Development of a Roving Laboratory in Vibrations for Undergraduate Engineering Students

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Abstract

Details on the development of a roving laboratory for undergraduate students in a new vibrations course including the instrumentation, laboratory format and several laboratory projects are discussed in addition to the inquiry-based, observational instructional approach that is being developed to complement the laboratory. Experiments in the roving laboratory are to be carried out in class, in two different on-campus facilities, and in the field. These experiments are used by the instructor to motivate each and every theoretical discussion in class, to teach students how to plan, conduct and interpret their own experiments, and to expose students to important emerging areas of experimental mechanics. The unique observational instructional approach of the course complements the roving laboratory by reversing the roles of theoretical and experimental techniques that exist in traditional laboratory oriented classes. Instead of using experiments to validate theories, theories are used to validate experiments. The make-up of an industrial advisory committee, which supports the roving laboratory by donating test specimens, providing engineering problems of practical importance and evaluating the results of the course, is also described. The goals of the project are to give students more control of the learning process; to better educate students in vibrations and experimental mechanics; to encourage lifelong self-learning and an appreciation for experimentation; and to create a stronger and more direct link between industrial partners and the classroom. The evaluation procedure for determining whether or not and to what degree the goals of the project are met is also outlined. This project, DUE-0126832, is sponsored by the NSF Division of Undergraduate Education.

1. Introduction

The theme of this project in instructional adaptation and laboratory improvement is that “experiment is the sole source of truth” (Poincaré\(^1\), 1903). This theme dates back to the time of Aristotle, Archimedes, Newton, Euler, Bernoulli, Lagrange and other giants in the history of mechanics when theories were used to validate experiments rather than the other way around as is often done in traditional laboratory oriented exercises. In fact, the majority of all breakthroughs in the field of engineering mechanics stem from observations of phenomenon that were made before developing mathematical or engineering models to explain those phenomenon (Dugas\(^2\), 1988). For example, there is a relatively recent compelling advancement in the field of dynamics that highlights the importance of experimental observations. A phenomenon called chaos, which was once dismissed as ‘noise’ in experimentally observed data has turned out to be something much more subtle and important (Moon\(^3\), 2000). It has been speculated that one
possible reason for why chaos had been overlooked by very competent and well-trained engineers and scientists until recently, even though Poincaré discovered it at the turn of the century, is that students are traditionally taught that experiments should be carried out to validate theories. Unfortunately, chaos, which is a fundamentally nonlinear phenomenon, often escapes observation because it is very sensitive to the conditions of the experiment; consequently, scientists and engineers did not universally believe that chaos existed until the advent of the modern supercomputer, which provided the means to conduct millions of virtual experiments with digital precision and show once and for all that chaos is not noise but rather a complex nonlinear phenomenon. The scientific and engineering community did not fully accept that chaos was genuine until they could demonstrate it to themselves experimentally; students might also accept theory more readily if they could discover it for themselves rather than on faith during lectures.

In summary, experiments are powerful tools of science and engineering because one experiment can completely dismiss or divulge an entire theory; therefore, engineering students should be taught to design their experiments carefully and to glean as much information as possible from those experiments because they provide insight and lead to discovery. As for the engineering research community, there is no doubt that experimental observations are crucial because no proposal for research is ever funded without some hint of an experiment. The project described here aims to make experiments as important in teaching as they are in research so that opportunities in education and discovery are not overlooked like chaos was for so many years. This project is responding to needs in engineering education (Doderer and Giolma, 1995) to stimulate formal thinking, or “thinking out of the box” (Pavelich, 1984; Piaget, 1950), and adheres to Teaching Standard A from the National Science Education Standards (National Academy of Sciences, 1996) by emphasizing hands-on, experiential learning (National Research Council, 1986; Wankat and Oreovicz, 2000a, 2001) and student driven investigation and inquiry (McConnaughay et al, 1999).

