2006-324: A PRELIMINARY ASSESSMENT OF AN MSC.ADAMS CONTROL DESIGN PROJECT IN UNDERGRADUATE MECHANICAL ENGINEERING

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ABSTRACT

The required undergraduate controls sequence at the University of Texas El Paso consists of a lecture and laboratory. To supplement the hardware laboratory a design project was assigned. The project used simulation software to visually model the hardware. This format differed from traditional projects that use software such as Simulink because the students could see the hardware moving on their computer screens not just a "scope" output. The anticipated benefits of the project are:

- Reduced hardware maintenance costs – the students cannot damage the equipment.
- Enhanced learning experience – the visual simulator can be programmed to exclude or include complicating factors (friction and saturation) as required for the learning experience.
- Enhanced safety – the students cannot be injured by a controller malfunction.

This paper describes a control design project that uses an MSC.ADAMS simulation of a mechanical device. The students must design and implement a controller for the device then test the response. Students can see the simulated device moving on the computer screen and more easily relate scope output signals to the device's motion. Student attitudes about the activity were assessed to ascertain whether the visual nature of the project helps them better understand the control design process and if the design they perform helps make the theory more understandable. The hypothesis was that a "visual" model that students see being controlled will enable them to explain why theoretical design processes covered in lecture are important.

Introduction

Several faculty at the University of Texas El Paso (UTEP) have adopted the goal to produce MORE BS level graduates who are BETTER qualified at a FASTER rate than ever before. This is not to say UTEP graduates are low quality because they are not. UTEP engineering graduates can be found in the best graduate schools, at high levels in major corporations and national laboratories. The MBF goal is a means to drive the curriculum to higher levels of expectation. This paper discusses one component of the MBF strategy, the implementation of an integrated project supporting a required "lecture" course on controls.

The format for the controls sequence is a "lecture" portion plus a lab. The lab may be taken concurrently with the lecture or afterward. Approximately 10% of the students take the lab after completing the lecture. Since the lecture/lab can be taken separately, there is more flexibility in helping students arrange their studies around their work schedules, which is good, but it creates a problem trying to coordinate the subject matter in the two courses.

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Many of the UTEP faculty believe hands on experience is one component of an excellent curriculum. Ohland et. al. [1] makes a good case for this position and the author does not argue with the point. As far as control labs are concerned there continues to be excellent discussion on implementing technology with hardware [2]. This paper has a different focus and that is to use graphical simulations of mechanical devices to provide a rich design problem yet be financially feasible. The argument presented in this paper is that unlike hardware which can be (a) easily broken by a novice, (b) so underpowered as to provide little interesting challenges or (c) dangerously powerful; a visual simulation can provide a rich learning environment. Fortunately, UTEP has recently been admitted as a PACE partner [3] and one important benefit to this partnership is that UTEP students and faculty have a virtually limitless supply of certain types of real world engineering software. MSC.Adams is one of the software packages that is available. The basic idea described in this paper is to use simulation in the lecture to allow students to do a real design on what appears to be a realistic system then use simpler devices in the laboratory where students will learn to interface the hardware but not actually perform control design.

The use of simulation has been explored in a number of publications including the 2005 ASEE conference. In particular, see Yedidi et. al. [4] who apply technology to the distance delivery of lab assignments. This paper differs because it describes the implementation of technology in the lecture component of the class; this is similar to the idea of Li and Rajab [5]. The idea is to separate, or decouple, the issue of learning to design controllers from learning to implement controllers. The former, the author believes, is best done using a non-laboratory class, and the latter is best done in a lab. By separating the material, the course instructor (which is often different than the lab instructor) has better control on the pace of the material, and can integrate the experience in with the "textbook" topics. The laboratory equipment can also be much simpler because the students are learning to interface sensors and actuators in the lab and therefore the power and bandwidths of the lab devices need not be the most powerful and expensive.

