Paper 2006-727

DYNAMIC SYSTEMS TEACHING ENHANCEMENT USING A LABORATORY BASED PROJECT (R.U.B.E.)

Dr. Peter Avitabile, Associate Professor
Tracy Van Zandt, Jeff Hodgkins and Nels Wirkkala, Graduate Students
Mechanical Engineering Department
University of Massachusetts Lowell
One University Avenue
Lowell, Massachusetts USA
Peter_Avitabile@uml.edu

Abstract

A Dynamic Systems course always relies on materials from previous mathematics and engineering courses. In Mechanical Engineering, these underlying courses are critical to the student's success in understanding Dynamic System's material. However, students rarely see the inter-relationship between material from different courses since there is no obvious common link. A Dynamic Systems course must allow the student to see the inter-relationship of this material.

A new variation of this course has been incrementally developed over the past few years to include both an analytical project and a laboratory based project to help the students firmly grasp the material. The analytical project is an individual effort in which the student solves a second-order differential equation using multiple methods: closed-form solution, Laplace transform, and MATLAB and Simulink solutions. Each student has a different set of parameters defined based on student ID information. This reminds the students of the foundation differential equations knowledge they will require for the remainder of the course.

An updated laboratory project on a second order mechanical system further enhances the student's understanding. The students use a system referred to as RUBE (Response Under Basic Excitation). The RUBE system is an internet-based data acquisition system for a second order mass-spring-dashpot system. The system has variable mechanical parameters—it changes every time it is operated so that no two sets of data are alike (variable input, variable mass, variable stiffness). This forces each student to process his/her own data, as it will be slightly different from data sets collected by other students. Students work in groups, collect data, and prepare detailed reports summarizing their efforts. Students also perform a peer review of submitted projects, providing another valuable learning experience.

Assessments of the first three semesters of the project clearly indicate that the students enjoyed the hands-on project and clearly felt that they understood the material in much greater depth as a result of the project.

I. Problem

Understanding basic STEM (Science, Technology, Engineering, Mathematics) material is critical to a student's ability to progress satisfactorily in upper level courses. Earlier courses often appear to have no relevance, from a student's perspective. As a result, students feel that they do not command the subject matter well enough and sometimes feel that it is too late to catch up on review what they now realize they should have already known from previous courses. Figure 1 shows a cartoon expressing the student's eventual realization as they approach the latter part of the undergraduate educational career.

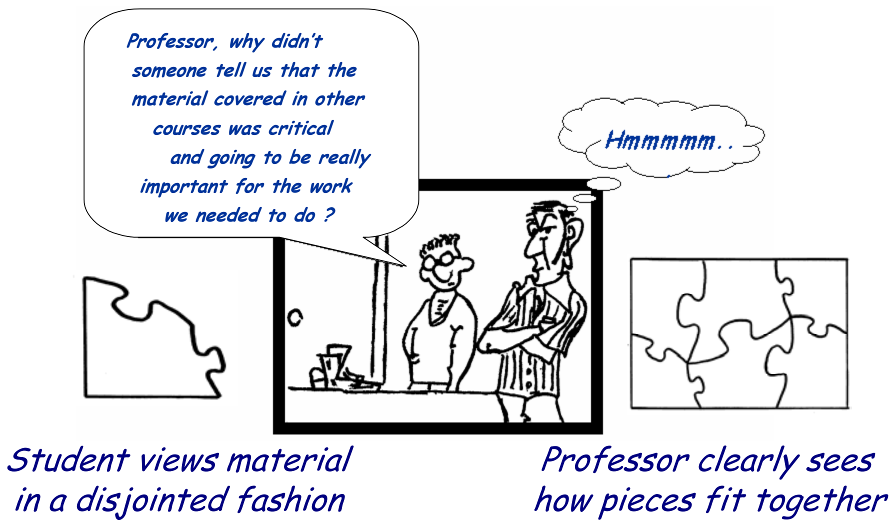


Figure 1 – Professor vs. Student View of Material Presented

This is especially true in a senior level Dynamic Systems course where previous material in Differential Equations, Mathematical Methods for Engineers, Dynamics, Solid Mechanics, Electrical Circuits, Thermal-Fluid Systems, etc. all have relevance to the understanding of the dynamic response of a system.

II. Introduction

The mission for all instructors is to educate their students in the most efficient manner possible. Teaching techniques should challenge, educate and promote innovative thinking from students. The lecture-based format of teaching which predominates in engineering education may not be the most effective manner to achieve these goals [1,2]. Constructivist learning theory asserts that knowledge is not simply transmitted from teacher to student, but is actively constructed by the mind of the learner through experiences. [3,4].