2. Challenges and Approach

The goals of this project are to give students more control of the learning process; to better educate students in vibrations and experimental mechanics; to encourage life-long self-learning and an appreciation for experimentation; and to create a stronger and more direct link between industrial partners and the classroom. There are three main challenges to overcome.

First, “experimentation is not just data taking” (Coleman and Steel, 1989); however, the majority of students think it is, probably because they perceive that this is what many of their instructors, advisors and mentors believe. This educational project underscores a need in engineering education to expose students to the wonders and pitfalls of experimentation beyond just data taking, especially where vibrations are concerned. As a part of this project, undergraduates will be asked to design, set up, carry out and interpret their own experiments. These lab assignments will be very different from the traditional prearranged laboratory experiments, which are effectively used to reinforce theoretical concepts but follow a fixed format and do not give students an opportunity to develop their own experimental planning and design skills. Students who are not capable of thinking on their feet in a purely industrial or R&D test setting are at a distinct disadvantage when seeking many types of engineering employment. The inquiry-based
roving laboratory will require students to work together in teams to solve engineering vibration problems by first developing their own experiments and then developing engineering models, which can be used to generalize those experimental results and make recommendations for addressing a given problem.

The second challenge to overcome in this project is to develop a roving laboratory that is flexible enough to grow over time, mobile enough to be used for on and off-campus testing, sustainable enough to evolve with the needs of industry, and interactive enough so that students get timely responses to their questions and concerns. Custom-made equipment was designed and fabricated for use in this project in order to meet the flexibility requirement and an additional durable mobile acquisition system was purchased to provide the means to carry out remote experiments (Figure 4 shows a typical students setup).

The sustainability of the roving laboratory has been ensured by developing an Industrial Advisory Committee for the project. These industrial partners, who range from practicing engineers to researchers at national laboratories to directors of engineering in major R&D firms, are donating test specimens for student projects, providing engineering problems of practical importance on which students can work and evaluating the project results by grading student team presentations and final reports. By forming an industrial advisory committee, this project recognizes that researchers, professionals, and instructors can better educate engineering students by establishing educational partnerships between academe, industry, and government laboratories (Wankat and Oreovicz, 2000b; Hoots, 1999; and Denton, 1998). Industrial partnerships like this one at universities are not unprecedented. For example, Professor Cipra in the School of Mechanical Engineering at Purdue University has also implemented this kind of open-ended project experience for undergraduates early in the curricula with great success and acclaim from industrial partners. Although faculty must give up a certain amount of control (Wankat and Oreovicz, 2000c) to teach this way, it seems to be extremely effective for preparing students to practice engineering (Wankat and Oreovicz, 1999).

In order to provide students with the right amount of interaction in the roving laboratory, the project follows recently successful trends in inquiry-based engineering education whereby instructors act more like learning coaches and less like teachers. In inquiry-based learning environments, students are given compelling problems to solve, the resources to solve them, and the freedom to fail; successful outcomes are sometimes but not always guaranteed (Keefer, 1999). The essential ingredient in all inquiry-based programs is student frustration, which leads to revelation when instructors intervene at the right times. For example, Professor Mosch (Walker, 2000) at the Colorado School of Mines has developed a hands-on mining safety course inside Edgar Mine. In this course, students perform simple experiments with mining tools to demonstrate analytical concepts directly while instructors work like coaches to field student questions as they arise. This format has been very well-received by the students. As a second example, Professor Arce at Florida State University (Creighton, 2001) has implemented a set of soccer coaching principles akin to the inquiry-based teaching methodology as discussed by Keefer. Arce hopes to transform the way students are taught the physics of transport in continuous media. There are many other good examples of where students and faculty interact in an experimental setting. For example, ‘test-trips’ have been used for decades by engineering graduate student advisors to successfully train their research assistants in experimental methods.
on research and development projects for industrial sponsors. These tests are usually packed full of good engineering lessons that expose students to everything from failed sensors to misapplied engineering assumptions.

