International Journal of Engineering Education Vol. 29, No. 1, pp. 139–153, 2013
Printed in Great Britain

0949-149X/91 $3.00+0.00

Take-Home Experiments in Engineering Courses: Evaluation Methods and Lessons Learned*

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This paper reports on the evaluation findings and the lessons learned from performing take-home laboratories in four undergraduate mechanical engineering courses at the University of Rhode Island. In this project, students were provided with a compact, low-cost kit with which they can perform an experiment at home using their own PC/laptop. A Student Survey was developed and used to collect perceptions of curricular effectiveness from the URI (University of Rhode Island) students on a post-course basis. In addition, pre- and post- quizzes were administered in the affected courses. The evaluation showed several things. First, student responses on the surveys and results of quiz grades indicated that the kits played an important role in the conceptual understanding of the course material and application of the course content to real world applications. Second, across the four mechanical engineering courses in which the kits were implemented, the majority of students consistently reported that they were comfortable working on, and with, the take-home kits independent of a lab or instructor. They also reported that both the software and the hardware of the take-home kits were easy to set up and use. Third, one semester after the kits were first placed into service, there has been a steady increase in undergraduate Mechanical Engineering student interest in system dynamics courses as evidenced by an increase in the student enrollment in three of the affected courses.

Keywords: evaluation; laboratory at home; mechanical engineering laboratory education; take-home kit

1. Introduction

The inclusion of take-home laboratories in a course has several benefits. It increases students' laboratory experience; it increases student interest and confidence; it provides personalized learning to students; and it supplements the course lectures with experiential learning. This paper reports on a project that was conducted over a three and half years' period in the Mechanical Engineering Department at the University of Rhode Island (URI) to improve the understanding of system dynamic concepts in an undergraduate student population. In this project, we developed instructional material in the form of low-cost take-home software and hardware kits that were used to perform laboratory experiments and measurements at home. The intent of the project was to develop a process at URI that would allow students to perform an experiment outside of a university laboratory using only their PC/laptop. The kits were designed so that the experiments could be conducted on the provided experimental setups or to perform dynamic measurements on engineering systems that are available at home such as motor powered devices and heating/cooling systems. The details of the kits design and the experiments performed with the kits were reported in [1–3].

It was anticipated that the resulting software and kit would both foster the educational development of engineering students, as well as increase their interest in System Dynamics as a field of concentration. This being done, the eventual goal would be to impact other curricula at URI to explore the use of take-home kits, as well as to offer a model for other institutions of higher education, worldwide, to adopt.

A survey of the literature shows that there is increasing interest in performing measurements and experimentation in engineering programs outside of the traditional university laboratory. Jiji *et al.* [4] described an approach where students build simple home experiments to illustrate solid mechanics principals using household supplies and materials. Scott [5] reported on take-home experiments in fluid mechanics to illustrate basic concepts such as hydrostatics and the Bernoulli equation. Cimbala *et al.* [6] reported on a pump flow take-home experiment in an introductory fluid flow lecture class. Berg and Boughton [7] reported on the use of commercially available attaché cases or electronic trainers that cost in the $200 to $350 range for conducting experiments at home in lower division electronic laboratory courses. Durfee *et al.* [8] were funded by NSF to develop take-home experimental setups. They developed two setups: a fourth-order linear mass spring–damper-system for frequency response and system identification, and an analog filtering system that uses music and synthetic sound as an input. Wang *et al.* [9] discuss the use of

* Accepted 27 July 2012.

the LEGO programmable brick as a portable data acquisition system to conduct personal engineering experiments at home to illustrate engineering concepts that are covered in sophomore or junior-level laboratory courses. Long *et al.* [10] reported on the use of a home experimentation kit for digital and analog electronics in a first-year undergraduate electronics course.

Many educators have also reported work on the remote control of experiments; see for example [11–23], where students perform an experiment at a distance location using the internet as the control interface. This approach allows the same experimental setup to be used by many students, while also giving the students the opportunity to conduct an experiment at a convenient time and location. However, it does not give the same experience as performing the experiment in person, and there could be issues in equipment availability, especially in large classes.

The take-home labs are an example of experiential learning, focusing on the role that experience plays in learning important concepts of system dynamics processes. Research has generally supported that active learning instructional strategies, including activities focusing on experiential learning, are likely to result in greater learning gains than traditional instructor-centered methods [24]. Furthermore, efforts on the part of engineering faculty to modify curricula to include more hands-on, active learning and to support rather than weed out students could play a significant role in increasing the participation of female and under-represented minorities [25].

A challenge in performing experiments at home is developing low-cost experimental setups that are rugged, easy to set up and use by the students, and also at the same time produce meaningful results and opportunities for testing of theory. The LABVIEW software, which is available at many institutions, is a powerful package for laboratory data acquisition, but it has a steep learning curve, is expensive for home use, and requires additional hardware. The authors believe that the approach developed by them offers a robust, scalable, and economical one for take-home kits development.

This paper reports on the evaluation findings and the experiences learned from performing this project. The remainder of this paper is organized as follows. Section 2 gives a brief overview of the kits and their usage in courses. Section 3 discusses the evaluation methodology used; Section 4 shows the results; while Section 5 discusses the results obtained. The concluding remarks are given in Section 6.

2. Kits design and usage in courses

Each take-home kit consisted of three components. The first component is a hardware interface board that is interfaced with the student's PC/laptop and with the experiment's hardware (see Fig. 1). The hardware interface board houses all the components that perform measurement, actuation, control, and communication. The hardware interface board was custom-designed and was built around a PIC18F4550 microcontroller from Microchip Technology, Inc.

The second component is a User-Interface Program that is loaded onto the student's PC/laptop, and used to run the experiment and collect data. A screen shot of the developed Windows-based User-Interface Program is shown in Fig. 2. The User-Interface Program transfers the experiment settings to the PIC microcontroller, provides monitoring and control of the experiment progress, retrieves the data collected after the experiment is completed, and saves the collected data to a file.

The third component is the actual experimental setup, or the sensor system to perform the measurement. Five different experimental setups/measurement systems were developed in this project, but all setups used the *same* hardware interface board and the *same* User-Interface Program. These are listed in Table 1 and are shown in Figure 3.

In this project, we fabricated 69 hardware interface boards, 25 DC motor setups, 25 heated plates setups, 55 temp sensor setups, 75 free vibration setups, and 30 forced vibration setups. An advantage of the take-home lab kit is its low-cost and the use of the *same* User-Interface Program for all experiments. The components cost (including assembly) for the hardware interface box is about \$101 and the components cost for the experimental setups ranges from about \$7 for the least expensive setup (liquid temperature sensor) to about \$26 for the most expensive set (copper plate with heater and

Fig. 1. Hardware interface board.

