Asya Öğretim Dergisi
[Asian Journal of Instruction]
2013 – 1(1), 1-8

www.e-aji.com
e-ISSN:2148-2659

THE EFFECT OF LABORATORY PRACTICES ON LEARNING OF SHAFT CRITICAL SPEED SUBJECT IN MACHINERY DYNAMICS CLASS

MAKİNE DİNAMİĞİ DERSİNDE LABORATUVAR UYGULAMALARININ KRİTİK HIZ KONUSUNUN ÖĞRENİLMESİNE ETKİSİ

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ABSTRACT: In the present study, the effect of a laboratory practice on learning of shaft critical speed subject in Machinery Dynamics class was investigated. The focus group of research consists of 20 undergraduate senior students in Mechanical Design Division at the University of Düzce, Turkey. The qualitative research method is used in this study. Semi-structured interview form was used for data collection. Interview was carried out as focus group discussions. The students were divided into three groups for interview. Data were collected performing the group interview before and after laboratory practice. Interviews were recorded by video-camera together with an educational scientist and a specialist questioner involved directly to group meeting. Then, the video-camera recording was converted to written document form for analysis. Then these documents were subjected to content analysis. Obtained concepts were classified on the base of interview questions. It has been observed that the teaching of the critical speed subject with laboratory practices besides the lecture has provided that the successes of the students have increased at a significant level. Based on the fact that the students cannot visualize the information they have been provided theoretically, it has been concluded that the practice should not only be performed during the lesson with mathematical calculations but also in real laboratory medium, personally. It is a fact that laboratory practices have been effective on the increase of general success of the critical speed subject and that the real medium of the performed practices have effected learning positively (Kılıç, Kara and Çiçek 2009; Kılıç, Kara and Çiçek 2010). With this study, it has been recognized that only lecture does not provide the realization of total learning. Based on the reality that the students cannot fully visualize in their minds the information that is taught to them in theory, it has been concluded that the practice should not only be performed in the lesson with mathematical calculations but within the real laboratory medium personally.

Keywords: Critical Speed, Laboratory practices, Lecture, Machinery Dynamics

ÖZET: Bu çalışmada, Makine Dinamiği dersinde kritik hız konusunun öğrenilmesi üzerinde laboratuar uygulamasının etkisi incelenmiştir. Teknik Eğitim Fakültesi Makine Eğitimi Bölümü Tasarım ve Konstrüksiyon Öğretmenliği son sınıf öğrencilerinden Makine Dinamiği dersini alan yirmi iki (20) öğrenci araştırmanın çalışma grubunu oluşturmuştur. Çalışma, nitel araştırma yöntemiyle yapılmıştır. Araştırmada nitel veri toplama aracı olarak yarı yapılandırılmış görüşme formu kullanılmıştır. Görüşme, odak grup görüşmesi olarak gerçekleştirilmiştir. Çalışma grubundaki öğrenciler, üç ayrı gruba bölünerek grup görüşmesi gerçekleştirilmiştir. Çalışma grubunu oluşturan öğrencilerle, laboratuar uygulamasından önce ve laboratuar uygulamasından sonra grup görüşmesi gerçekleştirilerek veriler toplanmıştır. Görüşmede bir eğitim bilimci, bir alan uzmanı ile birlikte soruları yöneltip görüşmeler video-kamerayla kayıt altına alınmıştır. Toplanan veriler, öncelikle kayıt cihazından çözümlenip yazılı bir doküman haline getirilmiştir. Bu dökümanlar daha sonra içerik analizine tabi tutulmuştur. Analizlerle elde edilen kavram ve cümleler görüşme soruları esas alınarak sınıflandırılmıştır. Kritik hız konusunun sadece teorik anlatımın yerine laboratuar uygulamaları ile işlenmesinin öğrenci başarısının anlamlı düzeyde artmasını sağladığı görülmüştür. Öğrencilerin teorikte öğrendikleri bilgileri zihinlerinde tam olarak