The third challenge to overcome is that textbooks in vibrations are not written in an observational format, so students often feel like they are taking giant leaps of faith from one section to the next when mathematics, calculus and differential equations are involved. To address this challenge, a unique set of course notes has been written in an observational format to complement the roving laboratory. The technical portions of these notes were adapted from a set of course materials that have been written and revised over the past twenty years by the staff within the Structural Dynamics Research Laboratory at the University of Cincinnati. By carrying out a virtual experiment before starting every new section, these adapted notes emphasize that experiments of all kinds including those that are physical, virtual (computer) and mental can be used to define the analytical approach. In this way, the notes aim to help students define the analytical approaches to be used rather than forcing the approaches on them.

A new course, ME 497A “Practical Experiences in Vibration”, that is working to overcome these challenges has been offered within the School of Mechanical Engineering at Purdue University in the spring 2003. The number of students enrolled in the first offering of the course was 14 undergraduates. Of these students, 21% are women, 7% are international students and the remaining students are white Caucasian males. A roving laboratory is the centerpiece of this course. This laboratory consists of state-of-the-art instrumentation for making dynamic measurements on vibrating structures in an on-campus laboratory or at an off-campus test site.

In summary, the unique observational instructional approach of the course complements the roving laboratory by reversing the roles of theory and experiment that exist in traditional laboratory oriented classes. Instead of using experiments to validate theories, theories are used to validate experiments. This pedagogical approach aims to enhance the role that experiments play in and out of the classroom and to give students a better appreciation for the types of questions that cannot be answered without mathematical models. As mentioned earlier, these experiments are used by the instructor to motivate each and every theoretical discussion in class, to teach students how to plan, conduct and interpret their own experiments, and to expose students to important emerging areas of experimental mechanics.

3. Roving Laboratory

The roving laboratory and complementary observationally taught series of lectures are the main innovations in the course. The roving laboratory will give students the opportunity to test a variety of mechanical structures in mechanical, civil and aero-engineering applications. Several roving laboratory experimental projects involving a tennis racket, baseball bat, golf club driver, remote controlled model automobile suspension system and helicopter fuselage are discussed below. Each of these projects will help to establish an educational link between university classrooms and industry and it is believed that when accompanied by the observationally taught lectures will foster higher-level learning in vibrations. The roving laboratory experiments are to be carried out in three locations in the first offering of the course: a Mechanical Engineering educational laboratory, the Ray W. Herrick Laboratories on campus, and a remote test site.
(basketball gymnasium, pedestrian bridge or other). Approximately three students will be assigned to each team and each team will work on a different project. Each team will also submit a final report summarizing their problem, approach and results for the industrial advisory committee and instructor to evaluate.