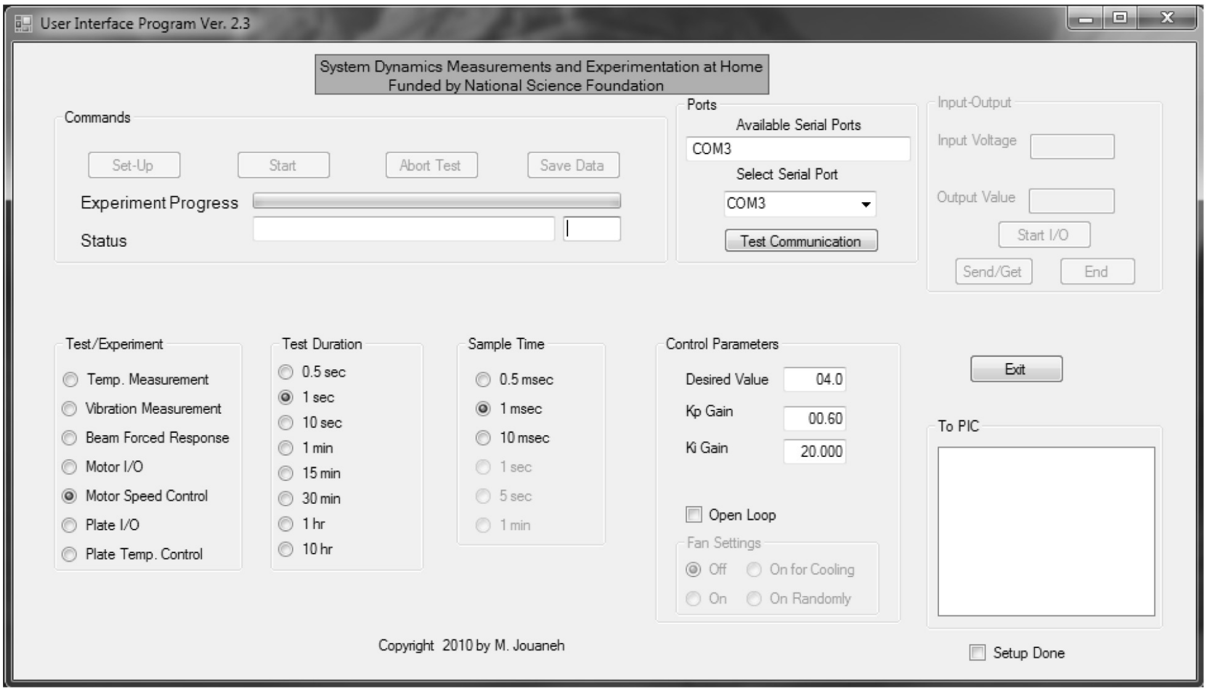

Fig. 2. A screen shot of the User-Interface Program.

Table 1. Experimental setups developed by URI

Label	Experimental setup	Abbreviation
A	A liquid temperature sensor	Temp. sensor
B	A DC motor with a tachometer	DC motor
C	A vibrating cantilever beam with an accelerometer	Free vibration
D	A vibrating cantilever beam with an accelerometer subjected to a forced input from a rotating unbalanced motor	Forced vibration
E	A copper plate with a heater, a fan and a temperature sensor	Heated plate

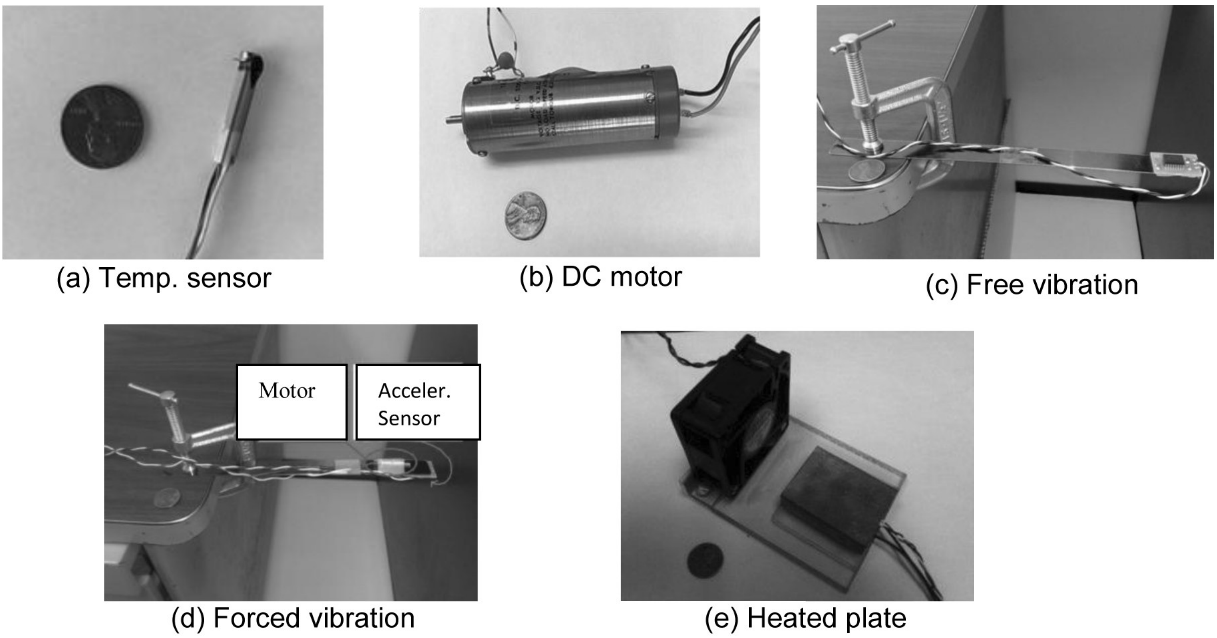

Fig. 3. Experimental setups developed by URI.

Table 2. Kit usage in courses throughout the project

Semester	Courses	Experimental setups	Enrolment
Spring 2009	**MCE431**: Computer Control of Mechanical Systems	DC motor	9
	MCE366: System Dynamics	Temp. sensor	47
Fall 2009	**MCE433**: Mechatronics	Heated plate	10
	MCE464: Vibrations	Free vibration	13
Spring 2010	**MCE366**: System Dynamics	Free vibration	56
Fall 2010	**MCE433**: Mechatronics	Heated plate	23
	MCE464: Vibrations	Forced vibration	28
Spring 2011	**MCE366**: System Dynamics	Free vibration	54
	MCE431: Computer Control of Mechanical Systems	DC motor	20

fan). Adding a maximum parts cost for $5 for wires, connecters, and connector pins, the total components cost for the most expensive experimental setup is below $132. The above figure does not take into account the assembly/machining costs of the setups nor the cost of the development of the software.

