Assessing the effectiveness of new teaching methods in engineering education

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Abstract: This paper presents an approach for assessing the effectiveness of new teaching methods in engineering education. The assessment, based on principal component analysis (PCA), requires only one, current data set of students' feedback and performance. The assessment method, demonstrated by a case study, is robust and can be applied to a wide range of engineering and non-engineering subjects.

1. Background and motivation

New teaching methods are often introduced to address difficult issues and topics in teaching and learning of tertiary engineering subjects. To assess the effectiveness of these teaching methods, we often compare the performances of students *prior to* (previous year) and *after* (current year) the introduction of the methods. Doing so, we either assume similar backgrounds and responses of the before and after student cohorts, or we eliminate bias that may exist. In many circumstances, historical data may not even exist for such an analysis.

Here we introduce an alternative to the traditional assessment method. The new assessment method, requiring only one (current) data set, analyses possible links between the current students' responses to the new teaching methods and their performances.

2. Method and analysis

The assessment method comprises two main tasks:

- A special questionnaire is designed to acquire data covering students' background, perception of and responses to the new teaching methods, and performance in the course.
- The data, in a matrix form, are then analysed using the principal component analysis (PCA) technique.

The analysis examines the main trends of the data, including the correlation among the different factors, student groups (according to their responses and performances) and factor groups. The aim of the analysis is to identify the important factors that affect the students' learning and performance. In particular, it determines whether and how the introduced new teaching methods have made an impact.

Principal components analysis is a commonly used technique in multivariate statistics (Jolliffe, 1986). The technique generates a new set of variables, called principal components (PCs), through linear combinations of the original variables. Although the full set of PCs is as large as the original dataset, the variances of the first few PCs often exceed 80% of the total variance of the original data. This is due to the fact that in most circumstances, more than one original variable measure the same driving principle governing the behavior of the system. By examining the relationship among the first few (2) PCs, one can develop a better understanding of the trends and behaviours of the original data. The results presented in this paper were obtained using the PCA functions in the statistics toolbox of MatLab (MatLab manual, v6.5.1.199709).

3. Case study

The assessment method is applied to an engineering subject at the University of Queensland, Surface Water and Groundwater Modelling (CIVL4140). CIVL4140 is a final year course, exposing most students for the first time to the analysis of unsteady state flow and mass transport processes in the environment. Many concepts require visualization in three dimensions. For the first time in 2005, particle-based simulations are being used for teaching diffusion/dispersion transport processes. PCA is used to critically evaluate the benefit of the simulations in enhancing student learning.

3.1. Questionnaire

The following questions were asked to acquire data covering students' background, perception of and responses to the new teaching methods, and performance in the course.

Questionnaire for evaluating the effectiveness of teaching method using simulations and animations (e.g., particle-based simulations of diffusion and shear dispersion): Part I of CIVL4140/2005

Name ___________________Student No. _________________

(1) How good do you think your background (fluid mechanics and mass transport) is for undertaking this subject?

- ☐ Very good
- ☐ Good
- ☐ Average
- ☐ Not so good

(2) In general, how helpful do you think the simulations and animations shown in the lectures are for understanding the concepts taught?

- ☐ Very helpful
- ☐ Kind of helpful
- ☐ Not that helpful
- ☐ Not helpful at all

(3) How helpful do you think the particle-based simulations are for understanding the molecular diffusion and shear dispersion?

- ☐ Very helpful
- ☐ Kind of helpful
- ☐ Not that helpful
- ☐ Not helpful at all

(4) How useful do you think the project is for understanding and applying the concepts and theories taught?

- ☐ Very helpful
- ☐ Kind of helpful
- ☐ Not that helpful
- ☐ Not helpful at all

(5) Do the simulations and animations make the subject more interesting?

- ☐ Very much
- ☐ Quite a bit
- ☐ Not much
- ☐ Not at all

(6) How well do you think you perform in learning this subject?

