USING HARDWARE-BASED PROGRAMMING EXPERIENCES TO ENHANCE STUDENT LEARNING IN A JUNIOR-LEVEL SYSTEMS MODELING COURSE

Johné M. Parker[a], Stephen L. Canfield[b], Sheikh K. Ghafoor[c] and Kassy M. Lum[a]
[a] – Department of Mechanical Engineering, University of Kentucky
[b] – Department of Mechanical Engineering, Tennessee Technological University
[c] – Department of Computer Science, Tennessee Technological University

Abstract

This paper describes a hands-on enhancement for a junior-level Mechanical Engineering Systems Modeling lecture course. A primary outcome of the course is to prepare students to construct, understand and analyze linear time-invariant models for physical systems. Many of the core concepts introduced in class to achieve this outcome are considered rather abstract by a significant percentage of students and there are often considerable disconnects in their abilities to link theoretical course concepts, computational solution techniques and the behavior of real-world systems. We hypothesize in this paper that part of the difficulty is that the course is lecture-based, and that the inclusion of hands-on activities will improve student learning. This hypothesis is supported by a model which uses hardware to integrate programming experiences throughout the curriculum; in the model, the learning principles deemed critical for success are student engagement, knowledge transfer and self-directed learning. We posit in this paper that the introduction of hands-on activities involving hardware will enhance all three learning principles, resolve many of the disconnects and improve overall student learning.

The specific hands-on activity discussed in this paper links the free response of an underdamped second-order system to the damping ratio and natural frequency parameters that characterize the system model. Secondarily, it introduces data acquisition via micro-controller hardware, thus integrating the behavior of real systems and the role of data acquisition with analytical techniques discussed during lectures. The instructor had previously taught the course several times, so a well-paced course schedule and solid foundation of course notes were already in place before the introduction of the hands-on activity. Additionally, hybrid and problem-based learning (PBL) techniques were incorporated to enhance student engagement, allow sufficient time to introduce the hands-on activity without sacrificing course content, and enable the instructor / research assistant / teaching assistant team to give necessary assistance and feedback during the activity.

The hands-on programming toolkit developed by Canfield and Abdelrahman at Tennessee Technological University (TTU) for direct programming of micro-controller units (MCUs) was used to acquire the free-response data in the Modelling Course at the University of Kentucky (UK). This toolkit has also been used to teach programming skills to first- and second-year engineering students. In the junior-level Systems course, the overall goal is to enable students to validate the analytical modeling and solution of a second-order system on real-world hardware without being hampered by significant obstacles or requirements for implementation. The MATLAB-to-MCU toolbox effectively addresses this challenge by allowing students to acquire data and verify system models using MATLAB, a language they concurrently use to simulate system response, “directly” on the micro-controllers with little additional overhead requirements.

An evaluation of the initial implementation of the hands-on activity is discussed and compared to the traditional (lecture-based) format. The paper concludes with a discussion of the effectiveness of the hands-on activity in enhancing student learning, the efficacy of the

toolkit in upper-level courses, suggestions for improvement and plans for future work.

Motivation and Related Work

Systems and Control Courses in Mechanical Engineering expose students to core course concepts in which the relationships between the mathematical underpinnings, practical design procedures and subsequent implementation are considered abstract for a considerable percentage of students; thus, there are often considerable disconnects between theoretical course concepts, computational solution techniques and relevance in real-world systems. A hands-on programming model and toolkit developed by Canfield and Abdelrahman [1] was used to mitigate student disconnects in this paper.

Related discipline-based education research (DBER) [2] has identified three key insights regarding STEM education challenges that might address these disconnects:

- student-centered learning strategies (including team-based learning) can enhance learning more than traditional lectures,
- students often have incorrect understandings about fundamental concepts, and
- students are challenged by important aspects of the domain that can seem obvious to experts.

We focus on all three areas in this investigation by implementing team-based learning strategies and implementing a hands-on hardware activity to correct misunderstandings with regard to fundamental concepts. Improving students' abilities to understand the value and role of programming and data acquisition to empirically determine a second-order system model is a key secondary objective of this study. Similarly, students experience significant disconnects between programming constructs and effective application in an engineering context in latter courses. The three principles deemed critical for successful programming in engineering contexts [3,4] are

1. Student Engagement: Engaging students' current knowledge to construct new knowledge.
2. Knowledge Transfer: Students' ability to transfer early programming skills to new contexts, applications and environments.
3. Self-directed learning: Students assuming control of their learning in programming to adapt to the rapidly evolving demands of computational techniques in engineering

Therefore, Systems and Controls courses are ideal to investigate effective ways to address all three areas of the DBER study and simultaneously augment students' ability to use programming as a tool in upper-level courses. The primary objective for this paper is to increase students' competency and understanding of fundamental Systems Modeling course concepts; secondly, we hope to simultaneously demonstrate to students that the experimental determination of a second-order transfer function is a specific application of programming concepts learned earlier in the curriculum (e.g., in CS 215 or CS 221).

Undergraduate education is undergoing a revolution fueled by both student preferences and DBER [2,5,6]. Much engineering research addresses student preferences by focusing on teaching and learning styles in STEM education and/or on the best practices in and benefits of team-based learning [7-11]. Scaffolding [12] was suggested as a strategy to help students through difficulties with important aspects of the domain that seem easy or obvious to "experts" like the instructor. Key scaffolding strategies include breaking a large task into smaller parts, working in peer groups and prompting [13-16]; as students gain confidence and competency in a topic, the instructor removes the scaffolding. The efficacy of scaffolding combined with team-based learning principles is investigated in several studies [9-11, 16, 17].