The kits were used in four undergraduate mechanical engineering courses at URI. Table 2 shows the usage of the kits in the various courses throughout the project duration. The MCE366 course is a required junior-level course, while the remaining three courses are senior-level technical elective courses.

For each experiment, the students were given a write-up that explains the experimental setup with instructions on how to load the control software and how to run that particular experiment/measurement. Each student was given a copy of the control program, the hardware interface box, and the particular experimental setup. Students were asked to return the kit to the instructor at the completion of the take-home assignment. Resources were made available to help students who are working at home alone when the experiment does not run properly. These resources include the ability to contact the instructor via e-mail or in the next class meeting, and to use the instructions, online videos and guides posted on the website for this project. Since the students were given seven to ten days to perform the experiment, they had ample time to resolve any issues with the experiment before the due date.

3. Evaluation methodology

The goal of this project was to improve the understanding of system dynamic concepts in an undergraduate student population. The project operationalized this goal through four Objectives:

- Objective 1. To increase undergraduate Mechanical Engineering student understanding of system dynamics concepts;
- Objective 2. To enhance undergraduate Mechanical Engineering student ability to conduct experiments and to analyze data;
- Objective 3. To increase undergraduate Mechanical Engineering student interest in experimental system dynamics; and
- Objective 4. To improve experiential learning in undergraduate Mechanical Engineering courses.

The above objectives were both programmatic and behavioral in nature. They reflected actions and activities that were to be undertaken to both administer the project and identify impact(s) that the project had on participants and institutions. Using these objectives as a basis, the evaluation design allowed for data collection on the following evaluation questions.

- Did the use of take-home kits increase student understanding of system dynamic concepts?
- Did the use of take-home kits enhance student ability to conduct experiments and to analyze data?
- Did the developed kits increase student interest in experimental system dynamics?
- Were the investigators successful in improving experiential learning by developing reliable, low-cost take-home laboratory kits?

In order to collect information to be used in the evaluation, the following instruments were used:

1. a Student Survey;
2. a Review of Project Records; and
3. Staff Interviews.

A Student Survey was developed and used to collect perceptions of curricular effectiveness from the URI students on a post-course basis. This instrument was used with all undergraduate students who participated in the targeted URI engineering courses taught by the project faculty.

Project records include grades on quizzes and exams on topics related to the take-home kits. It also includes enrolment in the four project courses that were reviewed to determine trends.

Staff interviews occurred over the three and a half years of project operation during meetings of the

Table 3. Response of students (percentage) to Question 1—How convenient is a take-home experiment than doing an experiment in the school lab?

Semester	Course	Class size	Sample size (*N*)	Very inconvenient	Somewhat inconvenient	Cannot decide	Somewhat convenient	Very convenient
Spring 2009	MCE366: System Dynamics	47	42	7.1	14.3	14.3	40.5	23.8
	MCE431: Computer Control of Mech. Systems	9	8	0.0	12.5	0.0	50.0	37.5
Fall 2009	MCE433: Mechatronics	10	8	0.0	0.0	0.0	62.5	37.5
	MCE464: Vibrations	13	10	10	30	20	20	20
Fall 2010	MCE433: Mechatronics	23	20	0.0	0.0	15.0	35.0	50.0
	MCE464: Vibrations	28	23	0.0	17.4	8.7	43.5	30.4
Spring 2011	MCE366: System Dynamics	54	44	2.3	11.4	6.8	29.5	50.0
	MCE431: Computer Control of Mech. Systems	20	16	0.0	6.3	0.0	18.7	75.0
	Results for entire sample (*N* = 171)			2.9	11.7	9.4	35.7	40.3

project staff that the evaluator attended regularly. The project evaluation was performed by the second author, who is a professor in the School of Education at URI.

4. Results

The intent of the project was to develop experiments that could all be performed outside of a classroom or a university lab, which would supplement the knowledge gained by engineering students taking four junior and senior-level mechanical engineering courses. To this end experiments were developed to address several concepts in the systems dynamics areas including: choice of sampling rate, modeling using simple first and second order lumped-parameter models, response time and steady-state response characteristics, gains determination for a closed-loop control system, and oscillation frequency and degree of damping for oscillatory systems. During the course of five semesters (Spring 2009 through Spring 2011) the kits were used for supplemental instruction in four courses as shown in Table 2. Note that the kits continued to be used after the Spring 2011 semester, but no evaluation was performed.

After the completion of each experiment, a Student survey (see Appendix for an example) was administered to the students taking the course. The purpose of this survey was to determine the students' perceptions on performing unsupervised experiments and to what extent the kits had contributed to their learning. Each survey had ten questions, eight of them (Questions 1 and 2, and 5 though 10) are common across all the experiments/ courses, and two (Questions 3 and 4) are specific to the particular experiment. Questions 3 and 4 were not used in the 1st semester (Spring 2009) in which the kits were implemented.

The survey results for Question 1 (How convenient is a take-home experiment compared with doing an experiment in the school lab?) are shown in Table 3 for all the courses[1]. The data shows that the majority of the students had reported that the take-home kits were convenient compared to doing an experiment in the school lab (40.3% of the entire sample reported it is Very Convenient and 35.7% of the entire sample reported that is Somewhat Convenient). Per course reporting varied from a low of 40% for these two categories for MCE464-Fall 2009 to a high of 100% in MCE433-Fall 2009. The low percentage in MCE464-Fall 2009 is due to software errors we had with the experiment in that course which was resolved in later offerings. Note that in MCE433 students perform other experiments in the school lab which is not the case for the other three courses.

The survey results for Question 2 (How comfortable are you in performing an unsupervised experiment at home?) are shown in Table 4 for all the courses. The data show that the majority of the students had reported that they were comfortable in performing an unsupervised experiment at home (49.1% of the entire sample reported they are Very Comfortable and 39.2% of the entire sample reported that they are Somewhat Comfortable). Per course reporting varied from a low of 79.5% for these two categories for MCE366-Spring 2011 to a high of 100% in MCE431-Spring 2009 and MCE 433-Fall 2009.

When students were asked to rate the extent to which the kits contributed to their learning of basic system dynamics concepts in the four courses (Question 3 on the Student Survey), the majority indicated that the take-home kits contributed either To Some Extent or To a Great Extent across all of the conceptual topics with the exception of one topic in MCE433-Fall 2009. The data are illustrated in Figs 4 and 5. In MCE366-Spring 2010, close to 90% of the students said that the kits had contributed either To Some Extent or To a Great Extent in

[1] In MCE366-Spring 2010, only data for Questions 3 and 4 were collected.

Table 4. Response of students (percentage) to Question 2—How comfortable are you in performing an unsupervised experiment at home?