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canlandıramadıkları gerçeğine dayanarak uygulamanın sadece derste matematiksel hesaplarla değil bizzat gerçek laboratuar ortamında yapılması gerektiği sonucuna varılmıştır. Kritik hız konusunun genel başarısının yükselmesinde laboratuar uygulamalarının etkili olması yapılan uygulamaların, gerçek ortamlarının öğrenmeyi olumlu şekilde artırdığı bilinmektedir (Kılıç, Kara ve Çiçek 2009; Kılıç, Kara ve Çiçek 2010). Yapılan bu çalışma ile sadece düz anlatımın tam olarak öğrenmenin gerçekleşmesini sağlamadığının farkına varılmıştır. Öğrencilerin teorikte öğrendikleri bilgileri zihinlerinde tam olarak canlandıramadıkları gerçeğine dayanarak uygulamanın sadece derste matematiksel hesaplarla değil bizzat gerçek laboratuar ortamında yapılması gerektiği sonucuna varılmıştır.

Anahtar sözcükler: Düz anlatım, Kritik hız, Laboratuvar uygulamaları, Makine Dinamiği

INTRODUCTION

The goal of engineering education is to prepare students for practicing what they have learned. The course of Machinery Dynamics is a fundamental subject for Mechanical Design Division students. This course is commonly taught through theoretical classes for 3 hours per week. Teaching and learning of the course has been considered, for sometime, to be a challenge due to technical, mathematical, and abstract nature of the subject. Especially, traditional class lectures encaurage passive learning, often creating a mismatch between the way teachers teach and the way students learn (Shyr 2010). For this reason, educators are constantly seeking new ways to actively engage students. The integration of a physical model by conducting experiment into the class provides innovative teaching and learning environments that allow for more interactive and effective applications to give students valuable experiences (Aziz 2011). Teaching by doing and experiencing in the laboratory gives an opportunity to use all sensory organs (Beach and Stone 1988). Kreitler and Kreitler (1974) in their study discussed whether the laboratory helps for occurring of correct opinion on the subject. They concluded that using laboratory helps the interpretation of information and elimination of misconceptions. Osborn and Wittrock (1983) determined that laboratory is more effective than teachers and other environments interested in class and develops critical thinking of students. The concept of learning motivation has been defined as the organized pattern of pursuing goals, beliefs, and emotions (Ford 1992). Diong et al (2004) in their study stated that the students learn and retain much more of what they experience directly or practice doing, as opposed to what they only hear or see. Fernao Pires et al (2012) developed an experiment for giving the students a sense of practical testing in order to see the influence of the real life effects on machine diagnosis difficulty. Gani and Salami (2004) in their study showed that students learn and retain much more when they experiment directly in the laboratory and perform computer simulation, in opposition to when they only listen or see concepts in traditional classroom lectures.

In the present study, a physical model is used to simulate and study shaft critical speeds encountered in rotating machinery. Critical speed is when the shaft rotating speeds correspond to one of its natural frequencies. Thus, the combined weight of a shaft and disk can cause deflection that will create resonant vibration at critical speed. The main achievement is having students involving and motivated in the real time study for gain deeper understanding and confirmation of the mathematical theory of the subject. Since the majority of the students graduated will be employed in industry, the theoretical expression of the subject will not be sufficiently enough.

METHODOLOGY

In the present study, the effect of an actual application on learning of shaft critical speed subject in Machinery Dynamics class was investigated. The focus group of research consists of 20 undergraduate senior students attending to Mechanical Design Division at the University of Düzce, Turkey.

Laboratory practice and process steps

The study in relation to the students was structured into three phases as: lecturing, simulation, and experiment. Instrumentation assessing these three forms of learning outcomes was used in this study to measure student learning outcomes for learning objectives of the subject. In the lecturing session; shaft critical speed subject in rotating machinery was carried out only by teaching the basics and formulations.