- ☐ Very well
- ☐ Average
- ☐ Can be better
- ☐ Not well at all

3.2. Data

For all questions, numeric values are assigned to the answers accordingly: 1 for 1st answer, 0.66 for 2nd answer, 0.33 for 3rd answer and 0 for 4th answer. The results are shown in Table 1.

Table 1. Results from the Questionnaire.

Student	Q1	Q2	Q3	Q4	Q5	Q6	Project Mark
1	0.33	0.66	0.66	1	1	1	0.9
2	0.33	1	1	1	1	1	0.9
3	0.66	0.66	1	0.66	1	0.66	0.92
4	0.66	0.66	0.66	0.33	1	0.66	0.92
5	0.66	1	0.66	0.66	1	0.66	0.88
6	0.66	0.66	0.66	1	0.66	0.66	0.6
7	1	0.66	0.66	0.66	0.66	0.66	0.65
8	0.33	0.66	1	0.66	0.66	0.33	0.6
9	0.33	0.66	1	0.66	0.66	0.33	0.6
10	0.66	1	1	1	1	0.66	0.88
11	1	1	1	1	1	0.66	0.85
12	0.66	1	0.66	0.66	1	1	0.88
13	0.66	0.66	0.66	0.66	0.33	0.66	0.5
14	1	0.66	1	1	1	1	0.88
15	0.33	1	0.66	1	1	0.66	0.88
16	0.33	0.66	0.66	1	1	0.66	0.9
17	0.66	0.66	1	1	1	0.66	0.85
18	0.66	1	1	1	1	0.66	0.9
19	0.66	0.66	0.66	1	0.66	0.33	0.65
20	0.66	1	1	0.66	1	0.66	0.9
21	1	1	1	0.66	1	0.66	0.85

The rescaled marks that the students received for their project are also listed and used as the performance indicator (the exam results are not yet available).

3.3. Analysis and discussion

PCA is applied to analyse the data (matrix, M, the shaded area in the table above). The generated new data are plotted along the first two principal components/axes (Figure 1). The vectors of these two components/axes are: V_1 = [0.1737 0.3770 0.1895 0.2429 0.5887 0.4679 0.4088]^T (superscript T denotes the transposing operation), and V_2 = [-0.9129 -0.0341 -0.1099 0.3713 0.0969 0.0359 0.0690]^T. These two vectors define the projections of the original data onto the first two principal axes. For example, for student 1, the first two components (PC_{1_s1} and PC_{2_s1}) of the new data are obtained as follows:

$$\left[PC_{1\_s1} \quad PC_{2\_s1}\right] = S_1 \times \left[V_1 \quad V_2\right]$$

where S_1 is the original data with the mean subtracted, i.e., [0.33 0.66 0.66 1.00 1.00 1.00 0.90]–[0.6305 0.8057 0.8381 0.8224 0.8871 0.6776 0.8043]. The percentage of total data variability explained by each principal component was also calculated and shown in Figure 2. The first two components account for 58% of the total data variability and thus describe the main trends of the data. In the following, we will discuss these trends in detail.