The author proposes that there are several advantages to this decoupling. If lower power equipment is used in the laboratory, there is less danger of a student being injured. If the hardware need not perform (because the students are only being taught to interface) then the equipment will be less expensive. The advantages of using simulation in the classroom include that the project can be easily changed to include or exclude complicating factors like nonlinearities, saturation and time delay. Finally, since students always talk to each other, so using simulations in the classroom will allow the instructor to change the project at will.

The use of computer software in the design and analysis of control systems is too common to write about. However when teaching Mechanical Engineering students, experience shows that the students do not relate to the use of "scope" outputs. The students desire to see things move and shake. The author believes that this is one of the unique aspects of the work being reported, the students can see the system moving. The simulation shows a detailed three dimensional solid model moving in response to the control inputs and sensors provide simulated positions and velocities of the device.

As you will see, the main student criticism of the use of this technology in the classroom is that they still want to touch the real equipment. It appears to be critical to keep the lab exercises so the students can touch and feel but the classroom project performed with simulation may still help make the lessons understandable.

Learning Objectives

Like most Mechanical Engineering Curricula, the education of UTEP graduates includes[2] Fluids, Energy (Heat) Transfer, Dynamics, Vibration and Design. In a very real sense, the controls class serves as a "mini" capstone course. Projects in the class can require the students to exercise the knowledge they have gained in all these subjects.

According to the most recent ABET report, the concepts covered in the prerequisite course are:

1. Free vibration, harmonic motion, viscous damping, modeling and energy methods, stiffness, measurement, and stability.
2. Harmonic excitation of undamped and damped systems, alternative representations, base excitation, rotating unbalance, and measurement.
3. Impulse response function, response to an arbitrary input, response to an arbitrary periodic input, transfer methods, shock spectrum, and stability.
4. Two-degree-of-freedom undamped model, eigenvalues and natural frequencies, modal analysis, more than two degree of freedom, systems with viscous damping, and modal analysis of the force response.
5. Design for vibration suppression; acceptable levels of vibration, vibration isolation, vibration absorbers, and damping in vibration absorption.
6. Distributed-parameter systems; vibration of a string or cable, modes and natural frequencies, vibrations of rods and bars, torsional vibration, bending vibration of a beam, and modal analysis and the forced response.

The catalog description for the controls class is [6]:

> "A study of classical control theory including transfer functions, stability and time response, error analysis and sensitivity functions, root locus, Nyquist diagrams, and Bode Plots; the analog computer as a simulation tool particularly as pertains to non-linear control systems. Also, an introduction to modern control theory is presented."

With the entrance expectations established by the formal prerequisite material and with the generic catalog description of the course, learning objectives were established. The author used Bloom's Taxonomy [7] to establish the objectives. There are many excellent references for the taxonomy; one the author especially likes was written by Allen [8]. The result of the class design is shown in Table 1. The symbol E in the table represents Entrance expectations, C represents what is expected from Class materials, and P represents what is expected from the Project (the subject of this paper).

Note that the course follows several standard major subject matter headings:

1. Modeling – finding mathematical methods for describing and predicting the system. Basically this includes deriving differential equations and transfer functions. Some of the components of modeling include linearization and handling time delays.
2. Measurement – some of the unique concepts covered under measurement include making frequency response measurements and using the measurements to identify transfer

[2] Obviously this is not a complete list of topics but it addresses those important to the topic of this paper.

functions. Since control involves signals, the concept of measurement noise is introduced, especially in the context of differentiating signals.

3. Analysis – identifying when systems are stable, the idea of a steady state error and time response analyses.
4. Design – the primary method used to design controllers in this class is the root locus method.
5. Evaluation – one of the more difficult concepts for students is to evaluate their controllers. Students do well producing a controller with a specific performance measure such as a given time constant. What they find difficult is to use a combination of conflicting performance measures to evaluate which controller is better than another. For example specifying a controller that has a small steady state error and a good time constant with a reasonable control effort drives them crazy.
6. Process thinking – throughout the course, students are taught to approach control design through an iterative process of model, simplify, analyze, design, simulate, build.

Note that the project is expected to push the students beyond the class in only two areas, in the evaluation of controllers and in the recognition of procedural process thinking. In other areas the project essentially shadows the "lecture" material.