The Dunkerley's Equations are employed to accomplish the calculation. The Dunkerley's Equations rely on a priori determination of shaft deflection at several locations. For uniform shafts with simple loading, the calculations are straight forward. The Dunkerly's equations (Dimarogonas 1996) for the critical speed are given as follows: the whirling frequency of a symmetric cross section of a given length between two bearing housings is given in Equation (1). A disk added to the shaft ignoring the shaft weight will have an angular velocity given in Equation (2). A shaft with disk added will have an angular velocity given in Equation (3).

$$\omega_s = 9.87\sqrt{\frac{E*I}{mL^3}} \tag{1}$$

$$\omega_d = \sqrt{\frac{3*E*I*L}{M*X^2*Y^2}} \tag{2}$$

$$\frac{1}{\omega_n^{\ 2}} = \frac{1}{\omega_s^{\ 2}} + \frac{1}{\omega_d^{\ 2}} \tag{3}$$

Where *E* is young's modulus, *I* is second moment of area, *m* is mass of the shaft, *M* is mass of disk, *L* is length of the shaft between bearings housings.

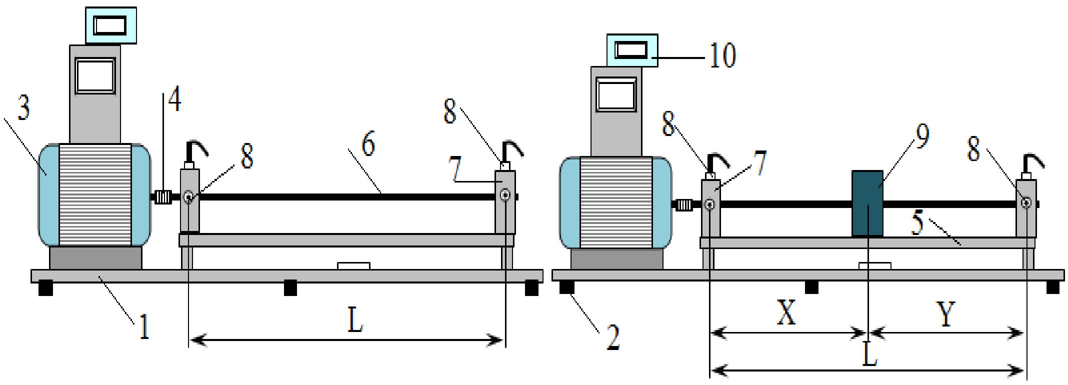

Figure 1. *Schematic diagram of experimental apparatus: (1) Base; (2) Rubber isolators; (3) Motor; (4) Coupling; (5) Extended rotor deck; (6) Shaft; (7) Bearing housing; (8) Accelerometer; (9) Disk; (10) Tachometer.*

In the simulation session, computer simulation related to the subject is shown to motivate and enhance the students learning in the class. In the final session, all students were given a brief instruction about how to use the test rig of the experimental study for the subject in order to conduct the experiment. The test rig for the experiment is shown in Fig. 1. The rig consists of a shaft with length of 850 mm and diameter of 19.05 mm. The shaft is coupled with a coupling to ½ HP motor. The motor can be run in the speed range of 0-3600 rpm. Two ball bearings are fitted in to the mounting housings to support shaft. A static loader weighting 5.04 kg is used in order to load the bearings for enhancing the spectrum amplitude of the system. The vibration of the bearing in the vertical and horizontal directions (x and y) is measured by four accelerometers. The accelerometers are mounted at 90° on the bearing housings. The system is composed of Data Acquisition (DAQ) Card provides four channels for vibratory response acquisition and one channel for rotational speed acquisition. The DAQ channels were set as ch1 and ch2 for the bearing fitted in outboard bearing housing in vertical and horizontal directions respectively while ch3 and ch4 for the bearing fitted in inboard (close to motor) bearing housing in vertical and horizontal directions respectively. All channels are simultaneous. The data were collected using the VibraQuest™ software and hardware system. Table outline for the parameters and data report shown in Fig. 2 is designed to be used in both the classroom lecture and experiment by the students.

Parameters		Value	
Distance between two bearing housing, L (m)			
Shaft diameter, d (m)			
Shaft mass, m (kg)			
Disk mass, M (kg)			
Elastic Modulus, E (Pa)			
Distance X (m)			
Distance Y (m)			
	Calculation from formulations		Theoretical	Experimental
	Shaft, ω_S	Disk, ω_d	Shaft + Disk, ω_n	
Critical speed				

Figure 2. *Table outline for the parameters and data report*.