Hands-on projects and problems with practical purpose tend to help students learn best [5]. Laboratory based projects are the best vehicle for demonstrating many aspects of engineering problem solving situations. But in most cases, laboratory environments are set up as "exercises" which have very clear, predetermined outcomes. This is done to reinforce lecture material that is presented in related courses [6]. These "canned" laboratory experiments are a strong complement to the course theoretical content. These types of labs have a very well-defined, deterministic outcome which reinforces basic inherent skills that the students need to master. Many professors are comfortable with this approach since the outcomes of the lab experiment are well defined and can be assessed and evaluated with very clear guidelines.

However, this does not exploit the laboratory experience to its fullest. Students get the impression that the experimental environment is very similar to the classroom environment where homework problems and tests have explicit answers given the problem statement. Unfortunately most, if not all, engineering problems do not follow this cookbook approach. Students must be afforded the experience of problems that require them to formulate solutions to problems with no specific straight-line structure to the solution – they must learn how to "think outside the box" [7].

Laboratory is the one place where students have the opportunity to "think on their own" and assemble separate pockets of knowledge to solve a complete problem. The biggest advantage is that real-world exercises and experimental approaches clearly show that there is not always an "answer at the back of the book". While students at times become frustrated by this, they learn that they need to employ many of their STEM skills in order to solve even the simple problems. Advisors from industry have clearly identified that students need to be exposed to a real-world laboratory environment where modern instrumentation and computers interface in performing data acquisition and data reduction [9, 10, 11].

Students must feel comfortable with formulating solutions to problems where no specific solution may be possible or a variety of different solutions may exist. Experiments are a critical part of helping students cope with this unknown situation. Students must also feel comfortable formulating solutions to real engineering problems using all of the STEM tools available to them. The STEM must become an integral part of their learning process throughout their entire educational and professional careers – the students must, in essence, "live the material" every day and in every course. Course materials must cease to be presented in this disjointed fashion if this is to happen.

"After two weeks, people generally remember 10% of what they read, 20% of what they hear, 30% of what they see, 50% of what they hear and see, 70% of what they say, and 90% of what they say and do."[8] Clearly, the students need to drive the need for learning STEM related material. Once they have been able to clearly identify the need to learn and understand these basic STEM principles, their ability to utilize the concepts and principles in solving real-world engineering problems will be enhanced. Students need to take ownership of the STEM material that is critical to solving engineering problems early in their educational career.

Real engineering problems are rarely solved by "looking up answers at the back of the book". Yet many engineering courses are taught this way and students feel that they can push the "reset button" after each class since they do not see the integration of all the material until late in their undergraduate career through the capstone experience. This is too late for them to realize the importance of earlier course material.

A Dynamic Systems laboratory-based, hands-on project has been implemented which attempts to address many of the issues identified above. This series of projects is described in the following sections.

III. Description of the Set of Dynamic Systems Projects Developed

A set of Dynamic System's projects has been developed to task the students, working either individually or in teams, to address several dynamic system characteristics. The first project is an individual effort, forcing the students to develop the necessary skills to solve systems described by differential equations, Laplace transforms and numerical techniques; this project is a hands-on based analytical project. The second project is a group effort and involves the identification of the mass, damping and stiffness characteristics of a simple second order mechanical system; this laboratory based project clearly helps the students develop intuitive skills necessary to address real world problems. The third project is a group effort and generally is some variation of a theme to extend the material developed in the first two projects; this project usually involves some integrated aspect of the first two projects that gives closure to the material. These have included filter characterization, development of techniques to reduce noisy signals, and related issues. The first two projects are described in detail in the next sections.

III.1 Analytical Modeling Tools for Identification of a Second Order MCK System

The students are instructed to develop generic models to address the response of a second order mass, spring, dashpot system using analytical closed form solutions by both ordinary differential equations and Laplace transformation techniques; these solutions are to be compared to the solutions obtained from both MATLAB and Simulink. The response of the simple single degree of freedom mechanical mass, spring, dashpot system due to external forces and/or initial conditions of displacement and velocity are to be evaluated.

Obviously, the students should have the ability to develop these models with no problems. However, since all the material needed to develop the theoretical solutions may be a little "rusty", the students struggle to varying degrees depending on their individual level of "rustiness". Now it is well known that students work together to develop these solutions and, in some respects, it is valuable to have students helping each other. This reinforces their ability to understand the material by taking ownership of the process. Of course, the closed form analytical solutions can be compared to the MATLAB and Simulink solutions so that the students have, in essence, "the answer at the back of the book".

Now comes the monkey wrench in the project! Each student is given his/her own individual MCK parameters and individual initial conditions of displacement and velocity. In this manner, each student has a different solution. This forces each student to "take ownership" of the solution to his/her problem. (The student can work with other students, but ultimately each must provide their own solution to their own particular system.)

The parameters of each model are very easily handled with private information of each student. The student's social security number (xxx-yy-zzzz) is used to define the mass, damping and stiffness and birth month and day are used for the initial displacement and velocity, respectively, according to Table 1. (Note that the birth month is divided by 10 to provide displacements that are reasonable. Also, note that the SS numbers are rounded up for confidentiality.)

