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Performance Assessment of Undergraduate Vibrations Course

Abstract

"Vibrations" and "Dynamic Systems and Control" are two of the required upper-level engineering courses in the undergraduate Mechanical Engineering program at Baker College. Both courses have the "Introduction to Differential Equations" as one of the pre-requisite courses. "Vibrations" however is not required to be completed before "Dynamic Systems and Control". This paper analyzes student performance in the two courses in order to determine if "Vibrations" should be made a pre- or co-requisite to "Dynamic Systems and Control". This could help students to better understand and learn the more challenging "Dynamic Systems and Control" course. In both courses Matlab is extensively used as simulation tool. "Vibrations" also includes two or three hands on experimental laboratories where students measure the behavior of single degree and two degrees of freedom systems. The paper will describe the assessment tools used in each course, provide a comparative analysis of student performance over the past few years, and conclude with recommendations and future plans.

Introduction

Mechanical Vibrations courses have been the subject of numerous papers presented at the ASEE Annual Conference in recent years. Some of these papers focused on course curriculum[1, 2], laboratory experiments[3], and using simulation software such as Matlab and Simulink[4], or in-house developed software[5] to help students better grasp and master the material. An interesting proposal to integrate topics related to Dynamic Systems, Vibrations, and Control into a two-semester sequence was presented in reference[2].

The undergraduate Mechanical Engineering program at Baker College includes both "Vibrations" and "Dynamic Systems and Control" (DCS) as required upper-level engineering courses. The pre-requisite courses for "Vibrations" are "Dynamics" and "Introduction to Differential Equations". These two courses are also pre-requisites for the DCS course, which has an additional pre-requisite of "Circuit Analysis". As a vibrating system is fundamentally a dynamic system, there is a deep connection between the topics covered in the two courses. This connection includes the modeling of a mechanical system, the analysis of the dynamic system and extends to practical applications such as vibration control. At our institution "Vibrations" and DCS are taken as two independent courses, in no specific order. While undergraduate students can find the mathematical analyses in both courses challenging, the concepts and topics related to Vibrations appear to be better understood by our students than the ones related to Dynamic Systems and especially Control Systems. This paper analyzes assessment results from the two courses with the goal of understanding if scheduling Vibrations first and DCS second would benefit students.

Description of "Vibrations" and DCS courses

Baker College follows a quarter system, with 10-week Fall, Winter, and Spring quarters. The student population is diverse in terms of age and experience, with a majority of students working full time in technical fields and continuing their education towards an engineering bachelor degree at the same time.

Vibrations

The "Vibrations" course is a 4-credit, upper level required course in the Mechanical Engineering program. The textbook used in the course is "Mechanical Vibrations" by S. Rao, now in its fifth edition[6]. The topics covered include single- and two-degree of freedom systems, free and forced vibrations, an introduction to multi-degree of freedom and continuous systems, determination of natural frequencies and mode shapes, and vibration control.

The Student Learning Outcomes are:
1. Formulate and solve free vibration problems of a single-degree of freedom systems.
2. Formulate and solve problems with harmonically excited vibration of undamped and damped systems.
3. Formulate and solve problems with transient vibration and vibration under general forcing conditions using convolution integral and Laplace transforms.
4. Evaluate systems with two or more degrees of freedom, undergoing free and forced vibration, and solve problems with and without damping.
5. Systematize properties of vibrating systems such as stiffness, flexibility and inertia influence coefficients.
6. Apply computational methods to solve eigenvalue problems of a vibrating system and determine natural frequencies using Jacobi's method and/or Choleski decomposition.
7. Solve partial differential equations of vibration of continuous systems.
8. Compare concepts of vibration control and solve problems involving reduction, isolation and absorption of vibrations in simple mechanical systems.
9. Complete laboratories and/or demonstrations of selected vibration topics, in team setting, and prepare professionally written reports.