The laboratory equipment purchased for the course is listed below in Table 1 with the exception of the instrumentation cabling. Included in the list are various types of sensors, data acquisition hardware and educational vibration trainers. An assortment of transducers is required for measuring forces and motions in medium (tennis racket) to large scale (pedestrian bridge) structural specimens. The SDC003-8H-kit units have 4 dynamic channels of data acquisition and were custom designed by The Modal Shop (Cincinnati, OH) of PCB Group using the Analog Devices Sharc™ chip for use by students in the roving laboratory. The equipment can be easily expanded to accommodate more measurement channels and is completely network ready to facilitate future over-the-network remote testing by students. Much of this equipment can be seen in the figures provided in the roving laboratory description below.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>QRDC vibration test stand</td>
<td>Two degree of freedom vibrating system driven to oscillate by a rotating component with imbalance</td>
</tr>
<tr>
<td>SDC003-8H-kit</td>
<td>LanSharc Process Analysis Box kit for data acquisition with 8 dynamic input channels including three IBM laptop computers</td>
</tr>
<tr>
<td>IBM A22m laptop computer</td>
<td>Laptop accompanies mobile data acquisition system</td>
</tr>
<tr>
<td>IOtech Waveport®</td>
<td>Mobile 16-channel data acquisition system for examining vibrating systems in the field</td>
</tr>
<tr>
<td>Twenty T356B18</td>
<td>Tri-axial, high sensitivity, ceramic shear ICP® accelerometers with 1000 mV/g</td>
</tr>
<tr>
<td>Twenty T393A03</td>
<td>Seismic, ceramic shear ICP® accel. with 1 V/g</td>
</tr>
<tr>
<td>Twenty 012E10</td>
<td>Low cost, black coaxial cable</td>
</tr>
<tr>
<td>One 086D50</td>
<td>Large sledge impact hammer with 1 mV/lb</td>
</tr>
<tr>
<td>Three 086C03</td>
<td>Modally tuned Hammer with 10 mV/lb</td>
</tr>
<tr>
<td>Two 086D80</td>
<td>Miniature modal hammer for 0-50 lbf. excitation</td>
</tr>
<tr>
<td>Eight 740B02</td>
<td>ICP® piezoelectric strain sensor</td>
</tr>
<tr>
<td>Two T288D01</td>
<td>ICP® impedance head, force/accel. with 100 mV/lb, and 100 mV/g</td>
</tr>
</tbody>
</table>

Table 1 Laboratory software and hardware acquired in preparation for spring 2003 offering
Technical material on lumped parameter mechanical models of linear and nonlinear vibrating systems, linear modal analysis, and linear impedance analysis will be presented during lecture and in the laboratory sessions in the context of student projects. In order to provide the students with practical examples of vibrations in engineering applications, several demonstrations and laboratory experiments have been designed that use everyday, real-world engineering examples to illustrate the importance of both theoretical and experimental techniques for studying vibration phenomena. Eight demonstrations/experiments have been constructed using examples from various engineering disciplines as well as various pieces of sporting equipment in an attempt to appeal to a wide range of students. Summaries of the objectives and approach for each demonstration are given below in some detail but the main concepts being taught in all cases are summarized in Table 2.

<table>
<thead>
<tr>
<th>Concept</th>
<th>Theory</th>
<th>Experiments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency response</td>
<td>[ H_{pq}(\omega) = \frac{X_p(\omega)}{F_q(\omega)} ]</td>
<td>All</td>
</tr>
<tr>
<td></td>
<td>Frequency response functions, ( H_{pq}(\omega) = \mathcal{F}[h_{pq}(t)] ), which are the Fourier transform of impulse response functions, are the primary analytical and experimental means for characterizing linear systems. The equation above relates the frequency domain input, ( F_q(\omega) ), to the output, ( X_p(\omega) ).</td>
<td></td>
</tr>
<tr>
<td>Transmissibility</td>
<td>[ T_{pq}(\omega) = \frac{X_p(\omega)}{X_q(\omega)} ]</td>
<td>Tennis racket, Baseball bats, Golf club</td>
</tr>
<tr>
<td></td>
<td>Transmissibility functions, ( T_{pq}(\omega) ), are ratios of frequency response functions and are the second primary analytical and experimental means for characterizing linear systems. The equation above relates the frequency domain output, ( X_p(\omega) ), to the output, ( X_q(\omega) ). Transmissibility functions are used to study vibration isolation systems, for example.</td>
<td>Vehicle road course</td>
</tr>
<tr>
<td>Modal superposition</td>
<td>[ h_{pq}(t) = \sum_{r=1}^{N_r} A_{pqr} e^{\lambda_r t} + A^*_{pqr} e^{-\lambda_r t} ]</td>
<td>Tennis racket, Baseball bats, Golf club, Plate with sand</td>
</tr>
<tr>
<td></td>
<td>Modal superposition is the primary analytical tool for studying linear vibrating systems. The equation above expands the impulse response function, ( h_{pq}(t) ), as a sum of ( N_r ) modes, each with its own modal frequency (( \lambda_r )) and modal vector (associated with residues, ( A_{pqr} )). Students will experimentally extract these modes and then compare their results with analytical estimates.</td>
<td>Aircraft wing, Exhaust system, Fuselage section</td>
</tr>
</tbody>
</table>