Project Description

The particular project that is assessed in the next section required the students to design and implement a control for a rigid pendulum. The students were provided with an MSC.Adams model of a pendulum. Since this was the first time using MSC.Adams in the classroom, the model had no complicating effects such as friction or saturation. Since the project went well the first time it will include saturation in future terms. The control outputs consisted of position and velocity, the control input was a torque proportional to voltage. The MSC.Adams model showed a three dimensional solid image of a pendulum that moved on the screen in response to the applied torque and gravity.

The MSC.Adams model is coupled to Simulink and the students build their controller using Simulink. When the Simulink program is executed it (a) measures the Adams model position/velocity, (b) computes the control output (the torque) (c) communicates the torque to Adams. The Adams model (a) receives the torque signal, (b) computes the pendulum's response to the applied torque, (c) updates the graphic image of the pendulum and (d) sends position and velocity information to the Simulink program. The cycle continues for the length of the simulation. The students can see the pendulum responding to their control. Since Adams is a high fidelity modeling software, it can easily incorporate friction, air resistance, impact and countless over complicating factors. Since this was the first attempt using Adams in the classroom, the Adams model was kept simple.

The project was assigned on the first class day and at the end of each class period, students were asked to list all the activities covered during the class that could/should be applied to their project design. For example, within the first two weeks, the students could derive the equations of motion, linearize them and derive the transfer function. Students were encouraged to keep up with the project by discussing what could be done on the project, plus it gave some perspective for why the material was covered in class.

The purpose of the MSC.Adams model was to solve the pendulum dynamics and show its response in the form of a solid model. The purposes of using Simulink were to provide a convenient method of designing the controller and for computing performance parameters such as steady state errors and time constants. A description of this process can be found in [9].

Assessment

The assessment tool was a student attitude survey conducted at the end of the project. The 31 students in the class all participated and they left many comments. This section gives the results of the numerical ratings and some of the student comments. The students typed their own responses and these are quoted literally, typographical errors and all.

Table 1 - Levels of Learning for the Controls Class.

	Knowledge	Comprehension	Application	Analysis	Synthesis	Evaluation
Modeling						
Differential Equations			E	P	C	
Transfer Function		E		CP		
Linearization		E	CP			
Time Delay	E	C				
Measurement						
Identification	E			C		
Frequency Response			E	C		
Noise		E	CP			
Analysis						
Stability		E		C		
Error	E			CP		
Time response			E	C		
Design						
Root Locus	E				CP	
Evaluation						
Performance measures		E		C		P
Knowledge of a process			E	C		P

In the remainder of the section, the questions posed to the students and their numerical ratings are given in Table 2 through Table 8. In a box below each table are student comments with author comments in between. In the tables note that SA is strongly agree, A is agree, N is neutral, D is disagree and SD is strongly disagree. Categories not shown in the table had no responses. Throughout you should note that the results are highly biased to the positive. Since it is not difficult for students to "anticipate" the "correct" answer these numerical results are a bit questionable.

Table 2

	Number	Percent	Question
SA	14	45%	"Graphical simulations help you relate controls to `something real.' Please explain how."
A	15	48%	
N	1	3%	
NO Response	1	3%	
	31	100%	

Some of the more interesting comments include the following:

> "That is true however you never know whether if that is going to happen in reality"

This seems to suggest the student doesn't necessarily believe that what the simulation shows is close to reality. Actually this is a good attitude of skepticism. An example of the more common response is:

> "When the pendulum project, the Adams simulation was very helpful to see how the pendulum behaves with the controller, and it gives a better understanding what you meant with time constant of the transfer function."

Here the student articulates what was expected; that is, seeing time response plots of a time constant does not help as much as seeing how quickly the device snaps into place.

Table 3

	Number	Percent	Question
SA	13	42%	"Admittedly, a real hardware device with a motor and sensor would be the best laboratory, but the graphical simulations help you understand how the theory applies to something real."
A	15	48%	
N	2	6%	
NO Response	1	3%	
	31	100%	

Again the results (see Table 3) indicate a very positive response to the statement. The MSC.Adams model was rather crude looking without chamfers or "cool" looking pivot point. The students were polled to see if this impacted their study.

