Project-Centered Modules in Mechanical Systems Engineering

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Abstract *— This paper presents a description of hardware and software modules used in dynamic systems and controls and related courses in manufacturing systems, mechatronics, robotics, and automation in the Mechanical Engineering curriculum. The modules span across a common set of equipment and are designed for varying degrees of depth, depending on use in a given course. The objective is to infuse a project-centered paradigm into the Mechanical Engineering curriculum. The idea is to coordinate theories taught in the classroom with physical devices and apparatus used in the project experiences to reinforce theoretical concepts and further stimulate student interest in Mechanical Engineering courses. This will also help to increase Mechanical Engineering undergraduate student retention rates. In this approach, students conduct hands-on exercises with physical hardware and in some cases also conduct corresponding simulations. The extent and scope of the hands on-exercises depends on the course may exist as supplemental motivational demonstrations, laboratory assignments, individual projects, or larger scale group projects. Thus, the projects are developed in a modular fashion with common physical hardware spanning across a spectrum of Mechanical Engineering courses and in varying scope. Undergraduate Mechanical Engineering students are primarily served by the project-centered paradigm discussed in this paper; however, some courses are cross-listed for other engineering disciplines. The physical systems are used to create demonstrations, laboratory exercises, and projects for the courses outlined in the paper. An initial series of project-centered modules are described. By the nature of the proposed paradigm, modules can be continuously developed, updated, and improved. Thus, an established approach represents the beginning of an infusion of the project-centered paradigm into the Mechanical Engineering curriculum. It is expected that the hands-on approach to teaching will prove beneficial as the project-centered paradigm is used to complement traditional teaching methods. Methods to evaluate the outcomes are also discussed.*

Index Terms *— Dynamic Systems and Controls, Experimental Equipment, Mechanical Engineering.*

INTRODUCTION

The North Florida Region is one of the fastest growing in the nation and has received recent acclaim as a top location for new and emerging businesses and industries to relocate or expand. The regional development agencies are aggressively recruiting industrial companies to this fast growing part of the nation. Recognizing this need, the University of North Florida (UNF) has recently expanded the established Electrical Engineering program to include Mechanical Engineering and Civil Engineering programs. The Mechanical Engineering program, now in existence for three years, is responding to the regional and national need for a stronger manufacturing infrastructure through enhanced learning in the machine sciences. The importance to manufacturing in the economy is crucial. Every individual and industry depends on manufactured goods. This sector continues to account for 14% of the US GDP and 11% of total US employment [1]. With the rapid development of new manufacturing industry in the region, it is necessary to also create skilled human resources for these burgeoning industries. Some of the direct input from local industry is that they desire students with hands-on experience with advanced machinery. Other survey results [2] conclude that manufacturing engineers must understand manufacturing processes and how they are controlled. The need for manufacturing integration and systems design appears to fall outside of the traditional domains of Civil, Electrical, and Mechanical Engineering [3]. The Mechanical Engineering program at UNF is striving to fulfill the demand for a regional need by addressing machine science and manufacturing systems engineering within the curriculum. One trend of engineering education [3] is to increase the manufacturing content in Mechanical Engineering by considering the effects of new and advanced technology. Another trend [4] is that engineering education is becoming more interdisciplinary and there exists a need for more hands-on laboratory experience.

PROJECT-CENTERED MODULE CONCEPT

One way to help the local growing industry is to develop a technologically sound engineering force well trained in fundamental engineering principles with exceptional hands-on experience with advanced machinery. An extensive hands-on approach is currently being integrated into the Mechanical Engineering curriculum. High technology training of the student by reinforcing theoretical concepts with hands-on learning enhances the development of scientifically and technologically literate engineering workforce for the region. The Project-Centered Modules (PCMs) are a catalyst for creating a more scientifically and technologically literate engineering workforce. The goals in developing the PCM concept are:

1. Develop and test new theories and knowledge about teaching and hands-on learning through development of the PCMs to engage students in processes and exploration of scientific and engineering principles,
2. Design and develop tools, materials, and methods through implementation of the PCMs to enhance learning through hands-on instructional technology, and
3. Develop an innovative instructional model by distribution and application the PCMs across an array of mechanical systems courses in machine science and manufacturing systems engineering.