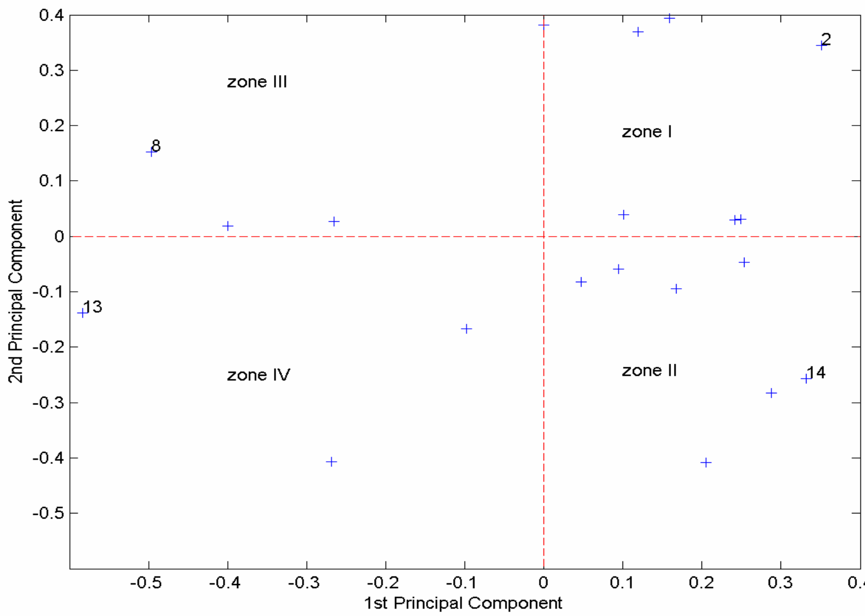

Figure 1. The first and second components of the transformed data (PCA applied to *M* directly). The number shown is the student No.

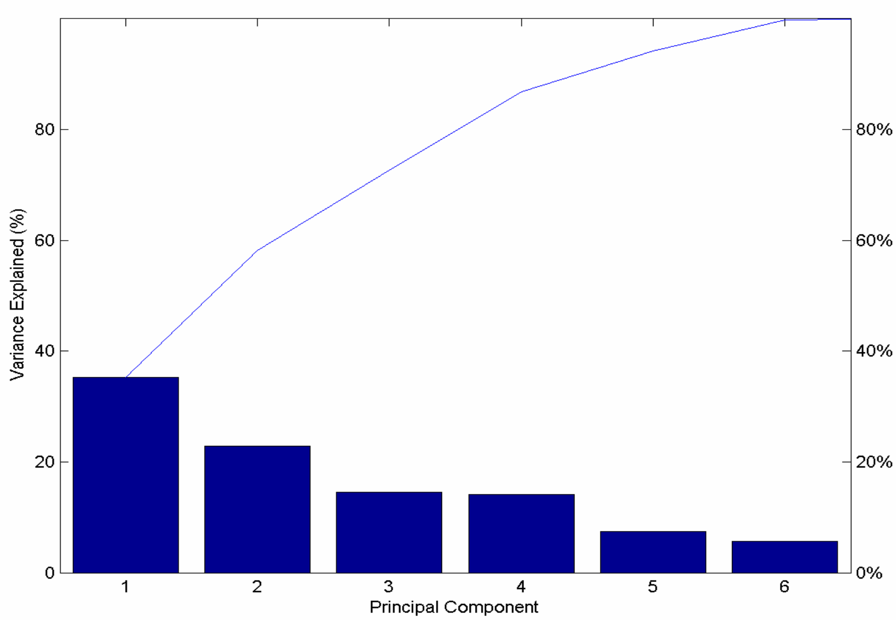

Figure 2. Variances explained by the principal components.

3.3.1. Main factor

All the elements of the first principal component vector are of the same sign, suggesting that the first PC is a weighted average of the original data. The largest weights are in the fifth, sixth and seventh element, corresponding to question 5, 6 and the project mark. This indicates that the behaviour of the data is mainly affected by these elements. In other words, the students' perception and responses to the new teaching method, their self performance assessment and actual performance in the project define the main feature of the survey data. In contrast, the students' backgrounds were weighted the least. These results suggest that the new teaching method was the main factor in the students' learning of the subject and has influenced positively their performance.

The second component vector is dominated by the first element that has a minus sign, opposite to those of element 5, 6 and 7. This suggests that the students' backgrounds did not correspond well to their responses to the new teaching method and their performance.

3.3.2. Analyses of four individual students' cases

Student 2 (shown in Figure 1; in zone I with large positive 1st PC and positive 2nd PC): responded well to the new teaching method, performed well in the project, and yet did not think he/she had a good background.

Student 14 (shown in Figure 1; in zone II with large positive 1st PC and negative 2nd PC): responded well to the new teaching method, performed well in the project, and thought he/she had a good background.

Student 8 (shown in Figure 1; in zone III with large negative 1st PC and positive 2nd PC): did not respond well to the new teaching method, did not perform well in the project, and did not think he/she had a good background.