The course format includes lectures, computation and visualization sessions using Matlab, and a few laboratory sessions. The course curriculum is quite challenging, due in part to the large volume of work needed to solve the various associated differential equations. In addition the course strives to introduce students to a large number of topics, including practical applications such as vibration control, rather than going in depth with a small number of topics. In order to keep the focus on conceptual understanding and on relating the mathematics to the physical systems, rather than pure mathematical work, computer programs need be used extensively. As instructors teaching the course, we developed additional Matlab programs to the ones provided with the textbook, which we made available to students. These simple programs compute solutions to the classical vibrations problems of free and forced, undamped and damped vibrations of single and two-degrees of freedom systems, and natural frequencies and mode shapes for two and three-degrees of freedom systems. By making the programs available to students, the instructors hope that this will stimulate them to start writing their own programs in Matlab, based on the model provided. In addition to the computational sessions, three laboratory experiments dealing with undamped and damped single-degree of freedom systems, and normal modes of a two-degree-of freedom system, are allowing students to have a more direct experience with mechanical vibrations. The experiments are based on an air-track system on which carts attached to springs move with little friction. The data is collected and plotted by a computer program.

The assessment tools used in the course include homework assignments, quizzes, a midterm exam, the final exam, and the laboratory reports for the experiments performed.

Dynamic Systems and Control

The "Dynamic Systems and Control" course is a 4-credit, upper level required course in the Mechanical Engineering program. The textbook used in the course is "Modern Control Systems" by Dorf and Bishop, now in its 12th edition[7]. The topics covered include: mathematical modeling of mechanical and electrical systems, Laplace transform, the transfer function and block diagram models, an introduction to state variable models, characteristics and performance of feedback control systems, stability, and the root-locus method.

The Student Learning Outcomes are:
1. Demonstrate knowledge of applications of control theory and control systems in modern engineering.
2. Distinguish between open-loop and closed-loop control systems, their design and applications.
3. Understand Laplace transform method and apply it to solve problems involving mathematical modeling of control systems.
4. Demonstrate an understanding of the transfer function and how to use it in modeling different control systems.
5. Use block diagrams to represent different control systems.
6. Understand basic state-space theory and how to use it to describe control systems.
7. Apply mathematical modeling to solve problems involving control of mechanical and electrical systems.
8. Apply transient-response analysis with and without computational software to solve problems involving control of first-order and second order dynamic systems.
9. Apply Routh's stability criterion to model and optimize different control systems.
10. Understand the effects and apply basic control actions commonly used in industrial automatic controllers in modeling different control systems.
11. Complete a course project involving topics of the course and transient and steady-state response analysis of the control system.

The course format includes lectures, and computation and visualization sessions using Matlab. As stated before, the mathematical modeling of mechanical systems overlaps with the similar topic in the Vibrations course. Anecdotally, students who have already taken Vibrations, or are taking Vibrations concurrently with DCS, remarked they already knew some of the material from the Vibrations course. This can be of great help to students in the DCS course, allowing them some confidence before tackling the control systems topics, which appear harder to understand conceptually and master by our mechanical engineering students. In this course, as in Vibrations, Matlab programs are very useful. The DCS course benefits from dedicated software such as the one found in the Control System Toolbox, as well as in Simulink. As of yet we have not used Simulink examples in the DCS course, but would like to include some of them in the future. Simulink programs can bring students closer to the current professional practice in control engineering.

The assessment tools used in the course include homework assignments, quizzes, a midterm exam, the final exam, and a design project.

Assessment results and analysis

An analysis of assessment results from the Vibrations course shows that students easily pick up the use of Matlab programs to solve typical problems with single and two-degrees of freedom systems, especially when the programs are provided to them. More challenging for students is the modeling and derivation of the differential equations of motion for a given system.

The assessment results from Dynamic Systems and Control show some students having trouble with block diagrams and transfer functions, in addition to the same difficulties encountered in Vibrations with mathematical modeling of given systems. From this perspective, having had Vibrations before or at the same time as DCS seems to be beneficial to students.

In order to test this hypothesis, student grades in the two courses were collected for a few recent years and analyzed. The students were separated in three groups. Group 1 were the students who took Vibrations after DCS, group 2 were the students who took the two classes concurrently in the same quarter, and group 3 were the students who took Vibrations before DCS. Figures 1 - 3 below show the Grade Point Value obtained in DCS vs. the Grade Point Value obtained in Vibrations for individual students in each of the three groups. Each point on the graphs represents a student, however in a couple of cases one point on the graph corresponds to multiple students who got the same grades in both courses. (This might not be evident from the graphs). Based on data from the last five years, group 1 had 15 students, group 2 had 10 students, and group 3 had 8 students, for a total of 33 students included in the study.