Semester	Course	Class size	Sample size (N)	Very uncomfortable	Somewhat uncomfortable	Cannot decide	Somewhat comfortable	Very comfortable
Spring 2009	MCE366: System Dynamics	47	42	0.0	7.1	4.8	45.2	42.9
	MCE431: Computer Control of Mech. Systems	9	8	0.0	0.0	0.0	62.5	37.5
Fall 2009	MCE433: Mechatronics	10	8	0	0	0	50.0	50.0
	MCE464: Vibrations	13	10	0.0	10.0	0.0	50.0	40.0
Fall 2010	MCE433: Mechatronics	23	20	0.0	5.0	0.0	30.0	65.0
	MCE464: Vibrations	28	23	8.7	0.0	4.4	39.1	47.8
Spring 2011	MCE366: System Dynamics	54	44	2.3	11.4	6.8	29.5	50.0
	MCE431: Computer Control of Mech. Systems	20	16	0.0	6.3	0.0	37.5	56.2
	Results for entire sample (N = 171)			1.8	6.4	3.5	39.2	49.1

understanding the four basic concepts covered by the experiment. The percentage decreased slightly in the Spring 2011 offering of the course. In both offerings, about 60% of the students said that the kit had contributed To a Great Extent in understanding the concept of "Calculation of beam oscillation period from data" (Concept 3b). The "Concept of equivalent mass of a cantilever beam" (Concept 3d) was ranked second in Spring 2010 and third in Spring 2011.

For the MCE431 class, close to 70% of the students have said that the kit had contributed To Great Extent in understanding three of the five concepts covered by the take-home experiment. The concept of "Choice of suitable sampling time" (Concept 3a) was ranked the least to be demonstrated by the take-home experiment, a similar finding to the rating of the concepts in the MCE366 course. Note that Questions 3 and 4 in the student survey were not used in the Spring 2009

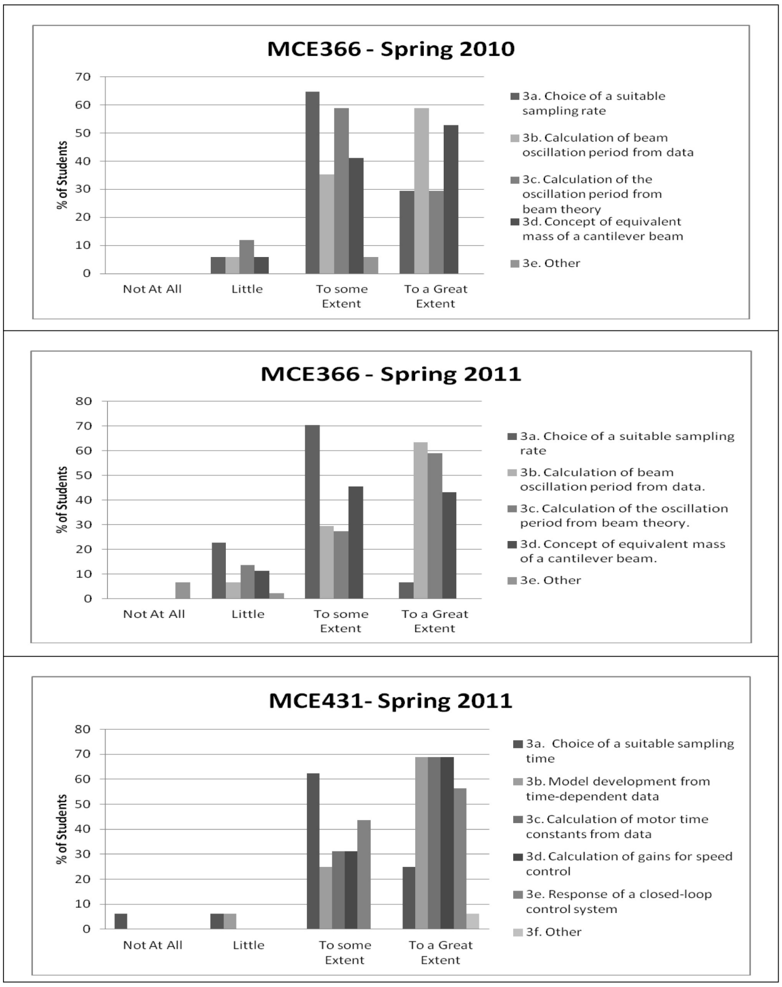

Fig. 4. Response of students to Question 3 in MCE366 and MCE431.

semester, so data for the MCE431 offering in the Spring 2009 semester are not shown.

For MCE433, more than 90% of the students said that the kits had contributed either To a Great Extent or To Some Extent in understanding the concept of ‘‘Response of closed-loop control system’’ (Concept 3e) in both offerings of the course (Fig. 5). The two concepts that the students ranked the least in Fall 2009 semester were ‘‘First order system response’’ and ‘‘Model development from data’’ (Concepts 3a and 3b). The 2010 offering data showed that more students have rated the kits as having To Some Extent or a To great Extent impacted their learning compared with the first offering with the kits in Fall 2009.

The rating of the concepts covered in MCE464 showed a similar trend to the rating in the MCE433 course with students giving better rating in the second offering of the course. Note that in MCE464-Fall 2009, the students performed a free vibration response experiment. In the Spring 2010 semester, the same experiment was performed in the MCE366 course, but none of the students in the MCE366 course should have done the same experiment since MCE366 is a prerequisite to MCE466. In Fall 2010, the students in MCE464 performed a forced vibration experiment, but the same concepts were asked on the survey.

When students were asked to further elaborate by ranking the extent of contribution of the kits, Lectures, Text(s) and Homework to their understanding of the main concepts (Question 4 on the

