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ENGINEERING PROJECT PLATFORM FOR ELECTRICAL AND COMPUTER ENGINEERING CURRICULUM INTEGRATION

Dr. Ramakrishnan Sundaram, Gannon University

Dr. Ramakrishnan Sundaram is on the faculty of the Electrical and Computer Engineering department at Gannon University, Erie, PA where he is a Professor. He received his Ph.D. degree from Purdue University. His areas of research include digital signal and image processing, artificial neural networks, and outreach in STEM education.

Engineering Project Platform for Electrical and Computer Engineering Curriculum Integration

Introduction

This paper discusses how engineering projects developed on a centralized engineering project platform can integrate the undergraduate Electrical and Computer Engineering (ECE) courses across four-year ABET-accredited programs. This integration is viewed as an essential step to produce engineering graduates with skills that make them competitive in the global workforce. Typically, the courses in the ECE curriculum are taught as discrete units in relative isolation of each other. This approach does not effectively deliver the critical-thinking competencies that are required by the students at the system, sub-system, and component level for the design and validation of engineering projects. Through the creation and adaptation of new learning materials and teaching pedagogy, the ECE department at Gannon University believes that curriculum integration through integrated projects on a central platform has the potential to transform undergraduate STEM education. The *problem-based*[1,2], *project-based*[3-5], and *project-enhanced*[6] learning environment created by integrated projects enables students to work in teams and apply the principles of electrical engineering to solve problems at different levels of system integration. This is similar to what the student would experience in the workforce after graduation. In addition, the following beneficial aspects of the centralized engineering project platform are also noteworthy.

Vertical integration of courses with research

The centralized engineering platform will not only link the content of courses taught across the four year undergraduate curriculum but will also promote vertical integration[7] of the course content with faculty research projects identified on the platform. In this manner, undergraduate students gain valuable research and project experience as part of their curriculum as they become engaged in faculty research projects alongside faculty and advanced level students. This engagement will grow as they advance from the first year to the senior year because they will have gained, and more importantly, retained the knowledge, comprehension, analysis, and synthesis skills from their integrated project experiences. In addition, this strengthens the alignment of the ECE undergraduate curriculum with the cognitive domain of Bloom's taxonomy[8].

Self-directed learning on self-organized cross-functional teams

The creation and adaptation of new learning materials and teaching pedagogy will inspire students to adopt *goal-oriented*, *self-directed* learning (SDL) strategies[9-10] in addition to *instructor-driven* learning thereby enabling them to become better lifelong learners. The centralized engineering project platform creates the environment similar to that in the engineering industry wherein senior-level students guide the junior-level students. This relationship shares some of the attributes observed in industry with senior, junior, and entry-level engineers. Collaboration and team work on integrated projects promote leadership, communication, and technical skills across the four years of the curriculum, attributes that are crucial for future global engineers. The students learn to work on teams, assume leadership roles,

and make decisions on how to work together by abiding by a set of rules that will help the team succeed. They inculcate discipline and take responsibility for actions and decisions, facets that would serve them well in their future professions and careers.

Pairing and Swarming

The centralized project platform promotes *pairing*[11] and *swarming*[12, 13] to help teams of students be more productive and produce higher quality work. *Pairing* is the formation of a two-person team, where one person plays the role of the driver and the other person plays the role of the navigator. The driver has a narrow focus on the problem to be solved, while the navigator sees the larger picture i.e. the context in which the problem is being solved. *Swarming* comprises the use of more than one team of students to work on challenging integrated projects with tight deadlines. These experiences of work and collaboration within and across teams will make our graduates more competitive in the workforce.

Agile, scrum and lean

The centralized engineering project platform provides the necessary infrastructure for the faculty and students of the ECE department to adopt software development practices such as *agile*, *scrum* and *lean*[14, 15] within the ECE curriculum. The adoption of these practices will result in continuous improvements to both process and product. Continuous improvement is one of the essential requirements for the program to maintain accreditation. *Agile* is based on iterative and incremental development, where requirements and solutions evolve through collaboration between self-organizing and cross-functional teams. *Agile* promotes adaptive planning, evolutionary development and delivery, and encourages rapid and flexible response to change. Integrated projects across all the ECE courses and delivered through the centralized engineering project platform incorporate continuous improvement within the ECE program. The centralized engineering project platform stresses collaboration and team work, thereby breaking down the barriers created by faculty in confined office spaces. *Scrum* is the software development method[16] for managing projects and product or application development. Office space can be optimized to facilitate *scrum* practices. Laboratory facilities with large open areas for *pairing* and *swarming*, whiteboard spaces and walls for post-its facilitate team collaboration and increase the efficiency of collaborating teams.