The emphasis of hands-on approach to learning enhances the traditional theoretical approach to education in many engineering courses while also contributing, in the machine and manufacturing systems facet of the curriculum, to the responsiveness to the needs of the regional industry. Thus, an overall goal is to leverage the benefits of a smaller engineering program to better serve the needs of the region.

PROJECT-CENTERED MODULE DESCRIPTION

The fundamental idea of Project-Centered Modules (PCMs) is their use in support of theoretical learning in the machine sciences by hands-on experiences and their applications to interdisciplinary manufacturing and industrial systems. The outcomes of the proposed work are to:

- Create prioritized prototype PCMs that support theoretical learning in the machine sciences and their applications to manufacturing
- Perform a pilot test using PCMs spanning across a series of mechanical systems science courses that provides credible evaluation of the impact on student learning
- Provide a report of the results of the evaluation
- Disseminate the prototype to the professional community through technical conferences and/or journal publications, the internet, and additional reporting opportunities

The Project-Centered Modules may be categorized in three levels:

- Level I – Motivational Demonstration
- Level II – Experimentation and/or Laboratory Exercise
- Level III – Individual and Group Projects

In Level I, Motivational Demonstration, the target student is a sophomore or early junior. Early engineering courses are typically rigorous in theoretical development but often lack the connection to real-world application beyond a textbook description of a problem. In these Level I exercises, the theoretical concepts are demonstrated for the entering engineering students to engage them in interesting and stimulating application of the theories they are developing in the classroom. A laboratory setting is used to demonstrate the theoretical concepts, and the student may perform a laboratory report based on interaction and observation of a supervised experiment.

In Level II, Experimentation, the target student is a junior or senior. The course may be a laboratory course consisting of well-defined experiments or a course primarily consisting of lecture, but having theoretical content supplemented with structured experiments. A laboratory setting is used to enhance the theoretical concepts and the student performs an experiment with laboratory reporting based on the structured experiment.

In Level III, Individual and Group Projects, the target student is a junior or senior. The course consists of lecture and has theoretical content as done traditionally supplemented with in-depth structured projects and/or open-ended projects using the equipment. A laboratory setting is used to enhance the theoretical concepts and the student independently performs the in-depth project solely or with a team. The activities typically span multiple sessions.

The initial prototype PCMs are intended to address the machine systems courses, including manufacturing systems, of the machine science offerings at UNF. This currently does not include the machine design focus courses of the machine sciences area of Mechanical Engineering, the thermo-fluids courses, or materials courses. Provided the paradigm is successful, these domains may formally incorporate the project-centered paradigm to a greater extent than currently done. The following Mechanical Engineering major courses at UNF can make use of initial prototype PCMs to complement the respective course:

- EGN 3203 Modern Computational Methods
- EGN 3321 Dynamics
- EGN 3331L Mechanical Systems Laboratory
- EML 4312 Modeling and Analysis of Dynamic Systems

- EML 4313 Control of Machines and Processes

The EGN 3321 Dynamics course is cross-listed to Civil Engineering and Electrical Engineering, thus these students benefit as well. The following Mechanical Engineering elective courses can make use of PCMs to complement the respective course:

- EML 4804 Mechatronics
- EML 4806 Robotics
- EML 4544 Material Handling
- EML 4990 Production Systems Engineering

Physical systems are used to create demonstrations, exercises, and projects for the courses outlined above. First a priority is established for development of the PCMs. The scope of the PCMs is subsequently defined for a set of course offerings. Some examples of PCMs under development in existing courses are provided below.

In the EGN 3203 course, Modern Computational Methods, a modular robot system provides complementary motivational exercises and demonstrations (Level I) for the otherwise exclusively math and programming content of the course. Thus, students see, experience, and work with applied mathematics through the physical system. Experiments can be devised, using the robot, to make use of Linear Algebra and Matrix Operations (students perform coordinate transformations), Solutions to Simultaneous Equations (students do simple inverse kinematics for the robot), Curve Fitting and Polynomial Interpolation (students define trajectories for the robot), Numerical Differentiation (students use difference equations to determine velocities and accelerations from position histories of the robot), and Numerical Integration (students determine path parameters).