Table 4

	Number	Percent	Question
SA	7	23%	"The graphical model of the pendulum was very crude. It would help you understand the material if the simulation looked more realistic. Please explain"
A	4	13%	
N	13	42%	
D	6	19%	
NO Resp.	1	3%	

It is interesting to note that the students did not necessarily believe the visual model needed to look too fancy. Some of the more interesting comments include:

> "I agree that something more realistic looking can give you a better idea of the design project. All we had to go on was a swinging pendulum but there was no real insight on to how an attached motor actually applies a torque to give ant output of the pendulum doing what u want."

This student has a good point and shows why the laboratory component is critical. The student basically wants to see how the hinge is held, how the motor is attached etc. Another student commented:

> "Although you could argue that the ADAMS simulation software used for this project is the high end hardware for real world working conditions of controllers and constructs, there could have been further use of other programs in order to develop the construct in this case the pendulum further. For example you could have built a model in solidworks of the pendulum that would allow you to apply it's basic design to something more realistic and not just a simply pendulum with a motor. For example this could have been use int he setting of a grandfather clock or in some other type of construct, like a crane arm or a digger arm. This similation having been developed in a program that made it look more realistic or with a real worl application could have further peaked interest in the development of the project."

This is another good point, that if the students see the model in the context of a complete device, the effect would be better. It seems the student has difficulty making the abstraction. Another interesting point is:

> "I went online in order to see a realistic (student built) pendulum in order to determine how I wanted my pendulum to behave. If the simulation looked more realistic, we could even add more variable to the pendulum and compare it to one that was already built."

Here it seems the student is asking for more ability to modify the actual pendulum itself. It sounds like he/she is in favor of using the model to explore the effects of changing values. This is certainly something to consider next time.

Table 5

	Number	Percent	Question
SA	11	35%	"A graphical simulation helps you better understand plots that come from a "scope."
A	16	52%	
N	1	3%	
NO Resp.	3	10%	

The author expected that Mechanical Engineering students would rather see motion than see scope output so the following statement was made and the student results in Table 5 confirms this.

The way the class and project was designed was to assign the project early and "teach" the required project material throughout the term. The student response to this was tested. The following statement meant to capture how the students felt about this idea. See Table 6 for the results.

Table 6

	Number	Percent	Question
Yes	26	84%	"Does a unified project that requires knowledge from the textbook help you understand why the theory from the book is important in a real application? Please explain."
Somewhat	4	13%	
No	0	0%	
NO Resp.	1	3%	
	31	100%	

One student got the point exactly:

> "The textbook helps you understanding several concepts on to achieve that project. Because when you try to solve your project, you may come up with questions that you are not able to anwser without the consulting the textbook. You may encounter problems that the textbook states, and it shows you how to solve it, as well as undestand the reason why that problem occurred."

And another student commented:

> "Yes theory provided by the book can help to explain real application so you understand why the project does what it does. Altough I would like to add that sometimes theory can create more questions about the project the previously intened."

Of course the second student got it right too, but perhaps did not realize it. The reason for integrating the project throughout the semester was to create the cognitive discord and force the students to go back and forth between theory and practice.

The students were also asked for information to help assess the idea that controls can be a mini-capstone course. Based on the student responses shown in Table 7, it is safe to say the project helps the students pull together information from previous classes, which is one objective of a capstone course.

Table 7

	Number	Percent	Question
SA	10	32%	
A	17	55%	"The controls project helps you relate material you learned in previous courses to a real world application."
N	3	10%	
NO Response	1	3%	

Finally the students were asked about how the project impacted their interest in the subject. The results of this are shown in Table 8. Of course one should be careful since the statement is probably leading. Most students would anticipate the "desired" response and may be giving it. Based on assessment results from previous statements it is probably safe to say the students generally believe the project experience makes the class more interesting, which one hopes, makes them study a little harder.