Employing the use of computing tools (such as spreadsheets, MATLAB or MathCAD) to illustrate key course concepts is suggested as an alternative to using high-level programming languages [18-20] (e.g., C or FORTRAN, for Mechanical Engineering). The proposed activity and hardware setup utilize a MATLAB-to-MCU framework.

Proposed Activities and Hardware Setup

The primary objective of this study is to assess the effectiveness of the proposed analytical and hardware activities described in Table 1 to enhance student learning and correct misconceptions regarding fundamental concepts in a junior-level Systems course. The proposed development toolbox [1] allows students to write and modify programs in MATLAB m-files, which are cross-compiled and loaded using a single MATLAB command at the prompt; this is an environment with which students are already familiar; e.g., MCU-specific functions are contained in a MCU toolbox similar to the other MATLAB toolboxes that students use in this course and for related analytical and numerical activities. Course notes, short Echo360 vodcasts, supplementary material and key links were available online on Blackboard; also, Piazza [21-23], an online threaded discussion forum, allowed students to post/answer questions (anonymously, if desired) and facilitated follow-up discussions about course content and PollEverywhere [24] was used to assess students' understanding of core concepts during class. In addition to online resources on Blackboard and Piazza, a hybrid team-based learning structure implemented in previous courses [25, 26] was implemented in this offering of the course to both address the concerns [2] detailed in the DBER study and allow sufficient time to effectively implement the activities proposed in Table 1.

System for Initial Implementation

The first set of demonstration activities (Table 1) were implemented at the University of Kentucky (UK) using a pendulum designed and constructed at TTU [27]; the pendulum was designed to facilitate easy modification of the mass moment of inertia, J, and rod length, L. Similar to spring-mass-damper systems, pendulum schematics and system models are both familiar to students and fairly easy to construct such that the second-order model well approximates actual system behavior. Additionally, pendulums provide an opportunity to examine the importance and validity of simplifying assumptions (e.g., linearization / small angle, neglecting the mass moment inertia of the rod, the effect of out-of-plane oscillation, etc.) and provide a good foundation for demonstrations utilizing more advanced system models.

Proposed Activities

The hands-on demonstration activity (e.g., Activity 2b in Table 1) was preceded by analytical/numerical assignments investigating similar system schematics (e.g., Activities 1, 1b and 2) to more effectively link demonstration activities to course concepts.

Activities 1, 1b: Analytical analysis of system model and solution (Chapters 5 and 7):

Students first obtain system models of similar mechanical rotational systems using free-body diagrams, and assuming lumped parameters and linear element laws to obtain the system model (i.e., a linear ordinary differential equation) for a one degree-of-freedom system (note: this activity is identical to initial HW assignments in previous offerings). In Activity 1b, students manually solve similar linear (linearized) ordinary differential equations to determine the time response using Laplace transforms and partial fraction expansion (or the equivalent), for both overdamped and underdamped scenarios.

Table 1: Proposed Activities for Initial Assessment.

Chapter[30]	**Topic**	**Proposed Activity (Objectives)**
5 7	Rotational Mechanical Systems (Obtaining the System Model) Transform Solutions of Linear Models	Activity 1: Analytical Determination of System Model; *Activity 1b: Analytical Investigation of Second-Order Linear Models for Varying System Constants, explicitly (via Partial Fraction Expansion by hand and via MATLAB)*
8	Transfer Function Analysis	Activity 2: Analytical Investigation of System Transient and Steady-state Responses using System Parameters ζ and ω_n; *Activity 2b: Experimental Determination of Transfer Function and Validation of Model using Pendulum, MATLAB and MCU*

Activities 2 and 2b: Time Response/ Experimental determination of transfer function/Model Verification (Chapter 8):

In Activity 2, students examine the behavior of similar underdamped second-order systems analytically and numerically via MATLAB. In Activity 2b, students empirically determine the approximate second-order transfer function describing the pendulum by finding the average period and log decrement of the data obtained from the pendulum via the MCU to yield system damping ratio and natural frequency values. This is similar to activities conducted *numerically* as a homework assignment in prior course offerings. The students also compare the ideal response generated by the model to the actual response.

Course Hardware:

The MCU board used for this study is a Dragon 12 Plus 2 (Figure 1) [28] using Code Warrior [29], with a 16 bit, 24 MHz CPU, 256K Flash EEPROM, 12K RAM, serial communication, 10 bit A/D, timer channels, pulse width modulation (PWM), and discrete and interrupt I/O. Input devices include eight dip switches, 4 momentary switches, [16 key] keypad, IR proximity sensor and photoresistor. Output devices include 2 16-digit LCDs, single-row LEDs, 4-7 segment LEDs and a Piezo speaker. The high resolution A/D and multiple I/O devices make the Dragon Plus 12 hardware flexible enough to handle higher-level courses (e.g., the senior-level Design of Feedback Controls course) and more complex systems.

Activity 2b Implemented as a Team Project Assignment in ME 340 Fall 2013:

The description of Activity 2b in this section is excerpted from the group project assignment from Fall 2013 (and demonstrates the use of scaffolding to link to earlier activities related to Chapters 5, 7 and 8 of the course textbook [30]). Groups were comprised of 4 students and were mostly self-selected; the same self-selected teams were used to complete all group activities (e.g., homework assignments and in-class group activities).