**Table 2** Three primary concepts to be examined in the course using the theory and experiments noted in the table.
3.1 Sports Equipment: Tennis Racket

The objective of this experiment is to determine the location of the ‘sweet’ spot of the tennis racket. Many students have experience with using tennis rackets, so they will intuitively understand that when a ball strikes the sweet spot on the strings, the vibration levels at the handle are relatively small. In order to locate the sweet spot, students will conduct an experimental modal analysis on the Wilson tennis racket shown in Figure 1 by impacting the racket at certain locations along the frame and strings with a miniature modal hammer and measuring the response of the racket at other locations using single axis piezoelectric accelerometers. By processing this frequency response function data at different resonant frequencies of the racket, students will then be able to animate mode shapes in order to identify the nodal lines for all modes in the measurement frequency range.

The theory underlying this experiment is that when the tennis ball strikes the sweet spot of the racket, the maximum coefficient of restitution at impact is achieved; therefore, minimal energy is translated to the racket handle. A sample of the data to be obtained by students is shown in Figure 2, which shows a set of measured frequency response functions for a single reference measurement. The first two modal frequencies and modal deflection shapes of the racket frame are also given in Table 3 in order to illustrate the type of result to be obtained by the students. These mode shape patterns were constructed using the X-Modal software package, which was developed as an educational tool for engineering students at the University of Cincinnati.

![Figure 1](image1.png)  
**Figure 1** Tennis racket instrumented with three reference accelerometers for modal impact experiment

![Figure 2](image2.png)  
**Figure 2** Measured frequency response functions from tennis racket with one reference accelerometer showing five clear flexible modes in the frequency range from 100 to 700 Hz
<table>
<thead>
<tr>
<th></th>
<th>Mode #1</th>
<th>Mode #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modal frequency</td>
<td>106 Hz</td>
<td>272 Hz</td>
</tr>
<tr>
<td>Mode shape</td>
<td><img src="image1.png" alt="Mode #1" /></td>
<td><img src="image2.png" alt="Mode #2" /></td>
</tr>
</tbody>
</table>

**Table 3** Modal frequencies and modal deflection shapes for the first two flexible modes of the racket frame; animations were obtained using the X-Modal software package from the Univ. of Cincinnati

3.2 Sports Equipment: Wood/Metal Baseball Bat

The objective of this experiment is similar to that of the tennis racket in that students again will be determining the location of the ‘sweet’ spot. However, in addition to determining the sweet spot, students will also observe certain phenomena associated with symmetric systems when analyzing data from this experiment. A picture of the experimental setup of a wooden bat is shown in Figure 3. The baseball bat was instrumented with four accelerometers, two at the grip and two on the impact region. In order to observe the nature of the symmetric mode shapes, two accelerometers at each location were positioned along perpendicular axes. According to the theory, any system like the baseball bat that is nearly symmetric will vibrate in either of two perpendicular planes with equal natural frequencies. The most notable example of this is that of a homogeneous cylinder (i.e., a flag pole), which can vibrate both in the plane and out of the plane.

![Figure 3](image3.png) Wooden baseball bat instrumented with four accelerometers for modal impact experiment

![Figure 4](image4.png) Picture of student SDC003-8H-kit for acquiring data
Impact data has been obtained for both bats and the data has been analyzed to determine the frequencies of the first four mode shapes. The custom-made student SDC003-8H-kit data acquisition system for acquiring this data is shown in Figure 4. After analyzing the data it was seen that due to the hollow nature of the aluminum bat, the impacts should have been located on the same side as the accelerometers to avoid deflections caused by the impacts. Students will learn this type of lesson in the course during their experiments. Additional tests are being done on the aluminum bat to quantify the effect that this deflection has on the frequency response functions and the mode shapes and to compare the behavior of the wooden and the aluminum bats. Transmissibility functions will also be analyzed for the bats because students can use these functions to determine the degree to which the handle of the bat vibrates when a ball is struck away from the sweet spot.