In the EGN 3321 course, Dynamics, a modular robot system (being a dynamic system), provides complementary exercises and demonstrations (Level I) for difficult-to-grasp abstract concepts. The students progress through the semester building on topics in Kinematics of Particles, Dynamics of Particles, Plane Kinematics of Rigid Bodies, and Plane Dynamics of Rigid Bodies. For example, in the topic Kinematics of Particles, the students plan paths (position, velocity, acceleration) for a simple symmetrical object in gripper. Then, using existing simulations, they determine the feasibility of the path based on path and kinematic constraints, and finally run the corresponding trajectory on a physical robot system after successful simulation. Thus, in this example, students see and experience first-hand the theory in action with the outcomes of intuition for kinematic parameters, familiarity with the application of numerical integration, and understanding of motion in different coordinates. The robot system is then available to make more in-depth project modules (Level II and Level III) in robotics and automation for elective courses in EML 4806 Robotics, EML 4804 Mechatronics, EML 4544 Material Handling, and EML 4990 Production Engineering.

The ECP physical plant and motion control systems are practical for experiments (Level II) in a Mechanical Systems Laboratory course and for project dynamics and control in the EML 4312 and EML 4313 course sequence. Again the students progress through the semester building on previous exercises, first by modeling the electro-mechanical system, determining the physical parameters for the system, and then proceed from modeling to control of the physical system. The physical plants are also useful for experiments in EML 4804 Mechatronics.

A series of PCMs based on the descriptions above is currently being created. By the nature of the proposed paradigm, modules can be continuously developed, updated, and improved. However, the scope will be limited based on an established priority. At least one module for the physical hardware systems will be completed and packaged for use in at least one course each. Thus, these initial PCMs represent a beginning of infusion of the project-centered paradigm into the Mechanical Engineering curriculum as indicated in Table 1. As seen in Table 1, the required machine system science courses (first five from left to right) make use of Level I, II, and III (Motivational Demonstration, Experimentation, and Project respectively) PCMs. The elective machine system science and manufacturing systems courses (remaining 4) are more in depth and naturally make use of Level II and Level III PCMs.

PROJECT-CENTERED MODULE IMPLEMENTATION PLAN

Although pilot PCMs have been initiated, the rollout of the prototype PCMs will occur over the next two years beginning in Fall 2004 semester continuing through Fall of 2006. Table 2 shows when the courses are planned to be offered in the Mechanical Engineering curriculum. The author has taught all of the courses but does not necessarily teach the course load of Table 2 simultaneously. For example, EGN 3321 Dynamics is always offered although the author does not always teach it.

Equipment and Resources

Two teaching and research laboratories in the new Science and Engineering Building at UNF are utilized for this effort. The building has recently opened in the first quarter of 2004. As noted earlier, the Mechanical Engineering program at UNF has been in existence for three years. Some of the equipment below exists. Since the program and the building are new, some of the additional equipment items discussed are anticipated acquisitions.

The two laboratories are:

1. Computer Automated Machinery and Manufacturing (CAMM) Laboratory
2. Robotics Laboratory

The CAMM Laboratory is 1000 square feet in the new Science and Engineering Building and serves as primarily a teaching laboratory. There exists an initial set of equipment as basis that can be extended. The objective of this laboratory is to provide a resource for courses in machine sciences and advanced manufacturing machinery. The laboratory is initially equipped with National Instruments data acquisition hardware; Educational Control Products (ECP) 210 Rectilinear Plant, 205 Torsional Plant; 220 Industrial Plant; 750 Control Moment Gyro; machine components donated from industry including industrial drives; computers; and software including Matlab, Labview, Dymola, and RoboWorks. The ECP systems in existence can be used for Level II and Level III PCMs however, there is only one each of these and more are needed to allow sufficient hands-on experience for all of the students to implement the PCMs.