- **Description:** An ideal pendulum (shown in Figure 2a) is modeled in Chapter 5 of Close, Frederick and Newell [30]. A comparison of ideal versus expected real behavior is presented in Table 2. Note that the *real* pendulum (Figure 2b),

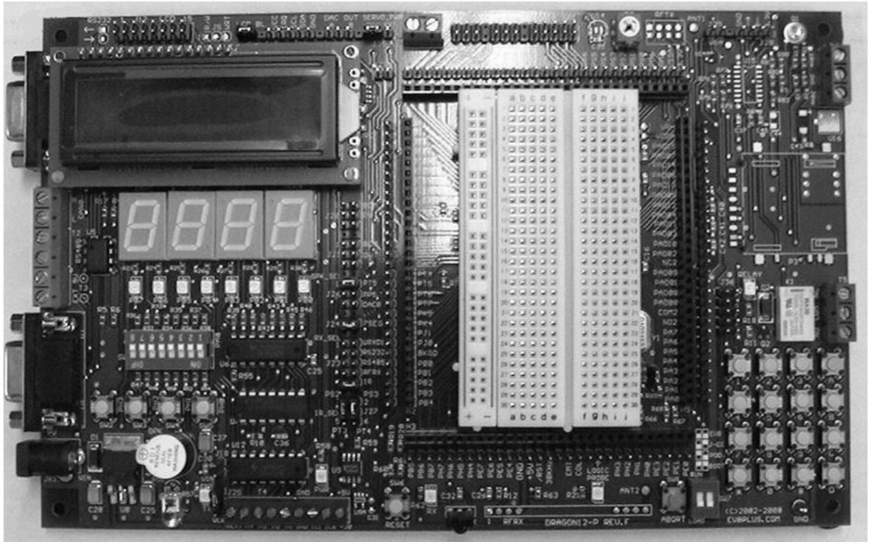
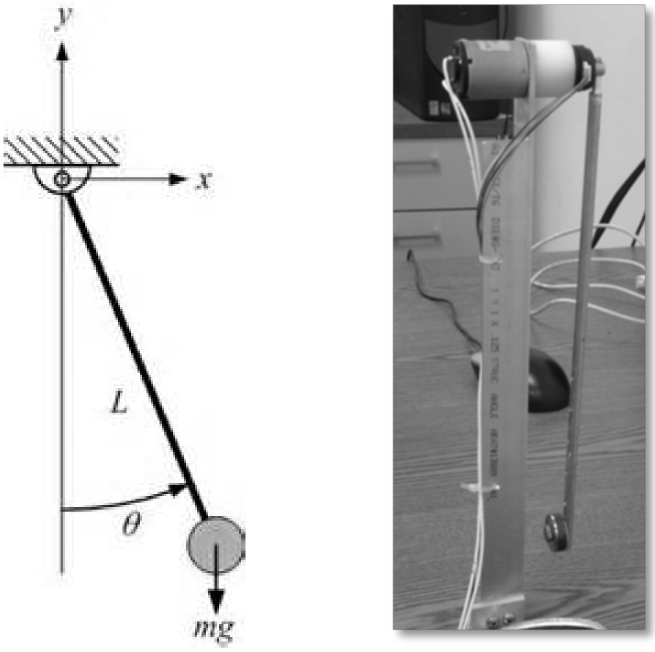


Figure 1: Dragon 12 Plus MCU board [30].



(a) (b)

Figure 2: (a) Ideal and (b) Real Pendulums.

developed and realized at TTU, and the pendulum modeled in the text both experience friction, which is modeled as viscous, at the pivot. By summing moments about a free-body diagram of the pivot, we obtain the system model presented in Equation 1:

$$J\ddot{\theta} + B\dot{\theta} + MgLsin\theta = \tau(t) \qquad (1)$$

where the mass moment of inertial, J, is ML^2. Linearizing about θ=0° (the vertical position), the free response (i.e., no external torque) yields

$$ML^2\ddot{\theta} + B\dot{\theta} + MgL\theta = 0 \qquad (2)$$

- For a non-zero initial angular displacement, θ_0, we can find the time response (using Laplace transforms and techniques from Chapter 7).
- The transfer function between θ and an external torque, τ, can be expressed in the form given in Equation 3, where θ is the output of interest (represented by Y(s)) and τ is the input (represented by U(s))

$$\frac{Y(s)}{U(s)} = \frac{K\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2} \qquad (3)$$

- From Equation 2, we can see that the pendulum is a 2nd order-system (and we can compare it to the general form of a second order system shown in Equation 3 and discussed in the text and in class lectures). From the assumptions in Table 2 (and the example response in Figure 3), the pendulum is a "lightly damped" [under-damped] second-order system (i.e., $0 < \zeta << 1$), and we can use the techniques discussed in the text and class to approximate the system model.
- The primary objective [of the project] is to experimentally determine the parameters ζ and ω_n which characterize the pendulum system model by using a non-zero initial angular displacement, θ_0, and the free-response of the pendulum in Figure 1(b); secondly, students compare the solution from the second-order linear ordinary differential equation presented in equation 2 to the actual response and discuss possible reasons the second-order linear model might differ from the empirical response.
- **Assignment**: From the free-response data obtained [on November 21], **find ζ and $\boldsymbol{\omega_n}$ to yield the approximate characteristic polynomial describing the pendulum**.
- **Extra credit opportunity**: Compare and discuss response from model to actual data for a similar initial angular displacement, θ_0.