Through the centralized engineering project platform, the ECE department takes on the identity of an ECE organization. In this organization, the faculty members of the ECE department, besides being traditional classroom educators, assume the role of integrated project managers. As a manager, the faculty member delegates responsibilities to the student and coordinates the project activities of the student teams. The students in the ECE program can be viewed both as four-year employees of the ECE workforce and as customers who pay for value-adding educational experiences. In addition, the students become mentors for new customers as they progress through the ECE undergraduate program. While the goal of the ABET education is to train the ECE students to achieve their highest potential, the goal of the ECE organization is to produce both the best skilled employees and the most satisfied customers who gain valuable experiences without incurring large expenses. This requires the ECE organization to operate as a

lean organization, the core idea of which is to maximize customer value while minimizing waste i.e. *lean* implies creating more value for customers using fewer resources, ensuring continuous product and process improvement, and eliminating activities that do not add any value. The ECE department envisioned as an ECE organization and conceived through the centralized engineering project platform will be a *lean* organization which understands customer value and focuses its key processes to continuously increase the value. The revised curriculum will reduce waste in material and inventory, improve workforce discipline, and the eliminate work in progress.

This paper comprises six sections. Section 2 discusses the set up of the centralized engineering project platform. Section 3 provides examples of laboratory workstations and integrated projects for the restructured ECE courses. Section 4 outlines the aspects of project management, project learning outcomes assessment, and project dissemination. Section 5 summarizes the current status of the project. Section 6 documents the conclusions and future considerations.

Section 2: Set up of the Centralized Engineering Project Platform

In order to promote *problem-based, project-based* and *project-enhanced* learning, the ECE department at our institution has adopted the electric golf cart as the engineering project platform to restructure the ECE lecture and laboratory courses. The electric golf cart comprises sub-systems such as the motor, power and, control which serve as the backbone for laboratory activities designed for core and elective ECE courses such as digital logic, electronics, electric drives, and embedded systems. Figure 1 illustrates the set up of the platform in the real-time integrated projects laboratory to deliver ECE courses through integrated projects on this platform.

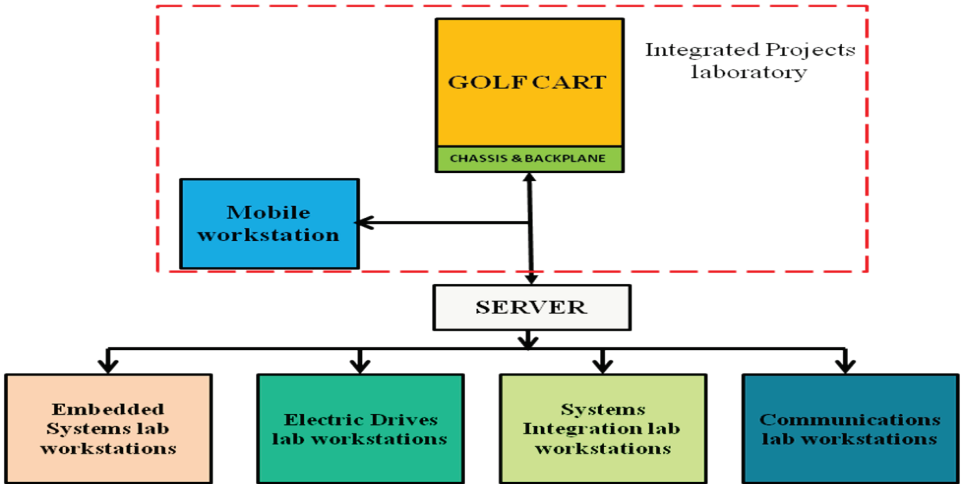


Figure 1: Project platform

The project platform comprises the following.