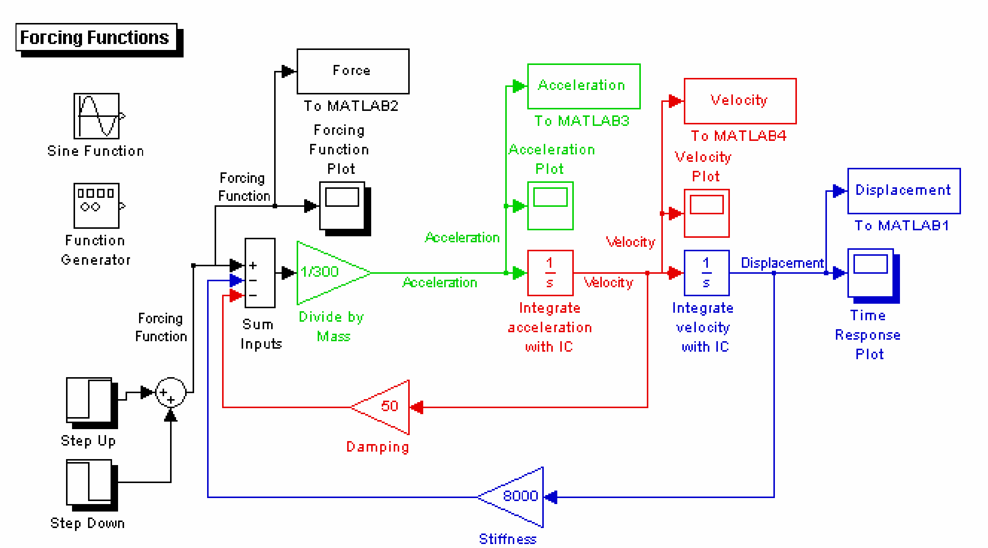
Table 1 – Parameters for Single Degree of Freedom Model

Social Security Number	***xxx***	***yy***	***zzzz***
System Characteristics	Mass	Damping	Stiffness
Birth month and birthday	***month***	***day***	
Initial displacement	month/10		
Initial velocity		day	

For example, SS 123-45-6789 with birthday of Feb 29th results in a model of

$200\ddot{x} + 50\dot{x} + 7000x = f(t)$; $x(0) = 0.2$ inch and $\dot{x}(0) = 29$ in/sec

Working individually, the students reinforce their skills in basic mathematical techniques learned in earlier courses. In addition, new skills are developed to assemble both MATLAB and Simulink models to address any type of first and second order model. The students develop Simulink models that are useful for the solution of many dynamic system responses due to various loading situations as seen in Figure 2.



Simulink model block diagram for single degree of freedom mass, spring, dashpot system with unit impulse input.

Figure 2 – Typical Generic Simulink Model Developed

III.2 Evaluation of a Single DOF System (RUBE)

The second project utilizes the analytical tools developed in the first project. The students work in groups of three or four members and address the measured response of a mechanical second order system. The students are asked to measure the displacement and acceleration response of a mass-spring-dashpot system. An overview schematic of the RUBE (Response Under Basic Excitation) mechanical system is shown in Figure 3.