The students were given Figure 4 and Equations 4-8 in class notes and online resources:

$$\boldsymbol{\frac{x_1}{x_2} = \frac{e^{-\zeta\omega_n t_1}}{e^{-\zeta\omega_n(t_1+T)}} = e^{\zeta\omega_n T}} \qquad (4)$$

$$\frac{x_1}{x_n} = e^{(n-1)\zeta\omega_n T} \qquad (5)$$

$$ln\left(\frac{x_1}{x_2}\right) = \frac{1}{n-1} ln\left(\frac{x_1}{x_n}\right) = \zeta\omega_n T$$
$$= \zeta\omega_n \frac{2\pi}{\omega_d} = \frac{2\pi\zeta}{\sqrt{1-\zeta^2}} \qquad (6)$$

$$\zeta = \frac{\frac{1}{n-1} ln\left(\frac{x_1}{x_n}\right)}{\sqrt{4\pi^2 + \left(\frac{1}{n-1} ln\left(\frac{x_1}{x_n}\right)\right)^2}} \qquad (7)$$

$$T = \frac{2\pi}{\omega_d} = \frac{2\pi}{\omega_n\sqrt{1-\zeta^2}} \qquad (8)$$

Table 2: Comparison of Ideal versus Real Pendulum.

Idealized Assumption	Real Pendulum
Rigid, massless rod connecting mass to the pivot	Mass of pendulum >> mass of rod (can ~ignore)
No friction at pivot	Minimal friction >> very small damping ratio
Linear behavior	Linear behavior for “small” angular displacement, θ

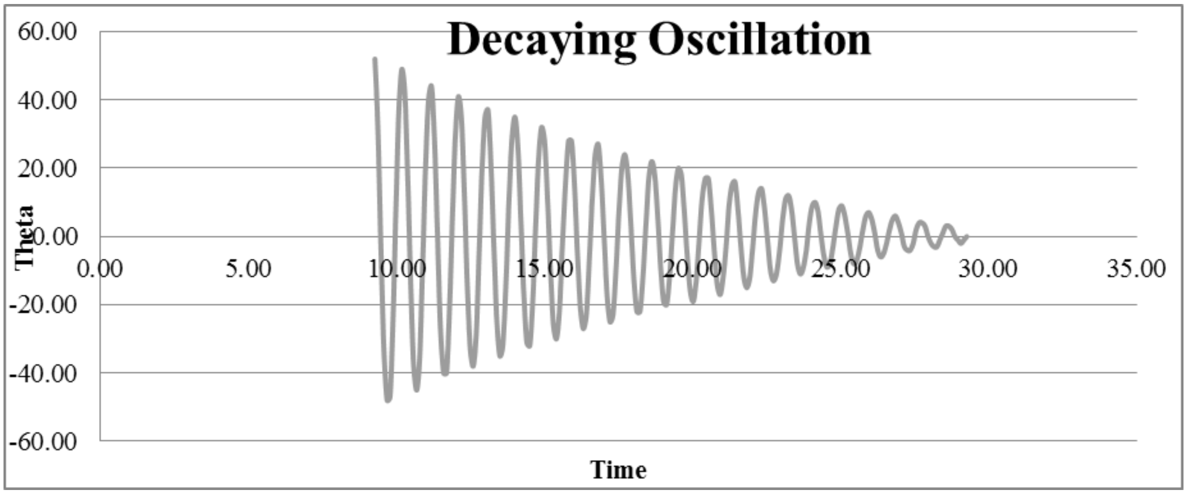


Figure 3: Example Free Response of (Real) Pendulum.

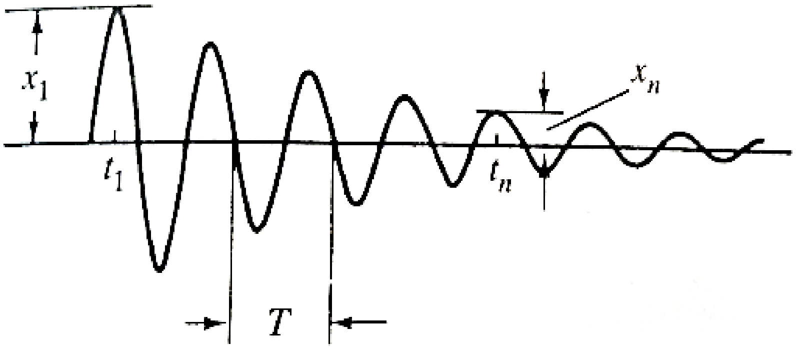


Figure 4: Decaying Oscillation (Ogata, 4th Edition) [31].

Follow-up Lecture (Example Feedback)

Example MATLAB code (Figure 5), sample calculations and a comparison of experimental and model data (Figures 6-9) were provided as feedback in a follow-up lecture following project submission; lecture PowerPoint slides were provided in online resources (on Blackboard) and the explicit free-response, θ(t), for non-zero θ_0, was derived on the board. Feedback was also given directly on each group submission.

Pendulum.m

```
A=[5.58 91.00                %load data in as a matrix (snipped to save space)
…
22.66   3.00];

t=A(:,1);                    %the first column is the time vector
y=A(:,2);                    %the second column is amplitude
t=t-t0;                      %subtract to from the time vector to facilitate comparison
y=y*pi/180;                  %change degrees to radians for the same reason
plot(t,y,'r:')               %plot actual data (shifted by to and changed to radians)
theta0=91/180*pi
pause
hold on
impulse([theta0 2*0.01677*6.49387*theta0],[1 2*0.01677*6.49387 6.49387^2])
pause                        %above line is the impulse response (see board notes)
axis([0 20 -1.6 1.6])        %zoom in … discuss
```

Figure 5: Example MATLAB code Comparing Model to Real Pendulum.