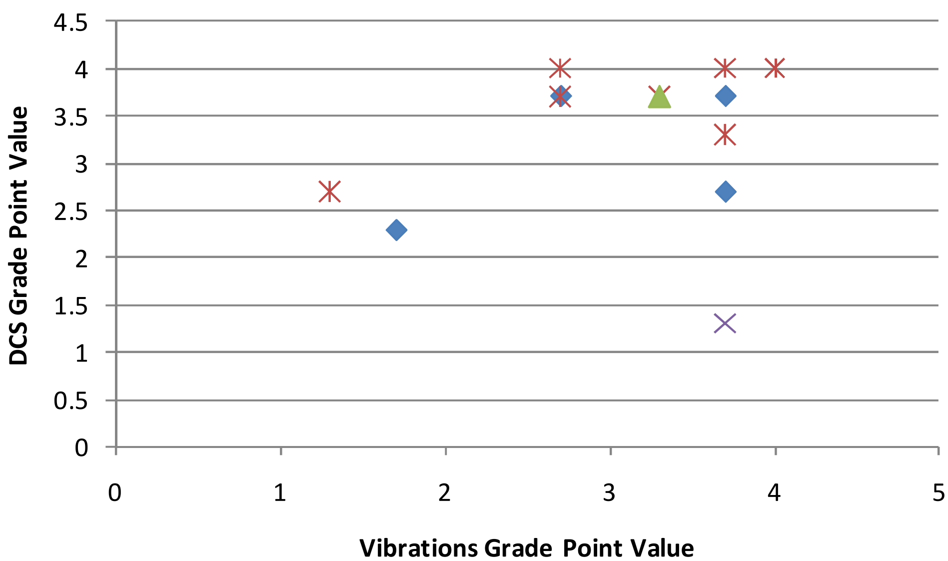

Fig.1. Grade Point Value obtained in DCS vs. Grade Point Value obtained in Vibrations for the students who took “Vibrations” after “Dynamic Systems and Control”. The different markers correspond to different combinations of professors teaching the two courses.

Figure 1 shows there is no correlation between the two sets of grades, regardless of who taught each course. It appears that getting a high grade in DCS did not correlate with a high grade in Vibrations, as shown by the students at the top of the graph.

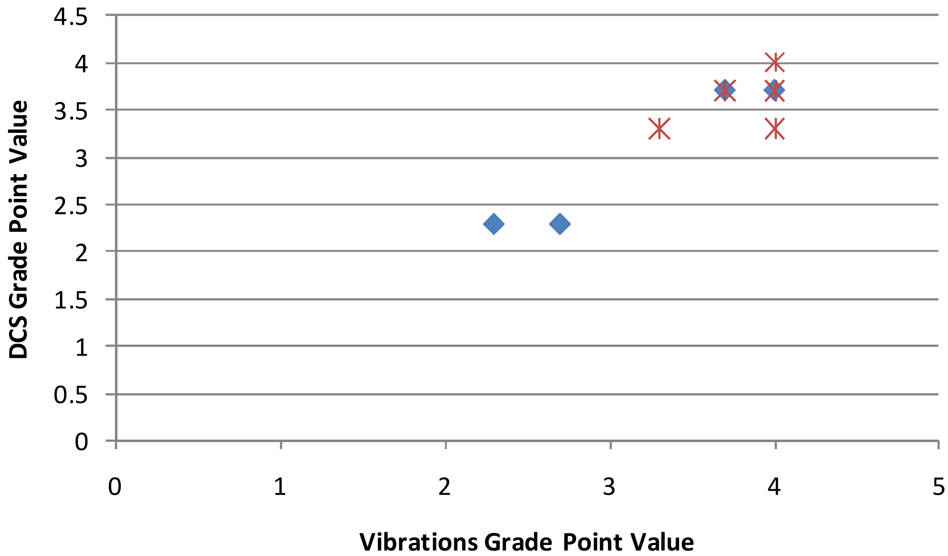

Fig.2. Grade Point Value obtained in DCS vs. Grade Point Value obtained in Vibrations for the students who took "Vibrations" concurrently with "Dynamic Systems and Control". The different markers correspond to different combinations of professors teaching the two courses.

Figure 2 shows there is linear correlation between the two sets of grades. By combining all the data in a single data series, a straight line with correlation coefficient $R^2 = 0.85$ from the 10 experimental data points is obtained. It is seen that for students who were enrolled in both courses at the same time, doing well in one correlated with doing well in the other one also. Same is true for not doing too well in any of them. This correlation can of course be attributed to the effect of good students overall vs. poor students overall. However, coupled with the results in the other graphs, a case can be made for this being the best scheduling of these upper-level senior courses.