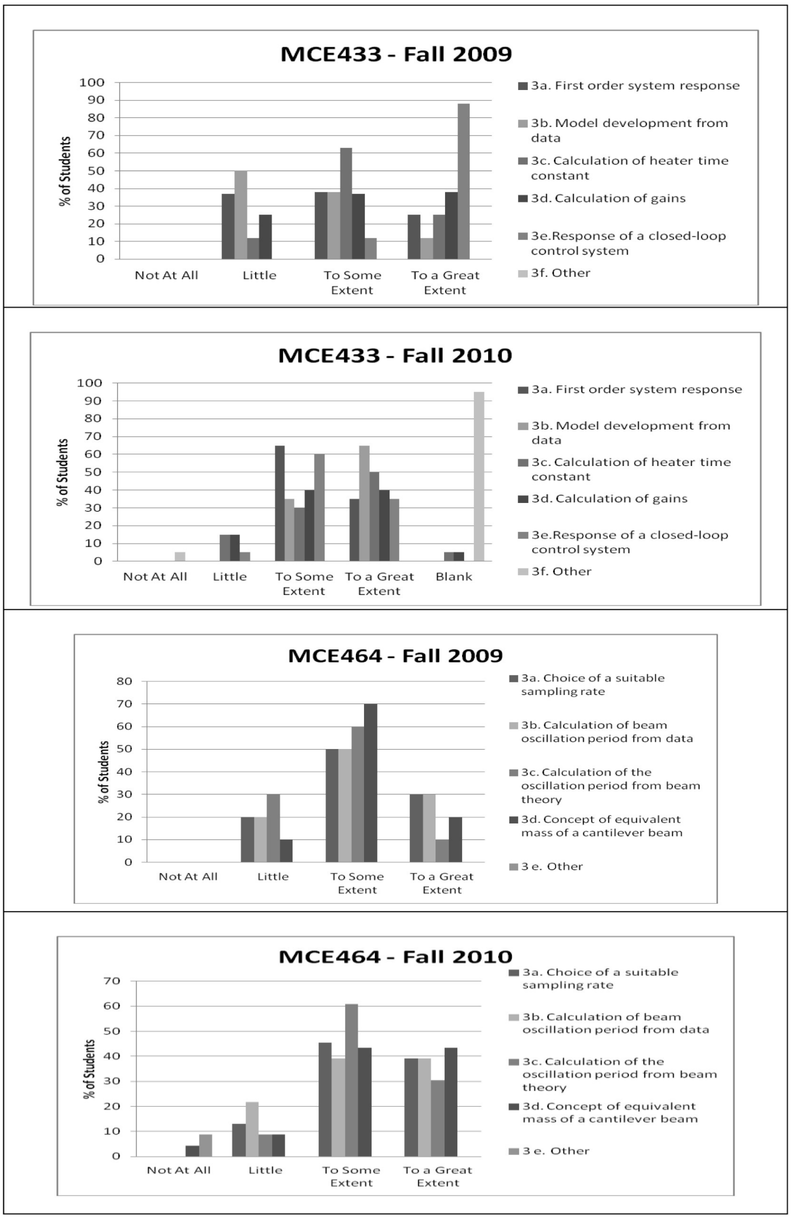

Fig. 5 Response of students to Question 3 in MCE433 and MCE464.

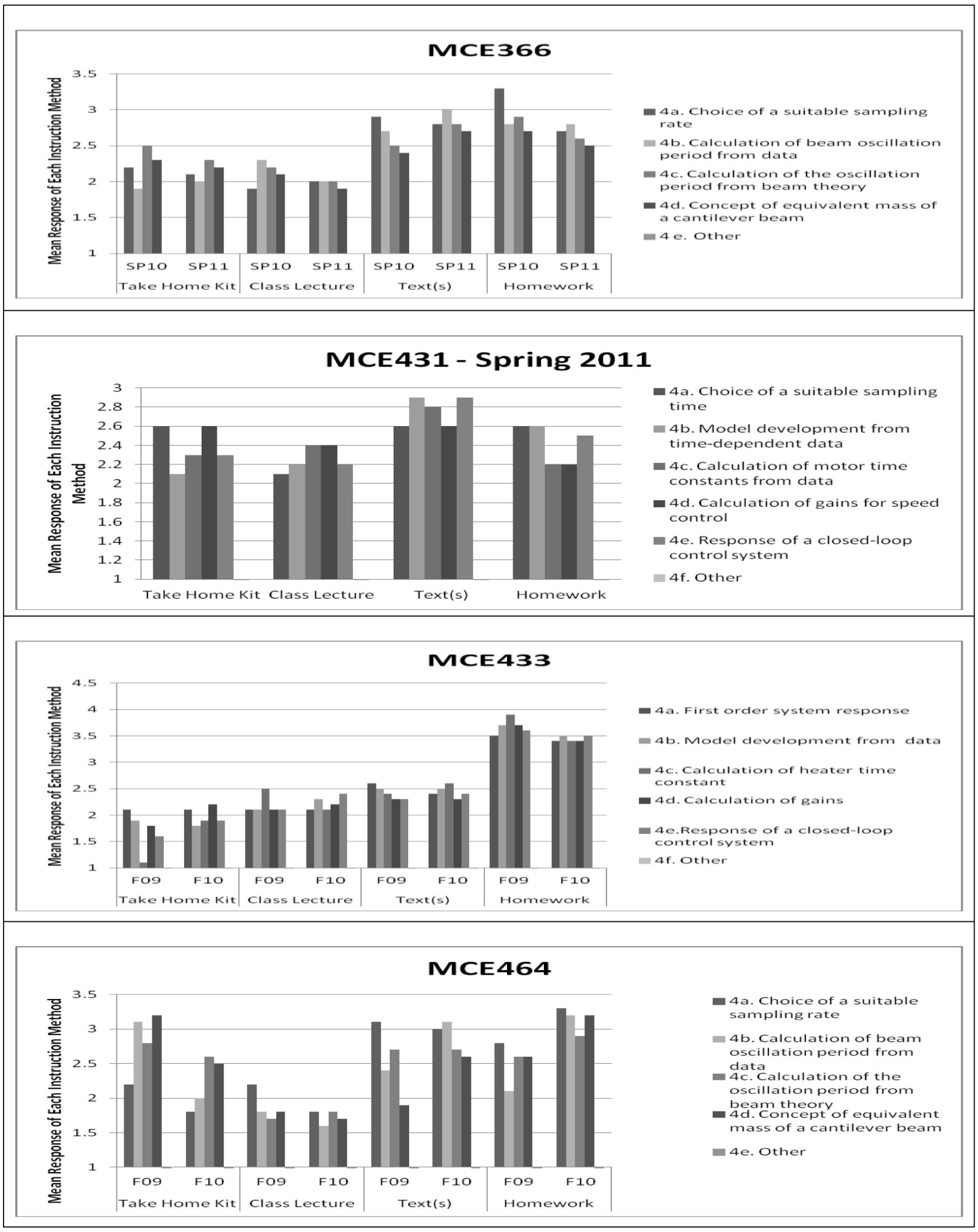

Fig. 6. Response of students to Question 4 that ranks the effectiveness of the different instructional methods (1: the most effective, 4: the least effective).

Survey), the response was mixed (see Fig. 6). In both offering of the MCE366 course (System Dynamics), the take-home kits were ranked slightly behind class lectures, but ahead of the text and homework. In the MCE431 course (Computer Control of Mechanical Systems), the kit was ranked the highest for one concept (4b) but behind class lectures in the other concepts. In both offering of the MCE433 course (Mechatronics), the students ranked the kit first, just ahead of class lectures, and significantly ahead of the homework. In the MCE464 course (Vibrations), the kits were ranked behind class lectures, and as comparable to texts and homework. From this data, we can say that the students had perceived that take-home kits have a contribution to their understanding of system dynamics concepts comparable to class lectures and more effective than traditional homework and textbook examples.

The results for Questions 5 (Do you live on campus or commute?) and 6 (If you commute, how many miles is it one way?) are shown in Figs 7 and 8 respectively.