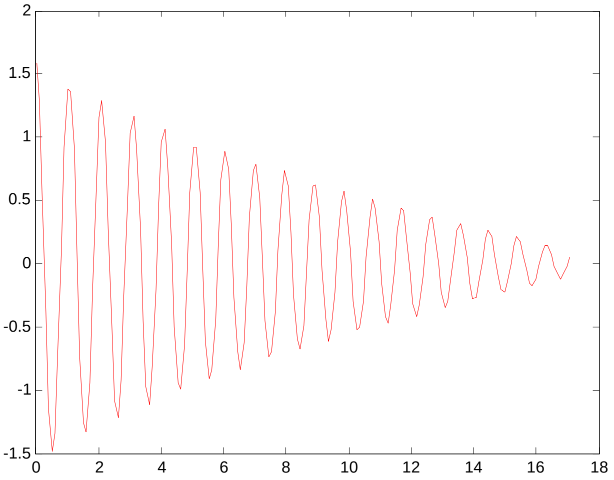


Figure 6: Experimental Data.

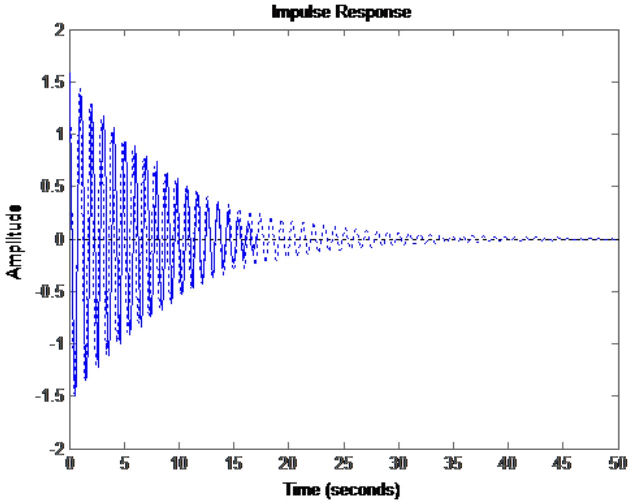


Figure 7: Linearized model (dashed) vs data (solid).

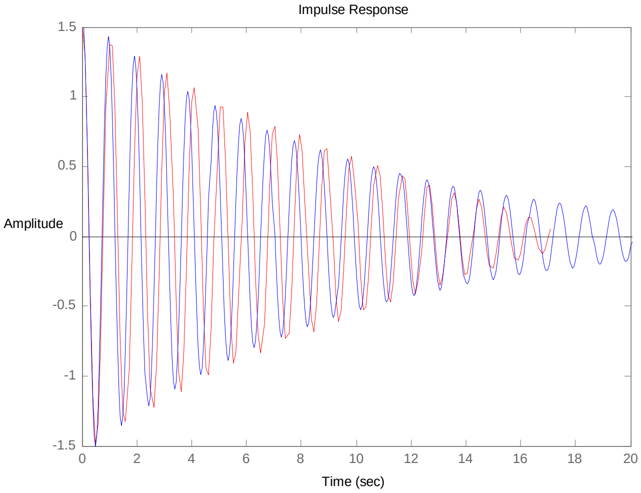


Figure 8: First 20 seconds of response.

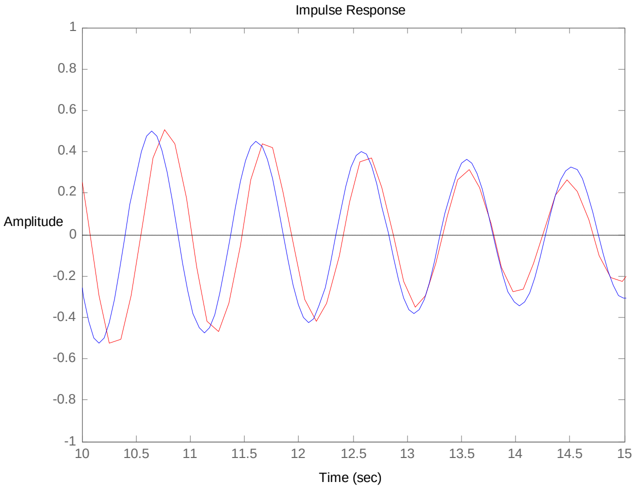


Figure 9: Seconds 10 – 15 of response.

Assessment of Initial Implementation:

The effectiveness of the hands-on assignment, Activity 2b, was assessed via pre-activity performance, project scores, post-activity performance and student perception.

Pre-activity performance was assessed by student scores on the second exam, which was given two days prior to the hands-on activity. The second problem on the exam focused on the transient response of an underdamped second-order system; the portion used to assess pre-activity performance was worth 9 points (9% of the exam total). Students were asked to provide the maximum displacement, x_{max}, and peak time, T_p, of the second-order transfer function in equation 9, given f(t)=10. Pre-activity performance is presented in Table 3. Of the students who made a significant effort to solve the problem (58 out of 66), the mean score was 6.29 (approximately 70%); the mean score of all students for the problem was 5.53 (61.4%), with 13 students achieving a score of 3 points or less for the problem.

$$X(s) = \frac{10}{s^2 + 2s + 10} F(s) \qquad (9)$$

Table 3: Pre-Activity Understanding.

Statistic	**Problem 2c**
Attempted	
Mean	6.29 (69.9%) [58]
Median	6.50 [58]
Mode	9.00 [12/58]
All	
Mean	5.53 (61.4%) [66]
Median	6.00 [66]
Mode	9.00 [12/66]
Min	0 [8/66]; ≤3 [13/66]

Student teams performed well on the project, with a narrow range of scores from 90-110% (including the 10% bonus described in section **Activity 2b Implemented as a Team Project**). Most teams attempted the bonus: many of the teams tried to scale and shift a zero initial-condition graph from MATLAB to match experimental data; however, a few teams successfully derived the zero-input (free response) and presented an excellent comparison of experimental and model data, commenting on the effects of linearization (for a significant θ_0 of approximately 90 degrees), pivot friction, etc.