The Robotics Laboratory is 600 square feet in the new Science and Engineering Building and serves as primarily as an undergraduate research laboratory for projects of robotics and automation with local industry. The laboratory is equipped with two Staubli RX60 CR robots, an AdeptOne robot; two Smart Technologies semiconductor robots; machine components donated from industry; computers; and software including C++, Matlab, Labview, and RoboWorks. This existing equipment is suited for Level III PCMs. The equipment to supplement the equipment above to create the PCMs is PowerCube robotics modules and additional ECP physical plants.

The ECP physical plants [5] provide experiments and equipment for projects in fundamentals of machine science including system identification and dynamic modeling of mass, inertia, friction, drive flexibility, backlash, gyroscopic dynamics, response for single and multi-degree of freedom systems and more. Control systems aspects include step response, impulse response, linearity principles, root-locus design, robustness, disturbance rejection, collocated controllers, noncollocated controllers, tracking control, single and multi-variable control and more. The versatility of these plants is well suited for PCMs.

The PowerCube modules are reconfigurable to allow for rapid generation of simple one, two, and three degree-of-freedom robots up to more complex six degree-of-freedom robots. Thus the simpler robots may be used in Level I PCMs while the more complex configurations of the PowerCube modules can be used in Level II and Level III PCMs along with the robots in existence as described above.

Timeline

A timeline for a 2-year development plan of PCMs is based on the course offerings and the requisite Level of PCM as follows:

- Fall 2004 – develop Level II, and Level III PCMs for EML 4313
- Spring 2005 – develop Level II PCMs for EGN 3331L and EML 4312
- Summer 2005 – develop Level I PCMs for EGN 3321
- Summer 2005 – develop evaluation criteria
- Fall 2005 – develop Level I PCMs for EGN 3203; refine/add PCMs EML 4313
- December 2005 – Pilot PCMs complete
- December 2005 – Begin evaluation
- Spring 2006 – Refine/add PCMs for EGN 3321, EGN 3331L, and EML 4312
- Spring 2006 – Develop Level III PCMs for electives
- Summer 2006 – Begin dissemination of results
- Fall 2006 – Refine/add PCMs EML 4313
- December 2006 – Proof-of-Principle complete
- December 2006 – Dissemination of results
- December 2006 – Reporting of two-year development activities

Evaluation and Dissemination of Results

Three methods of evaluation will be used to assess the effectiveness of using PCMs in the machine sciences and manufacturing systems engineering curriculum:

1. Comparison to baseline of course without PCMs
2. Student Evaluation feedback

3. Feedback from industry and other professional users

The author has taught many of the courses discussed above without the benefit of PCMs. These can be used to create a baseline for student's grasp of theoretical concepts. A set of norms for criteria will be designed based on conceptual material presented and tested in prior courses. These same concepts will be taught in subsequent course offerings with the benefit of PCMs. Improvements based on comparison to baseline norms will then be used to assess the benefit of PCMs. This will be the primary quantification for evaluation.

Course evaluations will also be used. The Mechanical Engineering Program has a supplemental evaluation in addition to the standard university evaluation that can offer targeted questions regarding the use of PCMs. Specific questions will be added to the appropriate Supplemental Evaluation each semester. Student feedback is an important means of achieving continuous improvement in course delivery and will be used each semester. Also, undergraduate Mechanical Engineering retention rates are monitored annually. Although many factors affect retention rates, it is expected that a hands-on approach to teaching will prove beneficial as the project-centered paradigm is used to complement traditional teaching methods.

Alumni surveys can also be useful to evaluate smaller programs [6]. Industry feedback will come from alumni who obtain jobs in industry for evaluation criteria for this project. Inquiries are distributed to all alumni of the Mechanical Engineering Program. Additional survey questions will be featured for those students who become employed in industry. Data regarding the relevance and preparedness of the former student with regard to their training using PCMs in their courses will be collected and analyzed.

Documentation for the prototype PCMs will also be made available for engineering educators, particularly in Mechanical Engineering disciplines. As part of the dissemination of information, ideally potential users could check out versions of PCMs. A survey feedback mechanism could then be used to gather evaluation data for effectiveness of the PCMs in augmenting established engineering courses at other locations.