Table 8

	Number	Percent	Question
Yes	22	71%	
somewhat	6	19%	"Does a graphical simulation make the in-class material more interesting? What could be done to make it more interesting? Please explain."
No	2	6%	
NO Response	1	3%	
	31	100%	

Some of the comments given include:

> "Actually if we would build the pendulum, and make the class more hands on, I feel that the class would be awesome and we would learn at a faster pace due to the demands of the project and willingness to build the model."

This is of course what the laboratory component should provide and not the class material. Another student had similar comments:

> "The material covered in class was interesting. Maybe adding some little projects instead of having a final project would be helpful and more attractive to the students while they will learn more. The Controls lab helps out a lot in visualizing and having a better idea of the use of the controls. Maybe if the lab can be taken along with the class would be helpful."

There is an obvious misconnect between the material in the laboratory and the class projects. This is an area for certain improvement. In fact there seems to be some evidence that students feel they would benefit by taking the class and lab concurrently.

In addition to responding to statements the students were asked to comment on several questions. One such question was: **"Has your attitude toward or appreciation for theory changed due to the design project? Please explain how."** Some of the more interesting comments include:

> "Actually, it has. I not only gained a better appreciation for the theory of time domain analysis and the transfer function (I got a tangible feel as to what the transfer function REALLY represented), but I also got to understand the dreaded root locus and learned to appreciate its usefulness! I would not have been able to do that without the project. Theory is good. But many cannot appreciate theory unless they know where the theory is being applied. Until an appreciation is created, there will be little hope for reconciling theory and the common student."

> "No, I have always taken into account that theory is the basis for which everything is taught, and learned. I understood that the theory we learned in class would actually need to be applied elsewhere, but how to apply was the key in understanding the theory and applting it, it gave more a sense of appreciation in that you can actually apply this theory to cars, jets, and everday applications."

The most common response to the question was affirmative.

Conclusions

This paper presented a case in which a class and its associated laboratory were in a sense decoupled from each other. This decision was made several years ago to facilitate scheduling a larger number of students taking a lab and a class. Allowing students to take a laboratory after taking the lecture class has resulted in approximately 10% of any given class choosing to take the laboratory after the class. To regain the integrity of a concurrent lab, a semester project was introduced in the class period. For the most part, the project seems to help in the class but assessment results are mixed but tend to show that the students still want (and probably need) the hands on component of a laboratory. Once the materials are decoupled however and the project is used in the class, it may indeed be possible to dedicate the laboratory to issues of interfacing sensors and actuators rather than trying to teach control design and/or analysis principles.

Based on the tentative assessment results, it appears that the control class has benefited from the use of a semester long project integrated into the class "lecture" materials. The integration causes students to test theory throughout the semester and toggle back and forth between in-class theory and project practice. This toggling should deepen the learning experience, although this statement has not been assessed to date.

Assessment results indicate that Mechanical Engineering students appreciate the visual aspects of the simulation. They comment that time response plots provide less intuitive feeling than watching an animation of a device moving on the screen. The students, for the most part, agree that the simulation need not be elaborately drawn though they do suggest making the animation part of a larger whole device or system.

Based on student comments, it appears that the controls class can pull together materials from several previous courses. In essence the controls class can serve as a "mini" capstone course.

The paper presented a table of cognitive outcomes for the controls course. It is the author's opinion that the students did relatively well on all of the objectives except trying to evaluate control performance and on the student's ability to evaluate a design process. This assessment is based on student performance on the project. For the most part, the students were unable to argue why their controller was "better" than any other. This may demonstrate an inability to discern what is good and what is bad. In control systems, there are often many competing constraints that cannot all be satisfied. This requires a designer to evaluate and assess each controller in some manner to enable selecting a good control design. It may be too difficult a step for the students to make. Expecting students to achieve evaluation levels of understanding control performance may be unrealistic. Also based on student comments about the design process they used to complete the project and their comments about how the process could be applied to other problems other than controls they are not demonstrating an evaluative level of the design process and therefore it may not be reasonable to expect that level of performance from the class. The student comments regarding the design process were not given in the paper because they were typically quite bizarre with few, if any, commonality.

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