Post-activity performance was assessed by student scores on the final exam, which was given approximately three weeks after the hands-on activity. The second problem on the final exam focused on the steady-state and transient response of an underdamped second-order system; the portion used to assess post-activity performance was worth 17 points (17% of the exam total). Students were asked to provide transient response characteristics in problem 2(b), which was worth 8 points; students were asked to apply their understanding of transient response characteristics in parts c and d, which were worth 9 points, cumulatively. Results are shown in Table 4. Of the students who significantly attempted the problem, average performance was 7.1 points for Problem 2(b) (88.8%) and 6.54 (72.6%) for Problems 2(c) and 2(d) combined; for all students, performance was 5.33 (67%) and 3.98 (44.4%), respectively.

While post-activity performance is *significantly* better for those students who made a serious effort to complete the problems, post-activity assessment is confounded by self-selection bias: students had to complete (any) four out of five problems on the final exam; problem 2 was the problem most often "skipped" by those students who completed four problems, or partially answered, for the students who completed all problems, knowing that the best four problems would comprise their final exam score. Additionally, performance on parts c and d of problem 2 indicated that students still had trouble *applying* the concepts. Exam scores are available from the Fall 2011 class (the prior offering of the course by Parker without the hands-on activity); however, a detailed assessment of student performance on specific questions relating to system response (as presented in Table 4 for the Fall 2013 class) is not available for the Fall 2011 class.

In Table 5, the students' perceptions of how the course helped to meet the most closely aligned learning objective, Teacher Course Evaluation (TCE) Supplemental Question 40, are compared for Fall 2011 and Fall 2013. TCE Question 40 asks the students how well the course helped to "Show how the system response is affected by the choice of time constant, damping ratio and natural frequency." In the Fall 2011 course offering, Blackboard was similarly used as an online resource, but team-based learning, in-class assessment via PollEverywhere and the hands-on activity were not part of the course. Mean student perception was similar and actually slightly lower in Fall 2013; standard deviation was the same (at almost 1) for both years.

The percentage of students who perceived that the class coverage of this topic was good or outstanding was also lower in 2013 (61.5% versus 66.1%). The students' self-assessment of their understanding of second-order system performance, as measured by open-ended (free text) PollEverywhere [24] polls given during class prior to and after the hands-on activity, did not necessarily correlate with student performance during Fall 2013. Most students indicated that they had no questions and fully understood second-order time response concepts prior to the second exam (although two students explicitly asked for additional example and practice questions prior to the exam via the poll).

Table 4: Post-Activity Understanding.

Statistic	Problem 2b	Problem 2c+d
Attempted		
Mean	7.10 (88.8%) [48]	6.54 (72.6%, [39]
Median	8.00 [48]	7.00 [39]
Mode	8.00 [27/48]	9.00 [14/39]
All		
Mean	5.33 [66]	3.98 [66]
Median	7.00 [66]	5.00 [66]
Mode	8.00 [27/66]	0.00 [25/66]

Table 5: Response to TCE Question 40.

Term	Enrollment	n	Mean	Standard Deviation	1	2	3	4	5
Fall 2011	54	41	4.0	0.96	2.4	0	31.7	29.3	36.8
Fall 2013	68	39	3.8	0.96	0	10.3	28.2	35.9	25.6

Additional Observations, Proposed Assessment Modifications and Future Work

The uniformly good performance on the project, followed by better performance post-activity is promising; however, the lower percentage of students responding favorably to TCE question 40 and the fact that many students still exhibited misconceptions after the activity and post-activity feedback are of concern. It is noted that perhaps too much scaffolding was provided with Activity 2b and that activities should be revised such that scaffolding only be provided as needed with the hands-on activity. Secondly, since data acquisition is fairly rapid and the pendulum is designed for easy modification of mass moment of inertia, J, and rod length, L, we propose that multiple configurations of the pendulum be studied by teams in future semesters to further enhance student understanding of underdamped second-order system performance.

Moreover, during post-assessment activities, including the final exam, it was noted that, while students generally better understood the effect of ζ on the behavior of underdamped systems, there were still significant misconceptions on how to assess overdamped systems. In both in-class polls and on the final exam, students were asked to examine overdamped systems with ζ significantly greater than one; i.e., with $\tau_1 >> \tau_2$ (such that the system's transient response can be essentially described as first-order with time constant, τ_1); many students correctly calculated a ζ value which was significantly greater than one (and several even factored the characteristic polynomial to show two real roots with one root much larger than the second), and still incorrectly used Equation 10 to find the settling time for the system).

$$T_{s(2\%)} \cong \frac{4}{\sigma} = \frac{4}{\zeta\omega_n} \qquad (10)$$

Therefore, the ECP® Rectilinear system [32] (Figure 10) or the equivalent is suggested for a second future hands-on activity. Students have (also) seen and solved systems of simultaneous linear equations using lumped mass-spring-damper schematics in several previous prerequisite courses, including physics, differential equations and dynamics, prior to investigating them in Systems Modeling. Secondly, the single degree-of-freedom configuration can be easily adjusted from lightly damped to significantly overdamped for the rectilinear plant. Moreover, the rectilinear system is highly configurable and able to mimic numerous first-, second- and higher-order schematics with great fidelity: sixteen unique configurations are possible for a three degree-of-freedom single-input-single-output system. Free or constrained configurations are possible at either end of the device and multiple possible adjustments in the mass, damping and spring constant values yield adjustable system poles and zeroes in the 1.5 to 7 Hz range. High resolution encoders (1600 counts/cm) provide feedback and actuation is provided by 8N rack-and-pinion Fe-Co brushless motors.