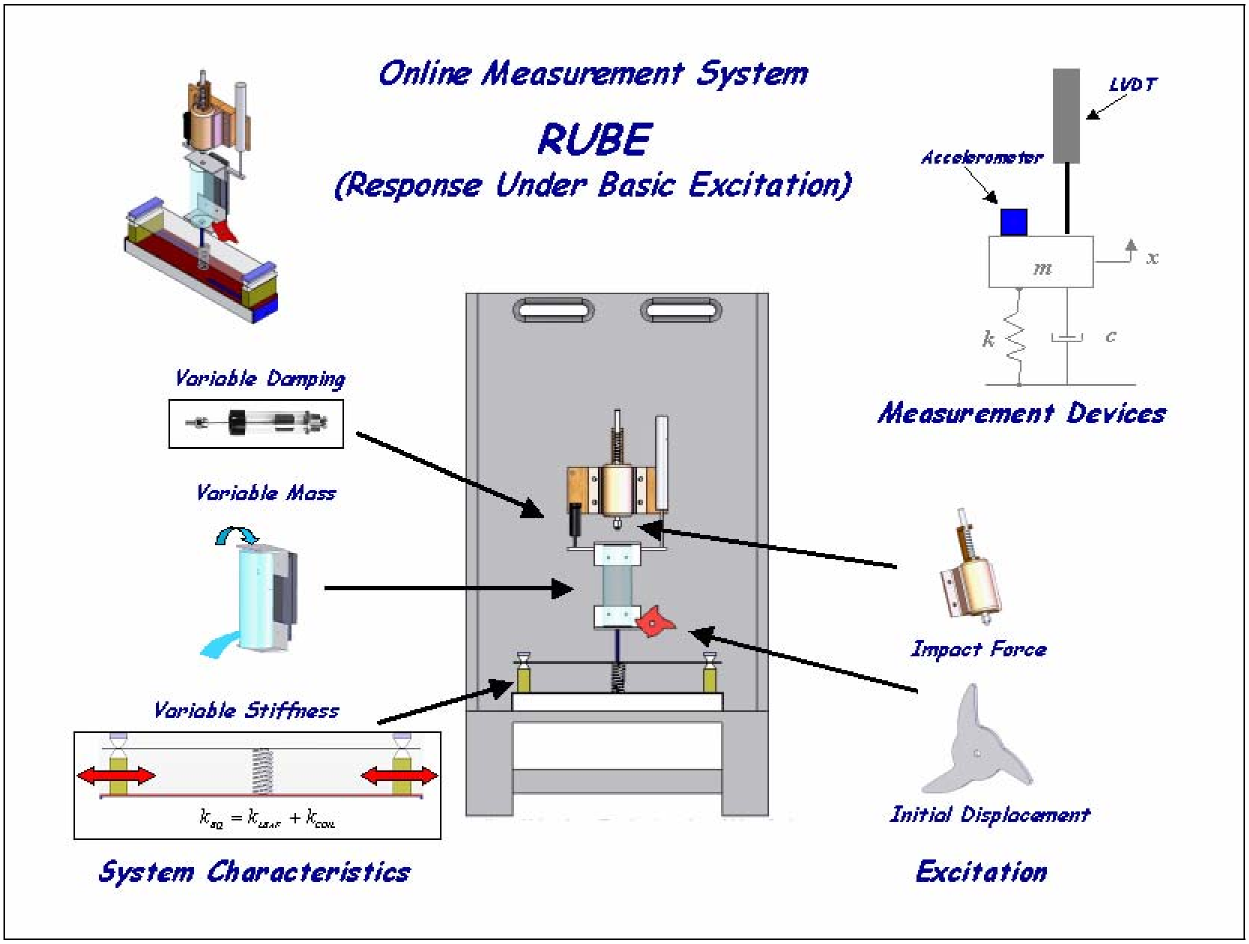


Figure 3 – RUBE Configuration

The system is available as an online experiment. Students have access to the experiment over the internet using a LabVIEW web-based Interface. A photo and sketch of the system and a screen capture of the LabVIEW interface is shown in Figure 4.