Data Collection and Analysis

For data analysis, qualitative research method was conducted to analyze various data sets acquired in the study. An interview protocol was developed and used to guide interviews. The interview questions were composed of two sections. In the first section, the students were asked to describe what they gained in the class and in the laboratory. In the second section, the interviews carried out face-to-face and were video-taped for later transcription.

Semi-structured interview form was used for data collection. The students were divided to the three groups for interview. Data were collected performing the group interview before and after labratory practice. Interviews were recorded by video-camera together with an educational scientist and a specialist questioner involved directly to group meeting. Then, the video-camera recording was converted to written document form for analysis. Obtained concepts were classified on the base of interview questions.

FINDINGS

In this study, the obtained data by interview technique, analyzed with content analysis, are reached to findings. Findings are presented under certain titles.

Learning difficulties experienced in lecture

Subject of the critical speed course of Machine Dynamics usually is taught by lecture in Department of Mechanical Engineering of Engineering Faculty and Department of Mechanical Education of Technical Education Faculty. The students' views regarding the learning difficulties experienced in the lecture are given in the Table 1.

Table 1. *Learning Difficulties Experienced in Lecture*

Students' views	Frequency
1- The absence of the desired efficiency from the class with lecture	15
2- No accommodation with real life examples given in the class	11
3- No rejuvenation of mind made calculations and concepts related to the subject after lecture	7
4- To make an impression in different ways in students' minds to the concept of critical speed subject	4
5- To forget the information quickly given by lecture	4
6- Because of the theoretical expression loss of interest in attending class activity	2

The obtained data by interview technique were analyzed with content analysis. As seen in Table 1, the required outcome was not met from the course with classroom lecture with the highest frequency. Many students claimed that the purpose of the lecture could not achieved and not much mental engagement pointed out during the lecture. Thus, the students did not accommodate with real-life examples given in the lecture. It is considered to be that the cause of this situation was not seen due to lack of the actual application environment.

Comparison of Lecture and Laboratory Applications

In Table 2, looking at the main points that have not been understood following lecture, knowledge and skills following the laboratory practice; as a result of addressing the subject with lecture, it is clearly understood from the statements above that some information notes have not taken place in the students' minds and that there are questions in their minds about various parts of the subject.

Table 2. *Student Views after Plain Lecturing and Experiment Applications*

After plain lecturing Not understood the key points	Frequency	After experiment applications Knowledge and skills attained	Frequency
1- Do not think that critical speed notion can be more than a single value	6	1- Realization of the fact that there is more than one value of critical speed.	6
2- Inability to visualize the subjects given in the lecture	7	2- Better understanding of the terms related to the subject, visualization and gaining the skills to comment	10
3- Not being able to grasp the importance of critical speed subject in the systems	8	3- Grasping the importance of critical speed subject in a system.	8
4- The thought that calculated values of critical speed will not be the same in real applications and uncertainty about the accuracy of the mathematically calculated values	10	4- Obtaining critical speed values at the application that are very close to the theoretical calculations and thus the accuracy of the calculations being proven through real-time laboratory practice.	10

From Table 2, it can be seen that some concept of the subject are not understood. The students were not clear for grasping the importance of the subject related to real application. After the plain lecturing, students with frequency of 6 were not aware that the critical speed in the system could be more than one. After the experiment application, they realize the fact that there could be more than one critical speed in the system. Also, it is important to be noted that the half of students were not sure about the calculated values of critical speed that would be the same with the ones obtained with experiment.

Method of Discussion of the Subject "Critical Speed"

As a result of the analysis addressing the method of discussion of the subject "critical speed" of Machine Dynamics Course in order to reach the aim of the subject, the findings at the table below have been obtained considering the views of the students.