Another challenge is that the personnel resources available for initial implementation (four part-time undergraduate research students and one-half time graduate research assistant, in addition to the course teaching assistant) will likely not be available for future implementations. While this level of assistance will not likely be needed in future offerings, Mechanical Engineering enrollments continue to grow at UK (and nationally), so the challenges detailed in the DBER study [2] partially addressed with the activities implemented in this paper will continue to be exacerbated in large lecture courses with three populations [25]: students with an excellent foundation in course pre-requisites, students with minor gaps in pre-requisite fundamental principles and students with significant gaps in pre-requisite fundamental concepts.

Finally, the instructor for the Systems Modeling course described in this paper is not necessarily assigned to teach the course in successive semesters, which makes comparisons to prior offerings and a rigorous assessment of the effectiveness of course improvements, including the hands-on activities presented here, more challenging. Based upon the initial assessment from this study, student perception of understanding did not necessarily correlate well with performance and the performance data available from Fall 2011 (overall quiz and test scores) was insufficient to yield a detailed comparison of the Fall 2011 and Fall 2013 courses similar to the pre- and post-activity assessments in Tables 3 and 4. In future offerings, we plan to augment summative assessment with more frequent formative assessments via Piazza and PollEverywhere and attempt to better link summative assessment metrics with students' self-assessment [33].

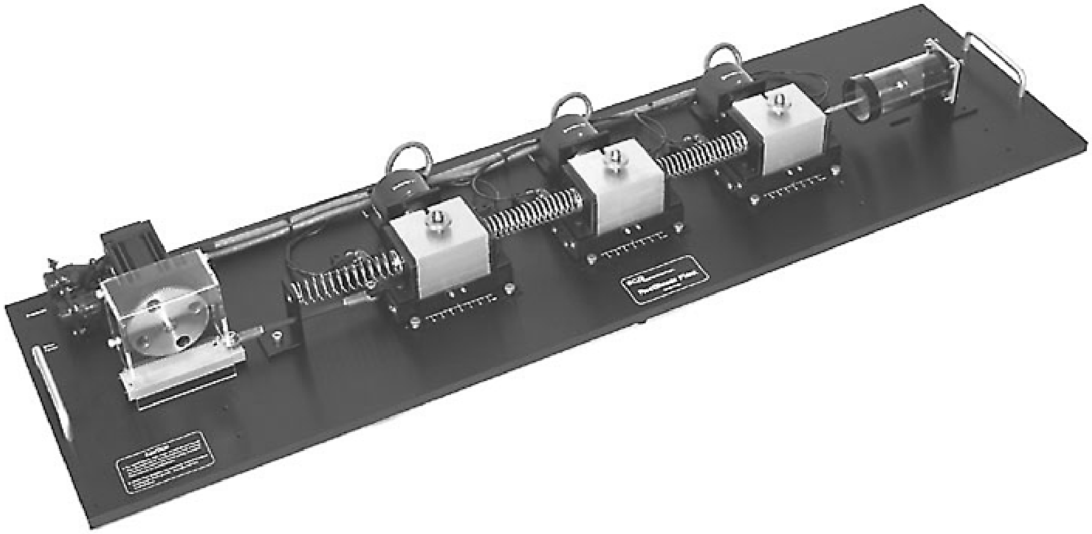


Figure 10: ECP® Rectilinear System [32].

Acknowledgment

The authors would like to thank graduate students John Hale (of TTU) and Ann Whitney (of UK) and UK undergraduate students Roger Maybrier and Zi Qin (Paul) Phua for their invaluable assistance in implementing the hands-on activity in ME 340 during Fall 2013.

The authors would also like to thank the National Science Foundations for its support of the reported work. Information from this paper is based on a NSF CCLI (Course, Curriculum and Laboratory Improvement) Phase II project, award DUE 1022934. Any opinions, findings, conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Bibliography

1. Canfield, S. L, and Abdelrahman, M. A., 2009, "Enhancing the Programming Experience for Engineering Students through Hands-on Integrated Computer Experiences" Proceedings of the 2009 ASEE Southeastern Section Annual Conference, Marietta, GA, April.

2. National Academy of Sciences. "Undergraduate science and engineering teaching needs improvement." ScienceDaily, 21 May 2012. Web. 29 May 2012.

3. Bransford, J. D., Brown, A., & Cocking, R., 2000, How People Learn: Mind, Brain, Experience and School, Expanded Edition, Washington, DC: National Academy Press.

4. Committee on How People Learn, A Targeted Report for Teachers, How Students Learn: History, Mathematics, and Science in the Classroom, M. Suzanne Donovan and John D. Bransford, *Editors,* THE NATIONAL ACADEMIES PRESS Washington, D.C., 2005.

5. Vander Ark, T., 2011, "Getting Smart: How Digital Learning is Changing the World," Jossey-Bass (Wiley and Sons).

6. Calechman, S, 2012, "Learning Revolution," Delta SKY Magazine.

7. Felder, R. M., and Silverman, L. K., 1988, "Learning and Teaching Styles in Engineering Education," Engr. Education, 78 (7), pp 674-681 (updated online 2009*).

8. Fink, D., 2003, "Creating significant learning experiences: An integrated approach to designing college courses." Jossey-Bass (Wiley and Sons).