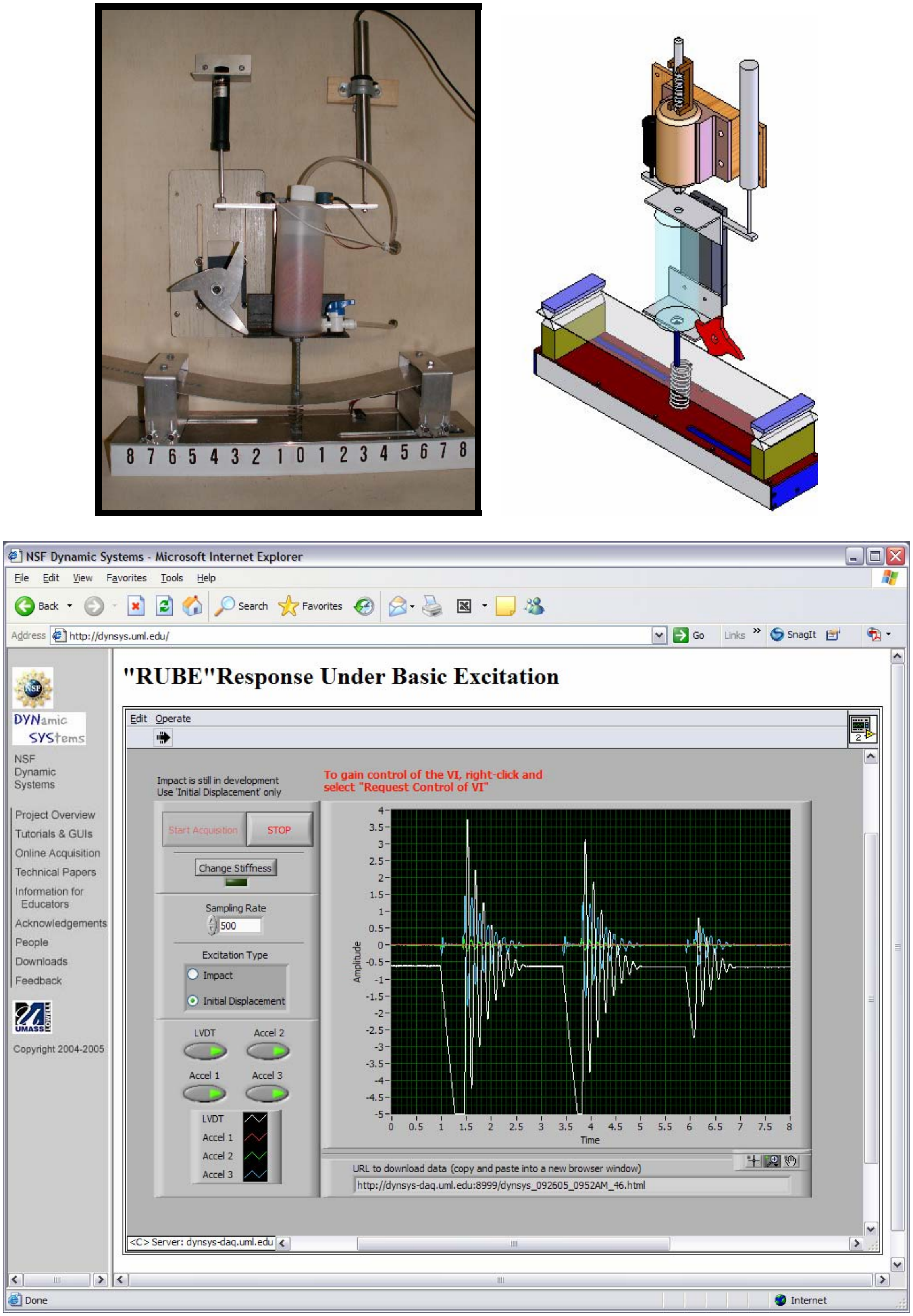
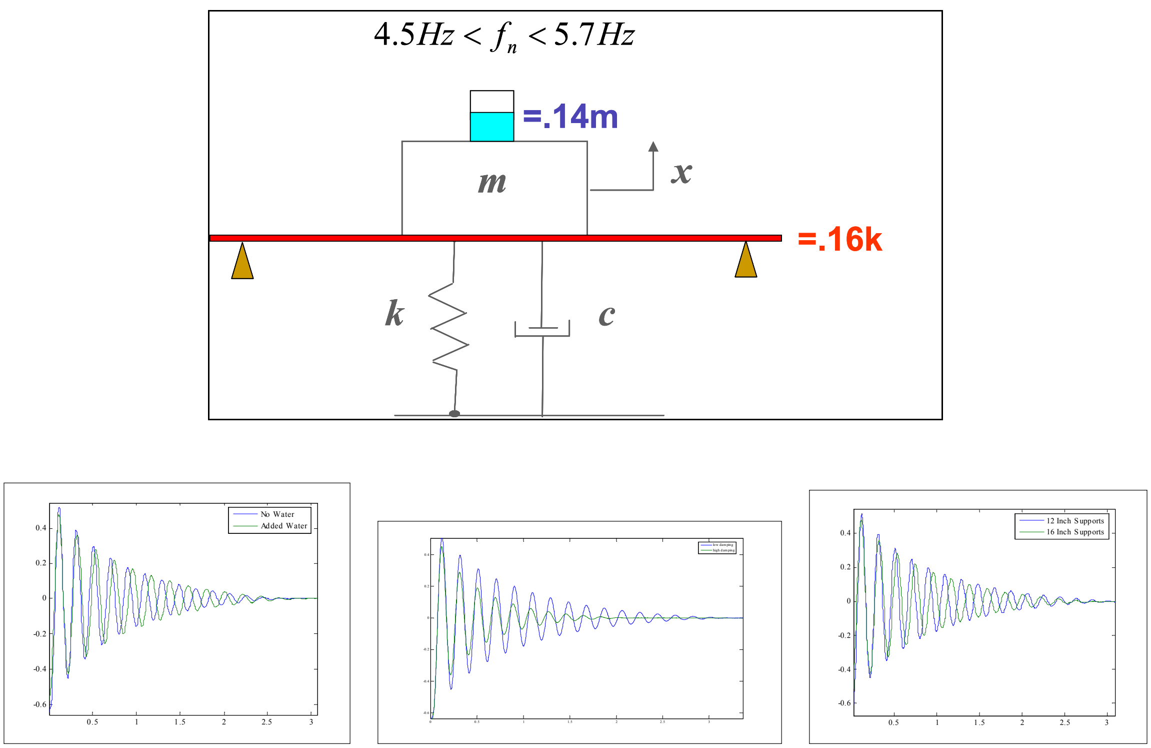


Figure 4 – Photo and Sketch of MCK System along with LabVIEW Interface

Several important features need to be mentioned regarding the RUBE system. Every time the system is accessed, the system parameters are changed. First, the mass of the system varies due to a constantly changing water level controlled by a float/pump system. In addition, the stiffness of the leaf spring support system changes each time the system is run with a variable distance between the supports. In this way, every student receives a set of data which is slightly different than any other set of data collected by other students. The excitation of the system is obtained by a variable impact force or three different input displacement initial conditions from a motor driven cam system.