(a) Power subsystem and sensors on the golf cart

Power distribution and control; voltage, current, and speed sensors

(b) Chassis and backplane to be mounted on the golf cart

Printed circuit board (PCB) interface cards in the backplane for (i) power management (ii) power system drive circuit (iii) real-time control

(c) Mobile workstation for test and measurement

Portable data acquisition equipment for signal display and analysis

(d) Server

Data logging and interface to the ECE laboratories

(e) Laboratory equipment for workstations

Equipment for integrated project development in each laboratory

Integrated projects are developed for ECE laboratory-based courses across the curriculum These integrated projects are team-based laboratory activities that establish the link between each ECE laboratory-based course and the centralized project platform. The content and flow of the topics covered in the ECE laboratory-based courses will be revised. This includes the preparation of course content and teaching methodology for instruction in each course and the technical documents for operation of the integrated project.

Figure 2 shows the conceptual view of the golf cart system in relation to the core courses within the curriculum. These core courses are from the two program options ---*Electrical and Electronics* (*EE*) option, and *Computer Engineering* (*CE*) option. Courses unique to the *EE* option are Circuits II, Electronics II, Power Electronics, and Electric drives. The courses unique to the *CE* option are Embedded Systems, Embedded kernel/RTOS, and Rapid Prototyping with FPGA. The remaining courses are in both options. The department also offers courses such as Introduction to Communication Systems, Digital Signal Processing, and Real-Time Applications as technical electives.

The faculty members in the ECE department are identifying laboratory projects within the core ECE laboratory-based courses that link to the centralized golf cart project platform and are categorized as follows:

(i) *structured* laboratory exercises for each student (*individual*)

(ii) *unstructured* integrated projects for each team of students (*pair*, *swarm*)

While the *structured* laboratory exercises teach and reinforce fundamental ECE theory and principles of application to students as *individuals*, the *unstructured* integrated projects define open-ended project activities on the centralized golf cart platform for students working as *pairs* or *swarms* (groups formed from several *pairs*) to nurture and develop (a) student learning of ECE concepts at the system and sub-system level (b) skills related to project management and collaborative work. The core courses are restructured to teach the students to (a) understand fundamental and advanced concepts (b) link and use this understanding to *structured* and *unstructured* laboratory exercises developed on the centralized project platform. The courses in the ECE curriculum which are classroom-based incorporate practical examples from the functionality of the centralized golf cart project platform.

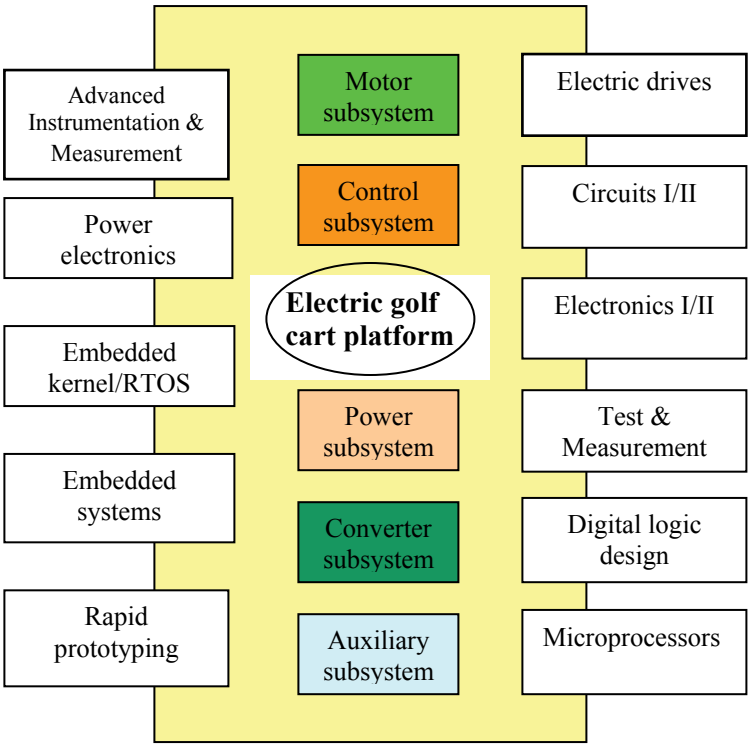


Figure 2: ECE core courses and the centralized golf cart project platform

Section 3: Examples of laboratory workstations and integrated projects

The department has the following cross-functional laboratories for integrated project development.