3.3 Sports Equipment: Golf Club (Driver)

This experiment is similar to the previous two experiments in that the location and size of the ‘sweet’ spot will be investigated; however, in this experiment the bulk of the mass of the club is located at the head to give students the opportunity to observe the difference between systems with lumped and distributed mass and stiffness characteristics. Moreover, a driver is much longer and less forgiving when it comes to hitting the sweet spot. The sweet spot for a driver is known as the location where the face of the club deforms the most and therefore allows for maximum energy transfer to the ball. In addition to the face of the club being contoured, the shaft of the driver is made of graphite, which is a rather heavily damped material that is used to minimize the vibration transmitted to a player’s hands. By analyzing the frequency response functions and transmissibility functions of the golf club, the students will learn how to find the sweet spot and will also note the effects that various materials have on measured frequency response functions. This experiment is currently being carried out; however, a picture of the driver being used for this experiment is shown in Figure 5.

![Golf club driver head instrumented with accelerometer and impacted with micro-hammer](image)

Figure 3 Golf club driver head instrumented with accelerometer and impacted with micro-hammer
3.4 Transportation: Vehicle Road Course

The objective of this experiment is to analyze the vibration isolation characteristics of a suspension system of a vehicle as it travels over various road surfaces. In order to simulate the suspension of an actual vehicle a radio controlled F-150 truck with a four-wheel independent suspension was purchased and instrumented with accelerometers to measure the response of the wheels and chassis. Because the intent of this experiment is to analyze the vibration isolation characteristics provided by a vehicle suspension system, a three-lane road course was constructed. The three road surfaces chosen to provide for the most variation in the road input were a stone road, a road with speed bumps that can be varied to provide various frequencies of excitation and a road with various sized potholes.

Trial data is currently being collected for this experiment and an analysis of the data will then be performed to obtain the transmissibility between the tire axle and the chassis. These experimentally measured functions will then be compared to theoretical values obtained from a simplified spring-mass-damper system model of the vehicle. Figure 6 also shows the IOtech Waveport data acquisition system that will be used by students in this experiment. The Waveport will also be used to acquire data on test trips with students in the field.

3.5 Noise and Vibration: Exhaust System

In order to motivate the industrial relevance of vibration analysis, an exhaust system from a Dodge Neon will be tested by the students to determine the modal frequencies and mode shapes of the exhaust system. In Figure 7, the exhaust system has been suspended on bungee cords to approximate a free-free boundary condition and has been instrumented with 10 tri-axial accelerometers. An electromagnetic shaker has been attached at the bellows of the exhaust in Figure 8 in order to simulate the input excitation from the rotating powertrain. Once students have estimated the modal parameters, they will then be asked to determine how these modes of vibration may be excited at various operating speeds of the engine. Finally, the students will be
asked to estimate the modal parameters of the exhaust system after a design modification is implemented to change the modal characteristics in some way. Both the baseline exhaust system and the modified exhaust system were supplied by ArvinMeritor (John Grace, Vice President of Research and Development) in support of this course. This project will give the students an opportunity to examine both the free and the forced response characteristics of the exhaust system before and after a design modification is made. Various frequency response experiments on the exhaust system using both an electromagnetic actuator and a modally tuned impact hammer have been carried out and the modal properties have been estimated for both exhaust systems. Examples of the frequency response functions that have been measured for this system are shown in the left of Figure 9 and the design modification of the exhaust system is shown in the right of Figure 9.

