equations*	58	118	49%
Exponents and Logarithms*	52	170	70%
Quadratic Equations	12	182	75%
Operations in Expressions	11	193	80%
Linear Equations	10	203	84%
Sets	10	213	88%
Inequalities	10	223	92%
Real & Complex Numbers	10	233	96%
Functions and Graphs	9	242	100%

*For this data distribution, it was decided to define the vital few as 25% of the categories that represent 75% of the non-conformities or errors. Thus the goal is to improve the process by 70% by focus on these three categories (25%). This goal is achieved by allocating 70% of the time and human resources available to these categories and the remaining 30% allocated to the other 30% or the useful many, in the tutoring program.

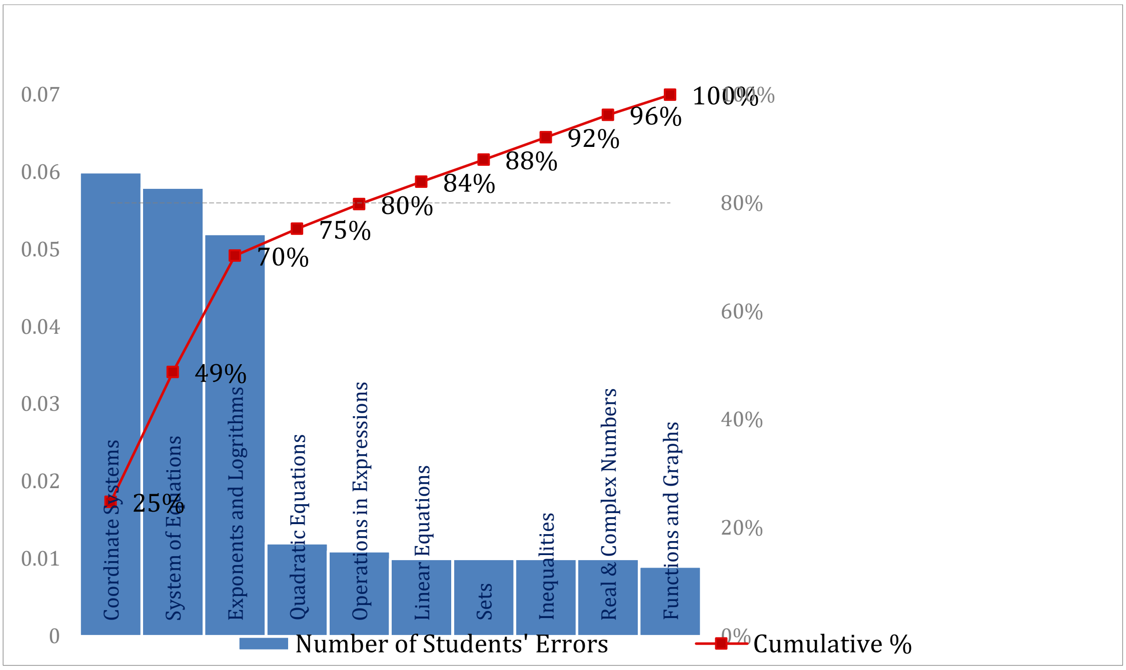

Figure 3. Pareto diagram of the frequencies of students' failures in mathematics topics

Table 4. Students' performances in tests – year-one cohort

Student #	Pretest (PRT)	Mid-Term (MDT)	Posttest/Final (PST)	Pass or Fail PST Grade
1	66	78	78	C+
2	44	48	60	
3	86	90	90	A
4	60	68	68	
5	47	66	68	
6	37	34	38	
7	20	50	68	
8	48	70	80	B
9	28	44	66	
10	48	70	78	C+
11	24	62	74	C
12	48	76	78	C+
13	42	46	46	
14	48	64	64	
15	70	88	78	C+
Average	**716/15 = 47.7**	**954/15 = 63.6**	**1034/15 = 68.9**	**7 (47%) Passing**

Table 5. Students' Performances in tests – year-two cohort

Student #	Pretest (PRT)	Mid-Term (MDT)	Posttest/Final (PST)	Pass or Fail PST Grade
1	46	50	88	B+
2	50	60	90	A
3	28	50	88	B+
4	42	42	46	
5	42	52	71	C
6	50	70	88	B+
7	22	26	34	
8	42	42	46	
9	84	84	96	A+
10	50	50	80	B
11	48	60	72	C
12	48	70	88	B+
13	50	62	80	B
14	28	54	75	C
15	66	62	90	A
Average	**696/15 = 46.4**	**834/15 = 55.6**	**1132/15 = 75.5**	**12 (80%) Passing**

6. Analysis of results

Table 1 compares the number of errors per category from the pretest and the midterm test (first two weeks intervention) after traditional tutoring approach. It can be seen that there was no significant improvement due to the intervention. This is what led to the conclusions drawn by Tessema, et al, about the year-one cohort. On the other hand, Table 2 shows a significant improvement between the results of the midterm test and the final test, the second two weeks of the program in which Pareto technique was employed. Comparing the aggregate reductions in error for the two periods show that the 174 points in error reduction for the second period is more than 250% improvement over the 62 points reduction in the first period.

Also, table 4 shows that using the traditional tutoring approach in year-one, there is an improvement as the tutoring progresses but we observe that there is no significant difference in the rate of improvement in students' performances from one period to another. Even with the presumed cumulative effect of the intervention, only 47% of the students showed readiness for college level mathematics and technology courses based on their mathematics backgrounds. Table 5 on the other hand shows a significant jump in students' results from midterm to final test – the period representing the application of Pareto technique. It may be observed that the average pretest scores for both year-one and year-two cohorts are similar, indicating that both samples are from the same population. Furthermore, there is no significant difference in the average increase in scores between pretest and midterm for both cohorts, when the same method of intervention was used. However, while only 47% of cohort-I students passed the final test, a whopping 80% of cohort-II students passed the same test showing the strength of the application of Pareto method in evaluating teaching effectiveness as a vital component of instruction delivery process.

7. Conclusion

A technique for using the information from test results to improve teaching effectiveness has been demonstrated to be efficient. Both longitudinal and horizontal analysis of the results obtained from traditional methods of instruction and the Pareto technique in this study show the strength of the later in achieving targeted goal. The authors therefore argue that assessment exercise is of little value if it does not lead to the improvement of teaching – learning activity. Realizing the expensiveness of quality improvement activities and that most engineering technology departments are often required to operate with limited resources, an instructional quality-improvement technique, which yields the greatest return on the investment, is desirable. The Pareto technique can achieve an improvement goal with limited resources and time.

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