Student 13 (shown in Figure 1; in zone IV with large negative 1st PC and negative 2nd PC): did not respond well to the new teaching method, did not perform well in the project, and yet thought he/she had a good background.

3.3.3. PCA based on M^T

The analysis can also be carried out on the basis of the transposed *M* matrix, in which case the new data are generated by linear compositions of all students' answers to a particular question or their marks. The size of the principal component vector is therefore the total number of students. This is in contrast with the previous analysis, which was based on linear transformations using all answers and mark for a particular student. This analysis reveals how the questions might have been answered differently.

The results show that question 1 and 6 were responded to by the students differently from the rest of the questions (Figure 3). Question 4 and 5 were answered in similar fashion by the students; their answers to these questions correspond well with their performance in the project of the course. These results are essentially consistent with the previous analysis based on the *M* matrix.

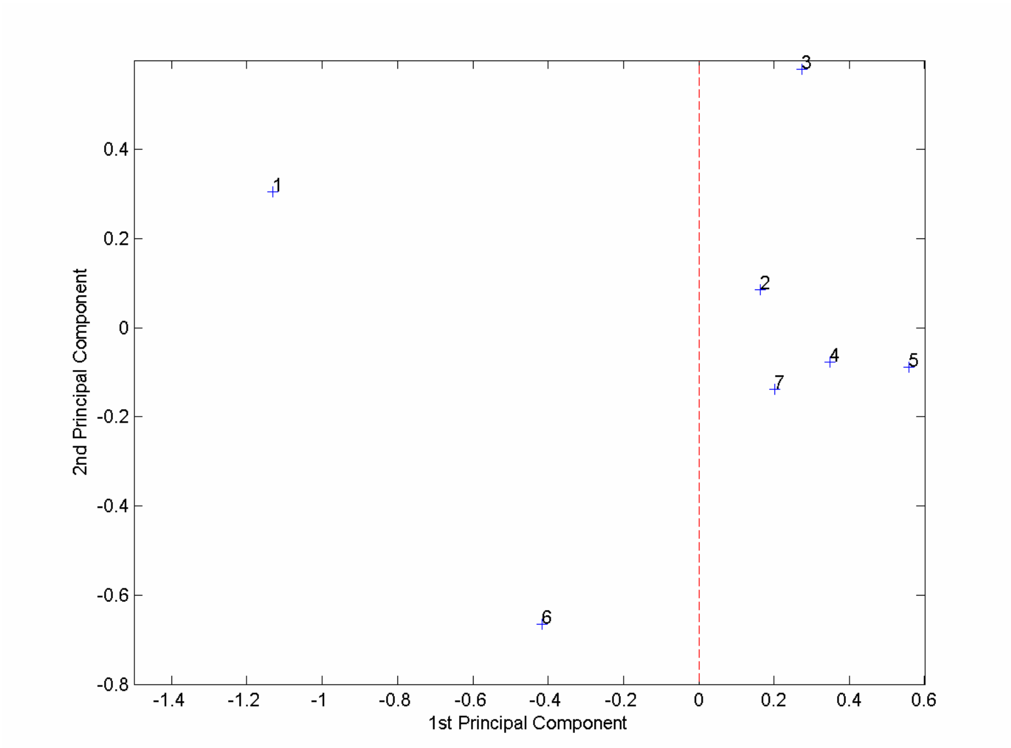

Figure 3 . The first and second components of the transformed data based on M^T. The number shown is the question No or for the project mark element.

In summary, the analysis indicates that the new teaching method was an important factor in influencing students' learning of the subject and has likely helped to improve their performance. In other words, the new teaching method was effective to a certain extent in addressing difficult concepts involved in the teaching of the considered subject.

4. Conclusions and Significance

A new teaching assessment method has been designed on the basis of principal component analysis. The new method, shown to be robust in the presented case study, is generic and can be applied to a wide range of engineering and non-engineering subjects.

References

Jolliffe, I. T., Principal Component Analysis, New York: Springer-Verlag, 1986.

MatLab manual (statistics toolbox), version 6.5.1.199709 (release 13), 1994-2005 The MathWorks, Inc.