**Figure 7** Dodge Neon exhaust system supported on bungee cords

**Figure 8** Shaker attached to exhaust

**Figure 9** (Left) Measured frequency response functions and (right) modified exhaust system with Metex joint inserted at inlet pipe at muffler for students to compare with baseline system.
3.6 Noise and Vibration: Helicopter Fuselage Section

In addition to the exhaust system above, students will also have the opportunity to conduct experiments on the helicopter fuselage shown in Figure 10. In these experiments, students will be asked to carry out impact hammer tests on sections of the fuselage such as the panel shown instrumented with multiple accelerometers in Figure 11. Note that the fuselage has been supported with a hoist from above in order to avoid vibration transmission from the floor into the helicopter strut. Because the vibration characteristics of the fuselage determine to a large extent the noise characteristics within the helicopter, students will be able to draw some basic conclusions about noise in the passenger cabin by measuring the modal vibration frequencies and mode shapes of a typical section. Table 4 gives two modal frequencies and mode shapes for the section of fuselage in Figure 11. Students will also measure sound pressure inside the cabin.

![Figure 10 Helicopter fuselage for performing modal analysis](image)

![Figure 11 Panel of fuselage instrumented with accelerometers](image)

These experiments will expose students to the importance of boundary conditions in determining structural vibration behavior. For example, the two modes in Table 4 indicate that the fuselage section is approximately fixed near the bottom and free near the top. By testing this same section of the fuselage when the door is opened instead of closed as in Figure 11, students will learn firsthand why boundary conditions are so important in experimental dynamics. The helicopter was supplied by Lord Corporation (Dr. L. Miller, Director of Mech. System R&D).

<table>
<thead>
<tr>
<th>Modal frequency</th>
<th>Mode #1</th>
<th>Mode #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>74 Hz</td>
<td></td>
<td>131.5 Hz</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mode shape</th>
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</table>

![Table 4 Modal frequencies and modal deflection shapes for the first two flexible modes of the helicopter fuselage section; animations were obtained using the X-Modal software package from the Univ. of Cincinnati](image)
4. Evaluation of Project

The students in the first offering have been surveyed with a formative set of questions (35) to identify a baseline set of responses for evaluating the course with a summative evaluation at the end of the semester. The initial demographic data has been used to assign laboratory teams. Student background in experimental work, GPA, mathematical training, reason for enrolling in the course, graduate or undergraduate student, gender, and ethnicity, interest in structural dynamics, comfort level with hands-on activities, preference for individual or group activities among other information has been collected in the initial survey. A few of the more interesting results are given in Table 5 below. Note that students are nearly split between wanting work in groups and wanting to work more individually; interactions with the instructor are very important to most students; physical demonstrations are very important to most students; most students feel that industry should be more involved in the educational process; and few students feel that they could currently seek employment in experimental vibrations in industry.

<table>
<thead>
<tr>
<th>Formative Survey Questions</th>
<th>Response Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you prefer to work more individually, to work more in student teams or somewhere in between the two? (1 – individual, 5 – teams)</td>
<td>3.46</td>
</tr>
<tr>
<td>Are interactions with the instructor not important to you, very important to you, or somewhere in between the two? (1 – not important, 5 – very important)</td>
<td>4.07</td>
</tr>
<tr>
<td>Do you feel that physical demonstrations during lectures generally do not help you learn, are very helpful for learning or are somewhere in between the two? (1 – not helpful, 5 – very helpful)</td>
<td>4.15</td>
</tr>
<tr>
<td>Do you feel that industry should not be more involved in the educational process, should be very much more involved or somewhere in between the two? (1 – not more involved, 5 – more involved)</td>
<td>4.07</td>
</tr>
<tr>
<td>Do you currently feel that you would have difficulty getting an engineering testing and experimental job in mechanical vibrations or structural dynamics, could easily get a job or somewhere in between the two? (1 – difficulty, 5 – easily)</td>
<td>2.69</td>
</tr>
</tbody>
</table>