For the entire 171 student sample, 30% reported that they lived on campus, and 70% reported that they commute. Figure 8 shows the distribution of how many miles they commuted. More than 30% of the sample reported that they commuted eleven or more miles one way. This data supports the notion

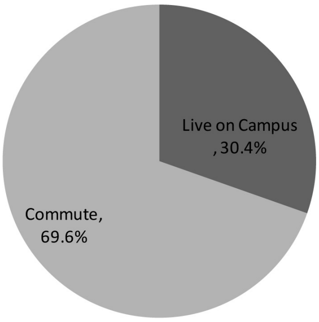

Fig. 7. Results for Question 5.

that at some institutions like URI, a sizeable number of students live away from campus, making scheduling lab times difficult.

The results for Question 7 (Are there barriers that make it difficult to come to campus for a three-hour lab session (for example, distance, family obligations, job, etc.)?) is shown in Fig. 9. About 42% of the entire sample said that there were barriers and 54% said that there were no barriers. The students were not asked to elaborate on the cause of the barrier, but from the response to Questions 5 and 6, we can speculate that commuting distance is one of those barriers.

The results for Question 8 (Was the take-home experiment's software difficult to set up?) are shown in Table 5. For the entire sample, more than 70% of the students reported that it was Somewhat Easy or Very Easy to set up the software. Note that the percentage reporting that it was Somewhat Easy or Very Easy to set up the software has improved in all affected courses on the second implementation of the take-home kit in that particular course. This is the result of solving issues in installing the software on multiple operating systems. The most dramatic improvement occurred in the MCE464 course where, in the second implementation, more than 86% of the students reported that it was Somewhat Easy or Very Easy to set up the software compared with 10% in the first implementation.

The results for Question 9 (Was the take-home experiment's hardware difficult to set up?) are shown in Table 6. For the entire sample, more than 88% of the students reported that it was Somewhat Easy or Very Easy to set up the hardware. Setting up the hardware mainly involves connecting

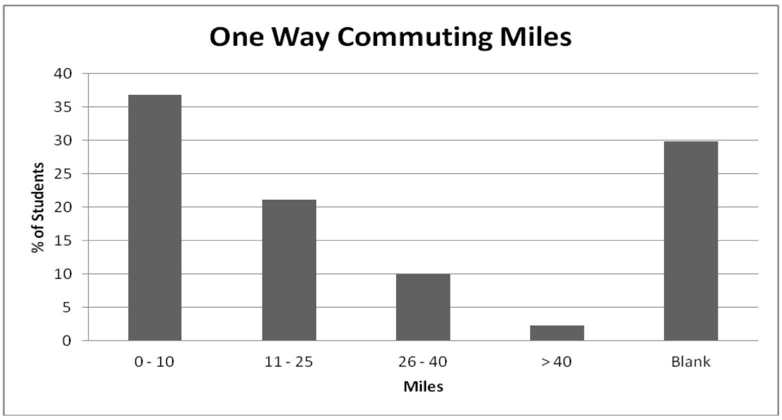

Fig. 8. Results for Question 6 on the Students' Survey.

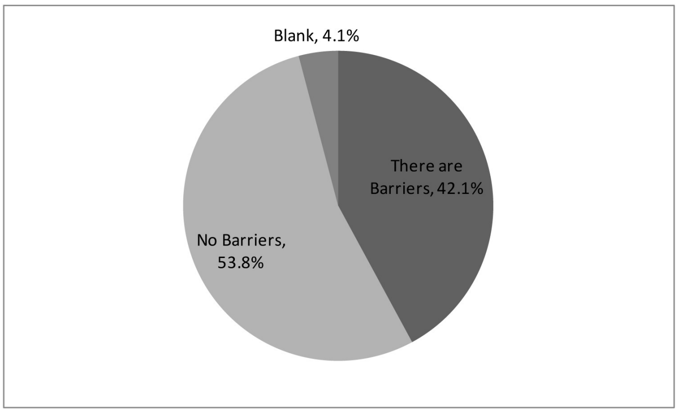

Fig. 9. Results for Question 7.

Table 5. Response of Students (percentage) to Question 8—Was the take-home experiment's software difficult to set up?

Semester	Course	Class size	Sample size (*N*)	Very difficult	Difficult	Cannot decide	Somewhat easy	Very easy
Spring 2009	MCE366: System Dynamics	47	42	4.8	28.6	11.9	16.7	38.0
	MCE431: Computer Control of Mech. Systems	9	8	0.0	25.0	0.0	12.5	62.5
Fall 2009	MCE433: Mechatronics	10	8	0.0	25.0	0.0	50.0	25.0
	MCE464: Vibrations	13	10	40.0	50.0	0.0	10.0	0.0
Fall 2010	MCE433: Mechatronics	23	20	0.0	5.0	0.0	25.0	70.0
	MCE464: Vibrations	28	23	0.0	13.1	0.0	47.8	39.1
Spring 2011	MCE366: System Dynamics	54	44	4.5	18.2	4.6	34.1	38.6
	MCE431: Computer Control of Mech. Systems	20	16	0	6.3	6.2	12.5	75
	Entire sample (*N* = 171)			4.7	19.9	4.7	26.9	43.8

the cables between the different kit components such as connecting the USB/serial interface cable from the hardware interface board to the PC/laptop and connecting the experimental setup's cable to the hardware interface board. Setting the hardware interface is easier than setting up the software interface because the latter involves downloading a driver to enable USB/serial communication. Note that the percentage reporting that it was Somewhat Easy or Very Easy to set up the hardware has improved from 70% to 86.1% in one course (MCE464) and decreased slightly (less than 10%) in the other three affected courses on the second implementation of the take-home kit in that particular course. There were no changes made to the hardware interfacing to affect the students' perception of the ease/difficulty of setting up the hardware.

The results for the last question on the survey (As a result of the take-home experiment, are you interested in taking more courses in the system dynamics area, such as mechatronics, control systems, or vibration?) are shown in Table 7. For the entire sample, over 74% of the students reported that they are Somewhat Interested or Very Interested in taking additional courses. For the required MCE366 course (which is a prerequisite to the other three courses in the table), the interest level was 54.8% in Spring 2009 and 79.5% in Spring 2011. The higher interest level of the students two years after the project started could be due to the refinement in the design of the take-home kits. The data shows that starting in the second year of this project (from Fall 2010), the actual enrollment in the technical elective system dynamics courses has jumped by more than 100%. While we cannot definitely say that the take-home kits were responsible for this, we believe that the students' experiences with the take-home kits in the required junior-level course has influenced their choice. The table shows that the interest level for students enrolled in MCE431 in Spring 2011 was higher than that in Spring 2009. In spring 2009, it was the first time that students have used the take-home kits, while in Spring 2011, the students enrolled in MCE431 have used the take-home kits at least once before taking the course.