The RUBE system is designed to have mass, damping, stiffness and natural frequency that have a 15 to 20% range in values due to the changing parameters of the system. In this way, the students have a different set of characteristics every time the system is run. The RUBE system is described in much more detail in References 14 and 15.

Specific information regarding the system is presented to the students in a set of documents. This forces the students to think about "what IS the actual mass, damping and stiffness of the system?" – rather than being spoon-fed the specific values. The students then work through many different scenarios to determine the best set of system characteristics to describe the overall system characteristics. An overview schematic of the system characteristics and effect on system parameters is shown in Figure 5.



(Variation in response due to the design variables are in order of mass, damping, and stiffness, respectively)
(Specific values are not intended to be read in plots – only a conceptual overview of the range of values is intended)

Figure 5 – Schematic of RUBE Range of System Parameters and Effect on Response

The students work with their data and try various approaches to describe the system based on different assumptions and starting points. For instance, they could assume the mass is known/calculated, measure the frequency and calculate the stiffness. The students often only take the minimum number of steps to find a solution. However, many forget to proceed further to check to make sure that the solution obtained is reasonable (is the assumed mass reasonable? -or- how could that little spring possibly be 40,000 lb/in?). While the results of the natural frequency may compare, the physical characteristics of the system may not be believable.

III.3 Report Evaluation

Once the teams develop their group reports, the next step is evaluation of the reports. However, instead of the professor reviewing the reports, another twist is thrown into the process. Each report is anonymously given to another team to review. Each team must give a sincere, critical evaluation of the report assigned to them. Written comments are then orally discussed with the group. This effort is multi-faceted and has numerous benefits.

The students get first-hand experience in reviewing reports and determining adequacy of the report and material presented. Since each team has just evaluated a similar set of data, they are well equipped to critique the report assigned. Since all groups may not have necessarily used identical approaches for assessment of their systems, the groups learn alternate technical mechanisms for evaluation of the systems. Each group learns from the experience of this review process. Generally, the group evaluation is very candid and EXTREMELY critical of every mistake – no matter how important each mistake may be to the overall assessment of the system. Generally, the students all start to quickly realize how hard it is to write a report, how hard it is to review a report when material is not well organized, and how deficient each of their own reports may have been.

This review process has been found to be extremely useful for the student learning process as well as a reminder of how important it is to be clear, concise, accurate and to the point in generating technical reports. This review process also serves as an aid to the professor since many errors are pointed out by the review teams in the preliminary evaluations.

IV. Professor Observations and Assessments Made

Having used this set of projects for a number of years now, several observations can be made relative to the student learning achieved. As the students work on the projects, questions arise about which they seek guidance from the professor. The questions generally tend to be well posed. Clearly, the students start to take ownership of the material as a result of this project. The project takes on a life of its own – students work the problem and try to sort out difficult and confusing issues that result from assessment of the data. Students query aspects of the problem with confidence. They rattle off equations related to the problem with true understanding – not just memorization of disjointed pieces of information. This knowledge results from an intimate understanding of the data collected and desire to solve the problem.

The project requires a substantial effort on the student's part. All the students agree that the project is a critical part of the course and they would not learn as much if the project were not included. From the student perspective, ad hoc discussions indicate that they feel that it is imperative that the first project must remain an individual effort. The reasoning is that this ensures that every student comes to the second project with all the skills and tools necessary to work on subsequent pieces of the various projects. In this way, each member of the team is assured to be able to provide equal support to the team overall. The following projects require more effort and a team effort is considered necessary by the students. But with all the skills in place resulting from the first project, each team member is guaranteed to be able to provide reasonable support to tackle the latter projects.

While ad hoc assessments are invaluable, several more formal assessments have been conducted on the overall redefinition of the Dynamic Systems class and on the newly introduced project-based assignments to supplement the course. Formal assessments have been given to the students that have taken the newly revised Dynamic Systems course. In terms of understanding Ordinary Differential Equations after completing that course, 48% felt that they had a vague understanding of the material overall and 45% felt they understood the material well. Upon completing the Dynamic Systems course (which instituted the new hands-on, laboratory-based open-ended project with a substantial review of ODE, Laplace, etc), more than 75% stated that they understood the basic ODE, Laplace, etc. well and the remaining 25% stated that they understood the material very well. When asked how well they would understand the material of the project were not included, over 45% responded that they would probably only vaguely understand how to solve a dynamic system problem. When asked if the project challenged them, 85% felt that the problem was significant and pushed them to be creative in solving the problem. Over 75% of the students felt that the physical measurement tremendously enhanced their understanding of the problem. When asked if the project should remain as part of the course, 85% felt that it is a critical part of the course and is necessary in order to firmly instill the underlying STEM concepts. To better understand the student's perspective, several student comments are included in Appendix A.