(a) *Systems Integration laboratory* – integration of previous circuit and electronics laboratories to provide an environment for system integration experience that includes functionality in circuit study and design, electronics study and design, test and measurement

(b) *Electric Drives laboratory* – enhanced functionality of the electric machines laboratory to include power electronics, real-time simulation, control, and rapid-prototyping

(c) *Embedded Systems laboratory* – enhanced functionality of the previous digital/microprocessor laboratory to include functionalities in FPGA studies, embedded applications

(d) *Communications laboratory* – functionality to perform basic and advanced studies in wireless and tethered data communication networks and protocols

(e) *Senior/Projects laboratory* – laboratory intended for seniors or any special projects to be conducted in a coordinated environment

The *structured* and *individual* laboratory exercises will train each student to use industry-approved tools (e.g. *Pspice* for circuit simulation, *NI-LabVIEW* for data acquisition and measurement analysis) to complete the laboratory activities that reinforce concepts in electrical engineering. The student will apply the learning from the *structured* laboratory exercises and the knowledge of electrical engineering principles gained from the lecture courses to work as a *team* (*pair/swarm*) of students to complete the *unstructured* integrated project.

Electric Drives Laboratory

Figure 3 shows the drive system of the centralized golf cart platform comprising the MOSFET switches, sensors and drive board. Course re-structure with integrated projects performed on this platform is achieved as follows. The students enrolled in the Electric Drives course (senior-level) and working in the Electric Drives Laboratory will (a) test discrete components (*structured*, *individual* laboratory exercise, as shown in Figure 4(a); (b) design, test and validate circuits (*unstructured*, *team* (*pair*) project, shown in Figure 4(b); (c) design, assemble, and test sub-systems (*unstructured*, *team* (*swarm*) project through the backplane of the centralized platform, as shown in Figure 5.

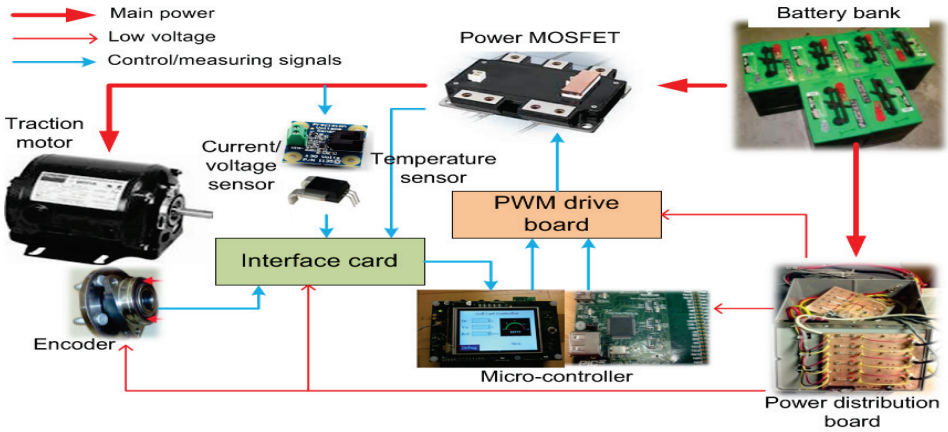
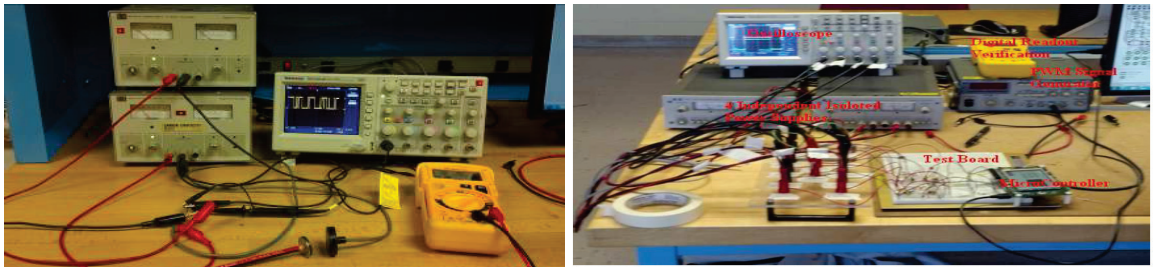


Figure 3: Drive system of the golf cart



(a) (b)

Figure 4: (a) *Individual*, *structured* laboratory exercise (b) *Unstructured*, *team* (*pair*) integrated project