The results of this effort will be disseminated to the professional community through technical conferences, conference proceedings and/or journal publications, the internet and NSF-sponsored reporting opportunities. Technical publication and presentation in conferences attended by engineering educators, particularly in the field of Mechanical Engineering will be the target audience to publicize the methodologies using PCMs. Technical journal publications will be submitted to further publicize the work.

Documentation of details regarding prototype PCMs may be published for use by others electronically on the web for public dissemination. These publication materials may consist of the Project-Centered Module descriptions including hardware and software requirements, and descriptions of Level I, II, and/or III PCMs for specified courses for other interested professionals teaching similar courses. A check-out procedure will enable tracking as a means to gather feedback to further aid in evaluation as discussed above.

CONCLUSION AND FUTURE WORK

The Project-Centered Module paradigm has been presented and described. In this approach, students conduct hands-on exercises with physical system hardware. The extent and scope of the hands on-exercises depends on the course may exist as supplemental motivational demonstrations, laboratory assignments, individual projects, or larger scale group projects. Thus, the projects are developed in a modular fashion with common physical hardware spanning across a spectrum of Mechanical Engineering courses and in varying scope. The aim is to integrate high technology training of the student by reinforcing theoretical concepts with hands-on learning to enhance the development of scientifically and technologically literate engineering workforce. The Project-Centered Modules are a catalyst for creating a more scientifically and technologically literate engineering workforce by this means. By the nature of the proposed paradigm, modules can be continuously developed, updated, and improved. Example descriptions of PCMs have been presented and a two-year development plan to advance the PCM paradigm has been discussed. Further implementation details using the equipment of the PCMs as well as the evaluation of the PCM paradigm will be reported in future works.

REFERENCES

[1] Manufacturing in America: A Comprehensive Strategy to Address the Challenges to US Manufacturers, US Department of Commerce, Washington DC, January 2004.

[2] Mason, G., "Results of an Industry Survey on Manufacturing Engineering and Manufacturing Engineering Education", Journal of Engineering Education, V87 Iss3, Jul 1998.

[3] Todd, R.H., Red, W.E., Magley, S.P., and Coe, S., "Manufacturing: A Strategic Opportunity for Engineering Education", Journal of Engineering Education, V90 Iss3, Jul 2001.

[4] Hsu, T-R, "Development of an Undergraduate Curriculum in Mechatronic Systems Engineering", Journal of Engineering Education, V88 Iss2, Apr 1999.

[5] http://www.ecpsystems.com/

[6] Puerzer, R.J., and Rooney, D.M., "The Alumni Survey as an Effective Assessment Tool for Small Engineering Programs" Journal of Engineering Education, V91 Iss1, Jan 2002.

TABLES AND FIGURES

TABLE I.
EQUIPMENT AND PCM LEVEL BY COURSE

PCM Equipment	EGN 3203	EGN 3321	EGN 3331	EML 4312	EML 4313	EML 4804	EML 4806	EML 4544	EML 4990
Staubli RX 60							II,III	III	III
AdeptOne						II,III	II,III	III	III
PowerCube	I	I	II		II,III	II,III	II,III	III	III
Industrial Drives	I		II	II,III	II,III	II,III	II,III	II,III	II, III
ECP 205	I	I	II	II,III	II,III	II,III			
ECP 210	I	I	II	II,III	II,III	II,III			
ECP 220	I	I	II	II,III	II,III	II,III			
ECP 750		I	II	II,III	II,III	II,III	II,III		

TABLE II.
SELECTED COURSE OFFERINGS 2004 TO 2006

FA 2004	**SP 2005**	**SU 2005**	**FA 2005**	**SP 2006**	**SU 2006**
EGN 3321	EGN 3321	EGN 3321	EGN 3321	EGN 3321	EGN 3321
EGN 3203	EGN 3331L	elective	EGN 3203	EGN 3331L	elective
EML 4313	EML 4312		EML 4313	EML 4312	
	elective			elective	