V. Summary

A new hands-on, laboratory-based project has been added as a supplement to a traditional senior level Dynamic Systems course. The students tend to better understand the material as evidenced by their improved capabilities and student comments regarding how they feel with respect to their overall understanding of the material. The hands-on, laboratory-based project helps the students to better understand the basic core STEM material necessary for solving these types of problems. The students appear to better understand the material overall through "living the material" rather than learning/memorizing equations that do not have any clear, practical relevance. Student comments on the project were overwhelming positive. The students feel that the project is a critical part of the course that helped them to better understand all the material presented in the Dynamic Systems course as well as material in related courses.

VI Acknowledgement

Some of the work presented herein was partially funded by the NSF Engineering Education Division Grant EEC-0314875 entitled "Multi-Semester Interwoven Project for Teaching Basic Core STEM Material Critical for Solving Dynamic Systems Problems". Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation The authors are grateful for the support obtained from NSF to further engineering education.

VII References

1 Higley,K.A., Marianno,C.M., "Making Engineering Education Fun", Journal of Engineering Education, Vol 90, No. 1, pp105-107, January 2001
2 Davis,B.G., "Tools for Teaching", Jossey-Bass Publishers, San Francisco, 1993, p100.
3 Piaget,J., "To Understand is to Invent", Grossman, New York, 1973.
4 Vygotsky,L., "Mind in Society: The Development of Higher Psychological Processes", Harvard University Press, MA, 1978.
5 Starrett,S., Morcos,M., "Hands-On, Minds-On Electric Power Education", Journal of Engineering Education, Vol 90, No. 1, pp93-100, January 2001
6 Felder,R., Peretti,S., "A Learning Theory-Based Approach to the Undergraduate Laboratory", ASEE Conference Proceedings, Session 2413 , June 1998
7 Pavelich,M.J., "Integrating Piaget's Principles of Intellectual Growth into the Engineering Classroom", Proceedings of the ASEE Annual Conference, pp719-722, 1984, Wash, DC
8 Dale,E., "Audio-Visual Methods in Teaching", 3rd Edition, Holt, Rinehart, and Winston, 1969
9 Wolkson,A. "Employers Demand New Skills", Machine Design, Sept 1992
10 Knight,C.V., McDonald,G.H., "Modernization of a Mechanical Engineering Laboratory using Data Acquisition with LABVIEW", ASEE Session 2266
11 Onaral,B., "A Road Less Traveled", ASEE Prism, September 1992
12 Wankat,P., Oreovicz,F., "Learning Outside the Classroom", ASEE Prism, p32, Jan 2000
13 McConnaughay,K., Welsford,I., Stabenau,E., "Inquiry, Investigation, and Integration in Undergraduate Science Curricula", Council on Undergraduate Research Quartley, pp14-18, September 1999
14 Avitabile,P., VanZandt,T., Hodgkins,J., Wirkkala,N., "An Online Acquisition System for a Second Order Mechanical System (RUBE)", Proceedings of the 2006 ASEE Annual Conference and Exposition, Chigago, Illinois, June 2006 (to be published)
15 Avitabile,P., VanZandt,T., Hodgkins,J., Wirkkala,N., "Second Order Mechanical Online Acquisition System (RUBE)", Proceedings of the 2006 ASEE Annual Conference and Exposition, Chigago, Illinois, June 2006 (to be published)

APPENDIX A - Student Observations and Candid Comments

Several student observations along with candid student assessments of the overall project validate the overall goals of the integrated hands-on, project based assignments included as part of the Dynamic Systems course. Some of these comments have been collected over several years and are included to help see the problem from the student's perspective. Student comments are contained below.

Student #1 (Junior level status during course) – "As a recent transfer to the UMASS Lowell Mechanical Engineering program, my exposure to this type of hands on project was limited. Prior to this course, the important concepts of a particular subject did not necessarily "click" in the same semester in which I was taking the course. Many times I grasped the concepts in the following class which built upon the class I had just completed; this always left me feeling a semester behind. However, my experience in this Dynamic Systems course was different. In this course, the projects not only reinforced the material covered in lecture, but also went a few steps further by forcing us to think about which variables can affect the response of the systems we studied. These variables were not always intuitive and in order to obtain the correct response, they had to be addressed. The projects did not have simple solutions and involved interpretation of data, application of concepts discussed in lecture, and understanding of the physical system in the lab. Although I often struggled through each project, after obtaining the solution I had a much firmer understanding of the behavior of each of these systems. In addition, the opportunity to review the work of my peers was extremely valuable as it provided insights into their method of solution."

Student #2 (Junior level status during course) - "I almost always learn more completely when I do something as opposed to when someone instructs me. I believe relevant hands-on experience is much more effective than theory by itself. Struggling with a project makes me think harder and pursue other possible approaches to solving the problem. Project work forces me to learn the material to complete the assignment. This is not necessarily the case with homework problems taken from a book. When pressed for time, it is easy to copy the steps from examples and finish the assignment without understanding the problems. As a student, the ultimate goal is to learn the material so I can apply it once I graduate. These projects helped me understand the characteristics of a system and methods used to characterize dynamic systems. The group dynamics in project work are beneficial, as well. When members of our group disagreed, we were forced to dig deeper into what we were doing to find out who was right."