Table 3. *Student Views on the Terms of the Subject Teaching*

<table>
<tr><th>Before Experiment</th><th>Frequency</th><th>After Experiment</th><th>Frequency</th></tr>
<tr><td>1- A real-time laboratory application should be made following the plain lecture.</td><td>11</td><td rowspan="3">1- A real-time laboratory practice should be performed by the students together with the plain lecture and the number of applications should be increased</td><td rowspan="3">16</td></tr>
<tr><td>2- The visual samples provided in the plain lecture should be enriched.</td><td>4</td></tr>
<tr><td>3- A simulation program should be used together with the plain lecture.</td><td>3</td></tr>
<tr><td>4- Critical speed subject must be given in a laboratory media, besides the experiment.</td><td>2</td><td>2- The related subject should be narrated only in laboratory media.</td><td>2</td></tr>
<tr><td></td><td></td><td>3- A real-time laboratory practice should be performed before the plain lecture.</td><td>2</td></tr>
</table>

Table 3 gives the students' views on the terms of the teaching subject. The most of the students come to conclusion that real-time laboratory practices should be performed by the students to acquire hand-on learning so as to effectively learn and understand the subject. Overall, the students believed that performing computer simulations and laboratory practices was a valuable part of the subject learning.

Ratios of understanding of the subject "Critical Speed"

With reference to the student opinions, in order for the aims of the critical speed subject to realize, as a result of the analyses of the extent to which the subject is understood by the students that take the lesson, the findings in Table 4 have been reached.

Table 4. *Percentage for Understanding of the Critical Speed Subject*

Lecturing	Frequency	Lecturing and Simulation	Frequency	Lecturing, Simulation and Experiment	Frequency
1- % 0	14	1- % 50	1	1- % 80	2
2- % 5	1	2- % 55	1	2- % 85	1
3- % 25	2	3- % 60	2	3- % 90	4
4- % 30	3	4- % 65	1	4- % 95	1
		5- % 70	4	5- % 100	10
		6- % 80	4		

Table 4 gives percentages for understanding of the subject. It can be seen from Table that the majority of students have difficulty to understand the subject by plain lecturing. Understanding of the subject was much better by adding the simulation elements to plain lecturing. Overall, the majority of the students believe that the integration of experiment to the plain lecturing and computer simulation provided valuable understanding of the subject.

CONCLUSIONS

The overall goal of engineering education is to prepare students to real world practice. Forcing the students to concrete the main concepts and physical principles of the subjects taught is a valuable part of learning. This is possible with integration of physical system in to the classroom environment that allow for more interactive, relevant, and effective learning. The main purpose of this study was to provide innovative learning environments that allow for more interactive, relevant, and effective applications to give students valuable experiences. A physical model is used to simulate and study shaft critical speed subject encountered in rotating machinery. Qualitative research method was conducted and frequencies and percentages were used to determine which terms were elicited most frequently and to gain a better understanding about the distribution of students' views across obtained data. The main achievement is to have students involving in the real-time study for gaining deeper understanding and confirmation of the mathematical theory of the subject. From the results, it was found that the actual application helped students better to visualize and understand the subject. Also, it was found that the experiment helped students better to visualize the mathematical theories developed in lectures and homework exercises. Beside, students believe that showing computers simulations in class is also a valuable part of learning.

It has been observed that the teaching of the critical speed subject with laboratory practices besides the lecture has provided that the successes of the students have increased at a significant level. Based on the fact that the students cannot visualize the information they have been provided theoretically, it has been concluded that the practice should not only be performed during the lesson with mathematical calculations but also in real laboratory medium, personally. It is a fact that laboratory practices have been effective on the increase of general success of the critical speed subject and that the real medium of the performed practices have effected learning positively (Kılıç, Kara and Çiçek 2009; Kılıç, Kara and Çiçek 2010). With this study, it has been recognized that only lecture does not provide the realization of total learning. Based on the reality that the students cannot fully visualize in their minds the information that is taught to them in theory, it has been concluded that the practice should not only be performed in the lesson with mathematical calculations but within the real laboratory medium personally.

SUGGESTIONS

For more interactive, relevant, and effective learning of the subject, suggestions can be made as follows: From the students' point of view, conducting an experiment is more effective and memorable than listening to a lecture. Thus, students learn much better by doing actual application rather than by just listening classroom lecture. Also, it should be noted that plain classroom lecturing is ineffective relative to teaching that involve students as active participants in the learning process, not as passive observers. So, it is evident from the results presented that actual application is an essential aspect of learning.

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