9. Michaelsen LK, Knight AB, and Fink LD, 2004. "Team-based learning: A transformational use of small groups in college teaching." Stylus Publishing, Sterling, VA.

10. Michaelsen, L. K., Watson, W. E. and Black, R. H., 1989, "A realistic test of individual versus group consensus decision making." Journal of Applied Psychology. 74(5), 834-839.

11. Michaelsen, L. K. and Black, R. H., 1994, "Building learning teams: The key to harnessing the power of small groups In higher education," in Collaborative Learning: A Sourcebook for Higher Education, Vol. 2, edited by S. Kadel, & J. Keehner, National Center for Teaching, Learning and Assessment, State College, PA

12. Lipscomb, L., Swanson, J., and West, A., 2004, Scaffolding," Emerging Perspectives on Learning, Teaching and Technology, edited by M. Orey.

13. Vygotsky, L. S., 1978, Mind in Society, Harvard University Press, Cambridge, MA.

14. Borthick, A., 1999, “Designing learning experiences within learner's zones of proximal development (ZPDs): Enabling collaborative learning on-site and online”

15. Kao, M., Lehman, J., and Cennamo, K., 1996, “Scaffolding in hypermedia assisted instruction: An example of integration,” Association for Educational Communications and Technology.

16. Parmelee, D. X, and Michaelsen, L. K, 2012, “Twelve tips for doing effective Team-Based Learning (TBL),” Medical Teacher, Volume 32, pp. 118-122.

17. Levine, RE, 2008, “Peer evaluation in team-based learning,” Team-based learning in health professions education," edited by Michaelsen, LK, Parmelee, D, McMahon, K, and Levine RE., Stylus Publishing, Sterling, VA

18. Clough, D. E., Chapra, S. C. and G. S. Huvard, “A Change in Approach to Engineering Computing for Freshmen, - Similar Directions at Three Dissimilar Institutions,” 2001 ASEE Annual Conference and Exposition, Jun 24-27, Albuquerque, NM.

19. Herniter, M. E., Scott, D. R., and R Pangasa, “Teaching programming skills with MATLAB”, 2001 ASEE Annual Conference and Exposition, Jun 24-27, Albuquerque, NM.

20. Colombo, M. A., M. R. Hernandez and J. E. Gatica, “Combining high-level programming languages and spreadsheets an alternative route for teaching process synthesis and design,” 2000 ASEE Annual Conference and Exposition, St. Louis, MO, June 18-21, 2000, p 773-784.

21. Piazza, www.Piazza.com

22. Qasem, A., 2012, “Using Piazza to Encourage Interaction,” The Chronicle of Higher Education.

23. Young, Jeffrey, 2012, “Students Endlessly E-Mail Professors for Help. A New Service Hopes to Organize the Answers,” The Chronicle of Higher Education.

24. PollEverywhere, www.PollEverywhere.com

25. Parker, J. M. and Polston, J. D., 2012, “Using Hybrid and Problem-Based Learning Techniques to Enhance Teaching Effectiveness in a Large Feedback Controls Lecture Course,” Proceedings of the 2012 ASME International Mechanical Engineering Congress and Exposition, Houston, TX, Nov 9-16.

26. Parker, J. M., Canfield, S., Ghafoor, S., and Lum, K. M., 2013, “Work-in-Progress: Using Hardware-based Programming Experiences to Enhance Student Learning in a Senior Feedback Controls Lecture Course,” Proceedings of the 2013 ASEE Annual Conference, Atlanta, GA, June.

27. Tennessee Tech “Pendulum Plot”, http://matlab-nsfwiki.csc.tntech.edu/index. php/Pendulum-Plot

28. Dragon12 plus, www.evbplus.com

29. Freescale Codewarrior,www.freescale.com

30. Close, C. M., Frederick, D. H. and Newell, J. C., 2002, “Modeling and

Analysis of Dynamic Systems”, 3rd edition, Wiley and Sons.

31. Ogata, K, 2003, System Dynamics, 4th Edition," Prentice Hall.
32. ECP® Rectilinear Plant, http://www.ecpsystems.com/controls_recplant.htm
33. Rensis Likert, 1932**, “**A Technique for the Measurement of Attitudes,” Archives of Psychology, No.140.

Biographical Information

Dr. Johné Parker is an Associate Professor of Mechanical Engineering at the University of Kentucky. She received her BME, MSME and Ph.D. degrees from the George W. Woodruff School of Mechanical Engineering at the Georgia Institute of Technology and has six years industrial experience with Shell Oil Company and Mobil Chemical Company. Her research interests include systems and controls, automation, emerging technologies and science/technology policy. She is also actively engaged in engineering education research, particularly as it relates to hybrid and problem-based learning.

Dr. Stephen Canfield is a Professor of Mechanical Engineering at Tennessee Technological University. He received his BSME from Gannon University, and his Ph.D. in Mechanical Engineering from Virginia Polytechnic Institute and State University. His research interests include robot kinematics and dynamics, topological optimization of compliant manipulators, in-space mechanisms and engineering education.

Dr. Sheikh Ghafoor is an Associate Professor in the Department of Computer Science at Tennessee Technological University. He received his M.S. and Ph.D. in Computer Science from Mississippi State University. His primary research includes parallel, distributed and high performance computing. He is also very interested and actively engaged in research in the area of computer science education.

Kassy M. Lum Hart received her B.S. and M.S. degrees in Mechanical Engineering from the University of Kentucky; she simultaneously earned a graduate Power and Energy Institute of Kentucky (PEIK) Certificate. She is currently an Additive Engineer for GE Power & Water.