The instructors for the MCE366, MCE431. MCE433 and MCE464 courses also administered quizzes for all the affected sections. Table 8 presents a compilation of the quiz and lab grades across all students. The quizzes were given before and after administering the take-home kit in each course. The pre and post quizzes contained similar conceptual

Table 6. Response of Students (percentage) to Question 9—Was the take-home experiment's hardware difficult to set up?

Semester	Course	Class size	Sample size (*N*)	Very difficult	Difficult	Cannot decide	Somewhat easy	Very easy
Spring 2009	MCE366: System Dynamics	47	42	0.0	2.4	7.1	21.4	69.1
	MCE431: Computer Control of Mech. Systems	9	8	0.0	0.0	0.0	12.5	87.5
Fall 2009	MCE433: Mechatronics	10	8	0.0	0.0	0.0	12.5	87.5
	MCE464: Vibrations	13	10	10.0	20.0	0.0	40.0	30.0
Fall 2010	MCE433: Mechatronics	23	20	0.0	0.0	5.0	15.0	80.0
	MCE464: Vibrations	28	23	0.0	8.7	4.3	26.1	60.9
Spring 2011	MCE366: System Dynamics	54	44	0.0	9.1	9.1	29.5	52.3
	MCE431: Computer Control of Mech. Systems	20	16	0.0	0.0	6.3	31.2	62.5
	Entire sample (*N* = 171)			0.6	5.3	5.8	24.6	63.7

Table 7. Response of Students (percentage) to Question 10—As a result of the take-home experiment, are you interested in taking more courses in the system dynamics area, such as mechatronics, control systems, or vibrations?

Semester	Course	Class size	Sample size (*N*)	Definitely not interested	Somewhat uninterested	Cannot decide	Somewhat interested	Very interested
Spring 2009	MCE366: System Dynamics	47	42	7.1	7.1	31.0	38.1	16.7
	MCE431: Computer Control of Mech. Systems	9	8	0.0	0.0	25.0	25.0	50.0
Fall 2009	MCE433: Mechatronics	10	8	0.0	0.0	25.0	62.5	12.5
	MCE464: Vibrations	13	10	0.0	0.0	30.0	60.0	10.0
Fall 2010	MCE433: Mechatronics	23	20	0.0	0.0	5.0	15.0	80.0
	MCE464: Vibrations	28	23	0.0	0.0	30.5	47.8	21.7
Spring 2011	MCE366: System Dynamics	54	44	4.5	4.6	11.4	50.0	29.5
	MCE431: Computer Control of Mech. Systems	20	16	0.0	0.0	6.3	31.2	62.5
	Entire Sample (*N* = 171)			2.9	2.9	20.0	40.9	33.3

Table 8. MCE366, 431, 433 and 464 Student pre/post tests

Course	Semester	Enrolment	Pre-lab quiz average	Take-home lab average	Post-lab quiz average
MCE366	Spring 2009	47	49%	99%	72%
MCE433	Fall 2009	10	48%	91%	61%
MCE366	Spring 2010	53	79%	93%	58%
MCE 464	Fall 2010	28	63%	90%	47%
MCE433	Fall 2010	23	44%	90%	60%
MCE431	Spring 2011	20	77%	91%	84%
MCE366	Spring 2011	54	69%	88%	81%

problems but were worded and presented differently. A review of this table indicates that for two sections of MCE366 and the sections of MCE431 and MCE433, the students quiz averages increased from pre- to post-testing. For one section of MCE366 and for MCE464, the pre- to post-quiz averages decreased. One explanation for this outcome is that students did not prepare for the quiz questions equally in all the courses. An examination of the Take-Home Lab reports scores indicates that for all the sections, the average grades were high, and were substantially higher than the quiz grades. One explanation for the higher take-home lab reports grades is that they were done at home with no limitation on time or additional resources to use.

There is no definitive way to credit the kits with this increase (or decrease) in student grades. The evaluation design did not include a control group so that a simultaneous comparison of both quiz grades and final grades to students in the four classes where the kits were not implemented can be performed. Nevertheless, the data indicated that the kits had a positive effect on student quiz grades.

5. Discussion

Student perceptions concerning their understanding of system dynamic concepts can be extrapolated from the responses to Questions 3 and 4 on the student survey. Examination of these data from the five semesters during which the kits were used in the four different MCE courses at URI, one can surmise that the kits played an important role in the conceptual understanding of the course material and application of the content to real world applications. The take-home kits have a contribution to understanding of system dynamics concepts comparable to class lectures and more effective than traditional homework and textbook examples. Also the pre- and post- quizzes grades indicated that the kits had a positive effect on student quiz grades. Given these findings, one must surmise that the objective of improving the understanding of system dynamic concepts was achieved.

Student perceptions concerning their ability and capacity to conduct and analyze data might be extrapolated from the questions on the survey that asked about Convenience (Q1), Comfort (Q2), Barriers (Q7) and Difficulty (Q8 and Q9). A review of the responses to these questions indicate that across all the MCE courses taught over the duration of the project, the majority of students found that the kits were convenient to use at home. The majority of students also reported that they were comfortable working on and with the take-home kits, independent of a lab or instructor. Finally, across the semesters and courses, the majority of students indicated that both the software and

Table 9. Course enrolments—2007 through 2011

Semester	MCE366 -Required	MCE431- Technical elective	MCE433 -Technical elective	MCE464 -Technical elective	Total enrolment in tech. electives
S07	69		17	21	38
F07		16	14		30
S08	59			20	20
F08			10	4	14
S09	47	9			9
F09			10	13	23
S10	56				
F10			23	28	51
S11	54	20			20
F11			23	25	48

the hardware of the take-home kits were easy to set up and use. Given these findings, one must surmise that the objective to enhance undergraduate Mechanical Engineering student ability to conduct experiments and to analyze data was achieved.

The interest of Mechanical Engineering students in system dynamics courses was measured in two specific ways. First, student responses to one of the questions on the Student Survey (Q10) indicated that the majority of students noted they were either Somewhat Interested or Very Interested in taking more courses in this area. A second manner by which this objective was measured was to examine student enrollment records in the courses that were impacted by the take-home kits. Table 9 presents the student enrollments in these courses over the last five academic years. This represents a time period from when the kits were being developed, but not yet used through the semesters that they were implemented. A review of this table indicates that, starting from Fall 2009, one semester after the kits were first placed into service, there has been an increase in student enrollment in the three technical elective courses affected by this project. Understanding that a number of environmental factors might have come into play to impact these enrollment figures, given the positive responses offered on the various Student Surveys administered and these enrollment figures, one must surmise that this objective is being achieved

As reported above, the majority of students have responded through the Student Surveys that the take-home kits were Convenient, Comfortable and Easy to set up and use. The nature of the experiments presented and covered though the kits allowed students to use real world applications and household resources to complete and understand the experiments. Given that the only opportunity that students might have had, previous to the kits, to perform such experiments would have been if such activities occurred during a class or through a separate lab session, these kits made it convenient and easy to perform at a time more convenient to them. Consequently, one must surmise that this was an improvement to the experiential learning of URI Engineering student and that this objective was achieved.