Table 5 Formative survey questions to establish baseline for evaluating project

In addition to repeat questions from the formative survey at the beginning of the semester, the summative evaluation at the end of the semester will include general comments by the industrial advisory committee on the quality of the final presentations and reports. The members of the advisory committee including Los Alamos National Laboratory (Dr. Charles Farrar), NASA Dryden Flight Research Center (Mr. Larry Freudinger), Lord Corporation (Dr. Lane Miller), ArvinMeritor (John Grace), Army Research Laboratory (Mr. Elias Rigas), Caterpillar (Mr. Matthew Bedwell) and Purdue University (Prof. Mete Sozen) have been informed of the course development activities and are prepared to assist in evaluating the course. During each semester that the course is offered, individual committee members will be more or less involved throughout the semester depending on whether or not their company is sponsoring a student project; however, all committee members have agreed to evaluate the conceptual and technical merits of the student project reports.
This procedure will be carried out in the first and second offerings and the results will be compared being careful not to make invalid comparisons between students and groups with dissimilar demographics. Multivariate regression analysis will also be carried out to correlate demographic, attitude and evaluative responses. Chi-square statistical hypothesis testing will be used to examine levels of correlation and coupling between the variables. Results of particular interest include differences in male/female responses and the effectiveness of the roving laboratory and the observationally taught lectures.

5. Conclusion

Example projects in a roving laboratory for undergraduate students in vibrations and the accompanying observational instruction format have been discussed. The observational instruction approach and roving laboratory reverse the roles of theory and experiment by using theories to validate experiments rather than using experiments to validate theories as is traditionally done in lab courses. The role of an Industrial Advisory Committee for the course has also been described and the merits of teaming with industry to better educate students in experimental mechanics have been given. The goals of the project have been defined and the challenges to achieving those goals and ways to overcome those challenges have been discussed. The evaluation procedure for the project has also been outlined. The first offering of the course described herein will be evaluated before the conference and the results will presented there.

Acknowledgements

The authors would like to thank the National Science Foundation Division of Undergraduate Education for their support of this work under grant DUE 0126832 and Dr. Ibrahim Niscanci for his sincere interest and support of the project as program manager in the Course, Curriculum, and Laboratory Improvement program. The authors would also like to thank PCB Piezotronics and The Modal Shop for their support with custom instrumentation and hardware gifts in-kind. Finally, the authors thank the members of the advisory committee, including Dr. Charles Farrar (Los Alamos National Laboratory), Mr. Larry Freudinger (NASA Dryden Flight Research Center), Dr. Lane Miller (Lord Corporation), John Grace (ArvinMeritor), Mr. Elias Rigas (Army Research Laboratory), Mr. Matthew Bedwell (Caterpillar) and Prof. Mete Sozen (Purdue University) for their enthusiastic support of this project.

Bibliography


Biographies

Mr. Nasir Bilal is a second year PhD student in the School of Mechanical Engineering at Purdue University in the area of mechanics. He is the Teaching Assistant for the new course discussed here and has been instrumental in helping to setup the roving laboratory and experimental projects. Nasir is conducting research in the area of uncertainty quantification in model predictions.

Mr. Harold Kess is a senior undergraduate student in Mechanical Engineering. He worked as a summer intern to develop many of the roving laboratory experiments discussed here. Harold is the winner of a John M. Bruce Memorial Scholarship for his research work in nondestructive evaluation of composites and will be pursuing a Masters degree in mechanics in the fall of 2003.

Dr. Douglas Adams is a third year assistant professor of Mechanical Engineering and is the instructor in the course discussed here. He is the winner of the 2003 Solberg Award for Best Teacher in Mechanical Engineering at Purdue and a 2001 Presidential Early Career Award for Scientists and Engineers from the DoD. Dr. Adams conducts research at the Ray Herrick Labs.