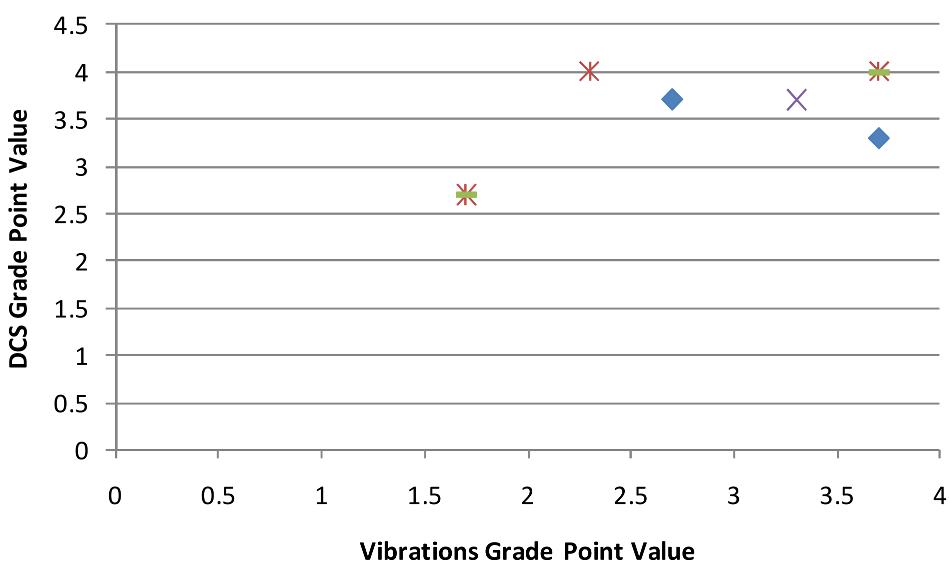

Fig.3. Grade Point Value obtained in DCS vs. Grade Point Value obtained in Vibrations for the students who took "Vibrations" before "Dynamic Systems and Control". The different markers correspond to different combinations of professors teaching the two courses.

Figure 3 again shows there is no correlation between the two sets of grades, which was also the case in Figure 1. What is different from Figure 1 is the fact that most students here did quite well in DCS, regardless of how they did in Vibrations. As DCS is the harder of the two for Mechanical Engineering students, the data seems to support the hypothesis that having had Vibrations before DCS could help.

Further comments are necessary regarding the results presented above. The correlation or lack of correlation found can also be affected by such factors as:
- the small number of experimental data points overall. This is due to the relatively small size of the program.
- the fact that the Vibrations course was taught by a number of different instructors in recent years, vs. the DCS course being taught by the same instructor most of the time. However Figures 1 - 3 do not show a large effect of this factor on student performance.
- the large time gap between the two courses for a few of the students. It is known that in general the retention of course material by students is not great, so after a couple of years even if a student did very well in a course, he/she might have difficulty applying the previously acquired knowledge to a present course.

To increase the reliability of the data interpretation we plan to continue collecting this data in the future. Having larger populations of students included in the study will allow for a better control of the variables.

The motivation of this study is to determine one approach that can contribute to increased student learning in the upper level courses of "Vibrations" and "Dynamics Systems and Control". Student grades are a direct indicator of student performance in a course and as such were chosen by the authors as the focus of this study. Other performance indicators can be chosen, such as performance on the course final exam, or on the specific portions of the Fundamentals of Engineering exam. The latter exam however is currently optional for Baker College seniors and is generally taken only by some of them. As suggested by one reviewer the performance of students on the senior design project can be another measure of the knowledge and abilities acquired by students in the above courses. Not all senior design projects though include control or vibrations topics, although it is seen that control is becoming more important in mechanical systems and it is expected that the projects will reflect that.

Conclusions

Based on a study of student results in recent years, the authors believe that the topics learned by students in the required Vibrations course in the undergraduate Mechanical Engineering program can have a beneficial effect on student learning in the Dynamic Systems and Control course. This implies that Vibrations should be made a pre- or co-requisite to the DCS course. The second option appeared the most effective based on the present study. The study will continue for a couple more years to gain enough confidence in making the associated change in the schedule.

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