It should be noted that the developed kits have proven to be rugged and reliable, and almost in the same shape after being used by hundreds of students over several years. The low component cost of the kits and the use of the same hardware interface box and User-Interface Program makes them scalable to classes of various sizes. We have continued to use the kits in courses after the expiration of the external support for this project. Funds needed to maintain the kits (such as to replace missing or broken setups) and to hire a student helper (to manage the check out and check in of the kits) were obtained from the funds allocated for laboratory expenses at our institution. Many schools such as URI have a tuition surcharge for lab fees. Part of this money can be used to fund the purchase of new kits and for the maintenance of the existing kits similar to what is currently is done with other laboratory equipment. This should serve as a model for other institutions interested in the project on how to find funding at their school.

While the development and use of the take-home kits was successful, there were some difficulties that were encountered during the project implementation. One difficulty was the reliability of data transmission from the PIC microcontroller to the PC using a USB interface across different Windows operating systems. This problem was resolved by using a USB-to-serial converter interface instead of pure a USB interface.

One interesting thing we have noted is that a few students (less than 5%) did not attempt to do the take-home experiment at all. This is no different from regular homework assignments where some students will not attempt to do the homework.

6. Conclusions

This paper has addressed the evaluation of incorporating take-home kits as a supplemental instruction in four undergraduate-level system dynamics courses at the University of Rhode Island. A Student Survey was developed and used to collect perceptions of curricular effectiveness from the URI students on a post-course basis. In addition, pre and post quizzes were administered in the affected courses. A major benefit of take-home experiments is that they give the students an opportunity to conduct an experiment on their own. The evaluation of this method of instruction has shown several things. First, student responses on the surveys and results of quiz grades indicate that the kits played an important role in the conceptual understanding of the course material and application of the content to real world applications. The students had perceived that take-home kits have a contribution to their understanding of system dynamics concepts comparable to class lectures and more effective than traditional homework and textbook examples. Second, across the four mechanical engineering courses in which the kits were implemented, the majority of students consistently reported that they were comfortable working on, and with, the take-home kits independent of a lab or instructor. They also reported that both the software and the hardware of the take-home kits were easy to set up and use. Third, after the kits were first placed into service, there has been a steady increase in undergraduate Mechanical Engineering student interest in system dynamics courses as evidenced by an increase in the student enrollment in the three technical elective courses affected by the project. Finally, given that the only opportunity that students might have had, previous to the kits, to perform such experiments would have been if such activities occurred during a class or through a separate lab session, these kits made it convenient and easy to perform the course labs at a time more convenient to them.

It should be noted that while student feedback on the administered surveys consistently showed that the kits impacted student learning, were appreciated by the students and were useful to their learning, it did not definitely show that it was due to the kits alone. Consequently, in future application of the kits in mechanical engineering courses, to determine whether the kits increased student understanding of system dynamics concepts, at a greater level than conventional instruction, an evaluation design should consider a control or comparison group of mechanical engineering students. This was not done at URI due to the small enrollment of students, where only one section of the affected courses was offered in each year.

Acknowledgments—This project was supported by a CCLI Grant from NSF, Award DUE-0736603. Special thanks to Jim Byrnes for his help with the detail design of the hardware interface board.

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Appendix

URI College of Engineering
System Dynamics Measurements & Experimentation at Home Project

MCE431 Student Post Survey

The purpose of this instrument is to obtain information from you, as a Student participating in the URIatHome Project. We are interested in collecting your perceptions of the particular skills you will be taught as part of this project. Please circle (O) your response.

Thank you in advance for taking the time to answer the questions below.

1. How convenient is a take-home experiment than doing an experiment in the school lab? (circle one)

Very Inconvenient	**Somewhat Inconvenient**	**Cannot Decide**	**Somewhat Convenient**	**Very Convenient**

2. How comfortable are you in performing an unsupervised experiment at home? (circle one)

Very Uncomfortable	**Somewhat Uncomfortable**	**Cannot Decide**	**Somewhat Comfortable**	**Very Comfortable**

3. For each of the following MCE431 **concepts** covered in your class, could you please tell us the extent to which the **Take-Home Kits** contributed to your learning each of the following concepts.

To what extent has the Take-Home Kit contributed to your learning the concept of:	Not At All	Little	To Some Extent	To a Great Extent
3a. choice of a suitable sampling time.	N	L	S	G
3b. model development from time-dependent data.	N	L	S	G
3c. calculation of motor time constants from data.	N	L	S	G
3d. calculation of gains for speed control.	N	L	S	G
3e. response of a closed-loop control system (steady-state error & time constant).	N	L	S	G
3f. Other (please indicate). ________________________	N	L	S	G

4. For each of the following MCE431 **Concepts** covered in your class, please **RANK ORDER** the extent to which the **Instructional Tools** in the four right hand columns influenced your learning of each concept. (**1** = Most Influence to **4** = Least Influence). Please place a **1, 2, 3,** or **4** under each Tool, for each Concept. (circle your response)

Rank from 1 to 4 (1 being the Most) **the extent each instructional tool influenced your learning the concept of:**	Take-Home Kit	Class Lecture	Text(s)	Homework
4a. choice of a suitable sampling time.				
4b. model development from time-dependent data.				
4c. calculation of motor time constants from data.				
4d. calculation of gains for speed control.				
4e. response of a closed-loop control system (steady-state error & time constant).				
4f. Other (please indicate). ________________________				

5. Do you live on campus or commute? (circle one) **On campus** **Commute**
6. If you commute, how many miles *one way*? (circle one) **0–10** **11–25** **26–40** **>40**
7. Are there barriers that make it difficult to come to campus for a three-hour lab session (for example, distance, family obligations, job, etc.) (circle one) **Yes** **No**
8. Was the take-home experiment's *soft*ware difficult to set up? (circle one)

Very Difficult	Somewhat Difficult	Cannot Decide	Somewhat Easy	Very Easy

9. Was the take-home experiment's *hard*ware difficult to set up? (circle one)

Very Difficult	Somewhat Difficult	Cannot Decide	Somewhat Easy	Very Easy

10. As a result of this take-home experiment, are you interested in taking more courses in the system dynamics area, such as mechatronics, control systems, or vibrations? (circle one)

Definitely Not Interested	Somewhat Uninterested	Cannot Decide	Somewhat Interested	Very Interested

Thank you for your assistance with this questionnaire.

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