Student #3 (Senior level status during course) - "This class has taken an approach to material presentation that is unlike any previous class. The theory and materials are presented in the class periods, and are driven home during project preparation. The projects have forced the students to indeed "think outside the box". This course curriculum has undoubtedly tied many ideas and previously learned material together. As a student that learns through hands on experience, as most students in this field are, I can say with conviction that due to the lab work associated with this class, I now understand the practical application of differential equations. As a part time student, it is common for there to be several semesters, sometimes years, separating Dynamic Systems from Differential Equations from Mechanical Engineering Laboratory. I have needed to spend time reviewing past material and I am now seeing this material in a new light. It is very fortunate that a class such as this is offered."

Student #4 (Senior level status during course) - "Admittedly, the Dynamic System course required more work and time than many other courses I had taken before it. However, the hands-on approach and struggling through the projects is exactly the process by which the information was absorbed – by not only learning, but really understanding. Very few engineering courses are successful at integrating information from previous semesters into a logical path to a problem solution. Granted, many of the previously covered skills had to be reviewed, and possibly relearned in some instances. However, after having used these skills in solving more realistic engineering problems, hopefully relearning will not be needed in the future. The only other courses that have left me feeling as in control of the information learned were the Mechanical Engineering Laboratories, in which use of transducers and measurement equipment became second nature. Understandably, this is for the same reasons as the Dynamic Systems course. Logical assumptions, trial and error, and asking one's self 'does this make sense' seem to be instinctive on the surface, however accepting that these are essential parts of engineering solutions and knowing how to use them wisely can only be developed in this type of realistic project setting. Likewise, working in groups of varying levels of understanding is required of professional engineers. One benefit of this course was that I learned that group members bring different qualities to the table. For example, while one member may not claim differential equations as a strong suit, that same member will notice the simplest, yet not the most obvious, method to determining the spring stiffness. This aspect of different points of view is also beneficial in the peer review process. Sometimes students find one solution to the problem and believe that it is the only solution. However, the during the peer reviews you find yourself thinking 'why didn't I think of that?'. In all, the time consumption and hard work paid off in not only learning the required information, but in understanding the engineering problem solving process much better."

Student #5 (Senior level status during course) - "With regards to previous course material (such as differential equations), it was very helpful to actually be forced to use earlier course material - I had to find my differential equations notebook and review some material before completing the first project. I feel that differential equations in particular is taught and then never used again, so that its significance is not clear until needed in this Dynamic Systems course."

"The development of both Matlab and Simulink to confirm analytical results was very useful. While the professor 'strongly suggested' that it would be helpful to use these models to study variation of parameters and types of inputs, I feel that it would have been helpful to have homework assignments requiring this to be performed; as all the students are very busy, it is easy to 'put off' this important but 'not required' task."

"In terms of laboratory work requiring collection of data, this definitely helped me understand that these problems are not as simple as they might seem! In homework assignments, specific physical values are assigned to problems but when we actually have to find these values ourselves based on physical measurements of the system, and compare analytical models to measured results, we have a greater understanding of how imprecise this can be. For example, all of the calculations performed assume viscous damping, and in the mass-spring-dashpot system part of the damping is actually friction. We don't have a clear understanding of the error that can be caused by this assumption until we actually see the results. We also become aware that there are multiple ways to determine the system characteristics of a physical system, and the importance of using multiple methods and comparing the results. Problems that seem easy when you do the homework at the end of a chapter in the text actually turn out to be much more complicated in practice – you are forced to really think about the material and how it all fits together"

"The peer review of other group project reports actually was quite enlightening. This should be done about three years earlier in our curriculum! I definitely think that more time should be spent on technical report writing. It was helpful to look for mistakes in other students' papers to understand the importance of clear writing, as well as to see other ways of approaching the problem solution. I do think that it would have been useful to actually read the comments written by the group that reviewed our paper. This would 'close the loop' on the review process."

Peter Avitabile is an Associate Professor in the Mechanical Engineering Department and the Director of the Modal Analysis and Controls Laboratory at the University of Massachusetts Lowell. He has 30 years experience in design/analysis and modeling/testing dynamic/structural systems. He is a Registered Professional Engineer with a BS, MS and Doctorate in Mechanical Engineering. He is also a member of ASEE, ASME, IES and SEM.

Tracy Van Zandt, Nels Wirkkala and Jeff Hodgkins are Graduate Students in the Mechanical Engineering Department at the University of Massachusetts. They are currently working for their Master's Degrees in the Modal Analysis and Controls Laboratory while concurrently working on an NSF Engineering Education Grant directed towards integrating STEM material critical for understanding dynamic systems response.