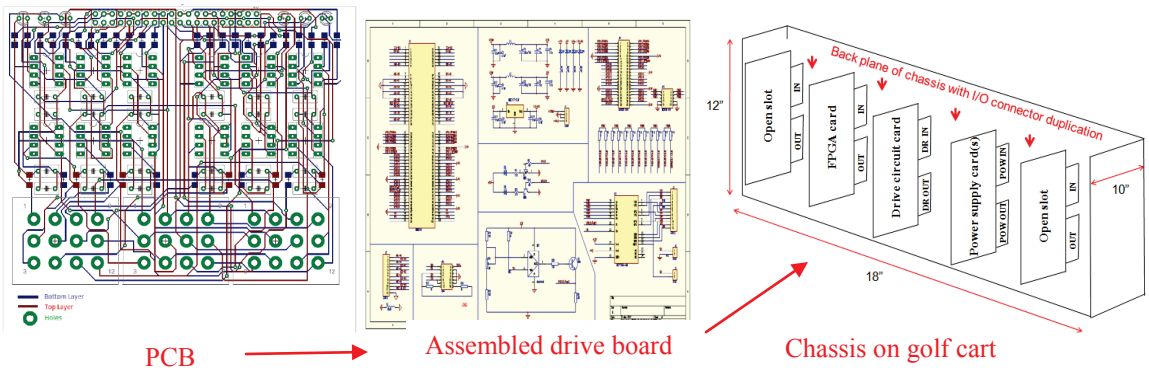


Figure 5: *Unstructured*, *team* (*swarm*) integrated project

Electronic Systems Integration Laboratory

Figure 6 shows the configuration of the typical laboratory workstation in the Electronic Systems Integration laboratory. In the *electronics* courses, the students (sophomore, junior-level) will (a) validate (e.g. *Pspice* simulations) the circuit design in *structured*, *individual* laboratory exercises; (b) build the protoboard-based sub-systems in *unstructured*, *team* (*pair, swarm*) projects; (c) assemble the PCB–based drive circuit board (Figure 5) for testing through the backplane of the golf cart. Since these students will not yet have taken the senior-level Electric Drives course, they will complete the testing of their design on the golf cart as part of the Electric Drives course. This ensures vertical integration of student learning experiences across a sequence of courses in the *EE* track.

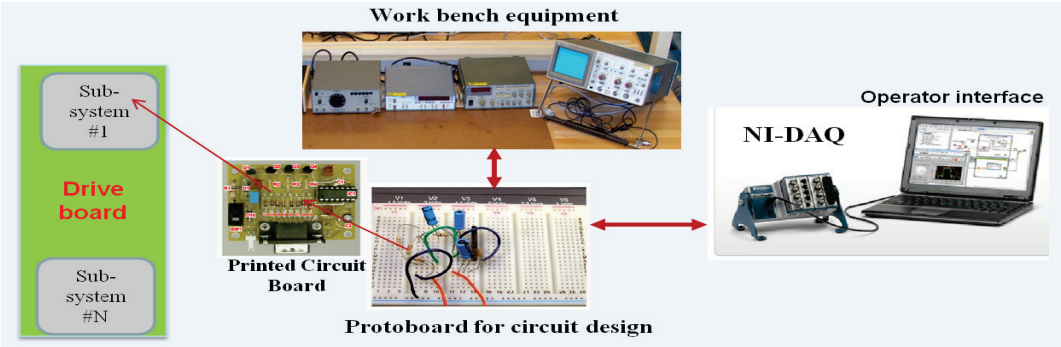


Figure 6: Typical workstation in Electronic Systems Laboratory

Embedded Systems Laboratory

Figure 7 shows the set up in the Embedded Systems Laboratory and the interaction with the centralized golf cart platform in the Integrated Projects Laboratory.

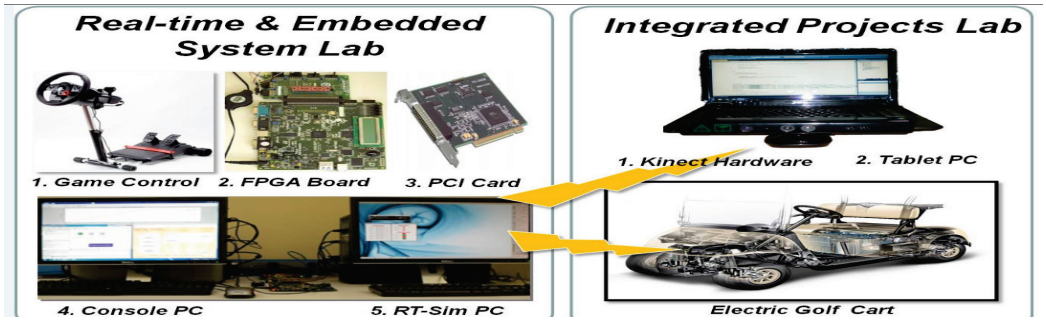


Figure 7: Embedded Systems Laboratory

First, students become familiar with laboratory equipment and programming tools in freshman-level (e.g. Digital Logic Design) and sophomore-level (i.e. Test and Measurement) ECE courses in order to successfully complete *structured*, *individual* exercises in this laboratory. An example of a *structured*, *individual* exercise is as follows:

- Generate and transmit data using the Spartan-6 FPGA Board
  Thereafter, junior-level students enrolled in Embedded System Design courses would have the necessary preparation to tackle *unstructured*, *team* (*pair*) projects identified as follows:
- Design the visual interface to measure the speed of an electrical vehicle.
  Finally, senior-level students in the CE track and enrolled in Real-Time Application would work on *unstructured*, *team* (*swarm*) projects such as
- Create the integrated real-time test and measurement environment for speed control.

In this manner, the vertical integration of student learning experience from a sequence of courses in the *CE* track is achieved.

Communications Laboratory

Sample laboratory activities in the elective course on Introduction to Communication Systems are shown in Table 1. These activities are identified in the categories of (a) *structured* for *individual* students (b) *unstructured* for *teams* (*pair/swarm)* of students.

Table 1: Sample laboratory activities in the Communications Laboratory

Activity	Broad objective	Specific objectives
structured individual	Understand the principles of analog modulation	• Set up the laboratory equipment for amplitude, frequency and phase modulation • Acquire, analyze, and present the data
unstructured team (pair)	Design the system for digital data transmission	• Set up the laboratory equipment for digital modulation techniques • Analyze the data and noise characteristics
unstructured team (swarm)	Build the wireless communication system for data to/from the golf cart platform	• Set up the network of sensors for data transmission to/from the golf cart • Send and receive data • Analyze the performance of the network

Section 4: Project Management, Assessment, and Dissemination

Faculty members are designated to be responsible for the following aspects of the project.

- *Reliable functionality of the centralized golf cart platform*
  Work with the laboratory manager to ensure the successful daily operation of the golf cart platform

- *Schedule integrated projects for each ECE course on the centralized platform*
  Maintain and circulate among all ECE faculty members the weekly schedule of integrated projects to take place on the platform

- *Project assessment*
  Coordinate all aspects of project assessment as discussed in the next section.

Project Assessment

The project will have both internal and external assessment.

Internal assessment

Internal assessment will be based on the assessment of course outcomes in each course (*embedded assessment*). At the start of the term, the course instructor will update the course information, set up the course outcomes, and define or create the *key assignments*. The course outcomes and the corresponding ABET student learning outcomes are assessed by the construction of the heuristic rule-based Excellent, Adequate, Minimal, and Unsatisfactory (EAMU) performance vector and its application to the *key assignments*. The construction of the EAMU vectors used for course assessment applies the following criteria: Excellent (E) is scoring 90% or better of the total points possible, Adequate (A) is 75% or better, Minimal (M) is 60% or better, and Unsatisfactory (U) is anything below 60%. The *key assignments* are judged by the EAMU vector as the metric to measure the course outcomes and ABET student learning outcomes. The instructor will prepare the *faculty course assessment report* (FCAR) to complete the self-assessment of the course outcomes.

The FCAR will have both *formative* and *summative* components. The *formative* component will be used to monitor student performance during the term and to adapt the instruction to meet the needs of student learning. The *summative* component will take place at the end of the term and will comprise the (a) determination of the attainment of course outcomes and ABET student learning outcomes from the EAMU performance vector for each key assignment (b) reflections on the delivery of the course, (c) the capture of action items from the delivery of the course, and (d) the closure on action items from the previous offering of the course.

The entire ECE department meets at the end of the term to review all the courses offered during that term. This leads to a consistent, department-wide recognition and acceptance of the revisions made to the re-structured laboratory courses and for changes to be incorporated within the curriculum that continuously improve the instructional practices. The ECE department uses the on-line survey tool, *EvalTools*®[17], to complete the stages of this process.

External assessment
The project requires *external assessment* in order to determine the broader impact of the centralized engineering project platform and the restructure of laboratory facilities to deliver critical systems-level teaching and learning skills through ECE courses across the undergraduate ECE curriculum. The three stages of the *external assessment* process are described as follows:

Prior to the start of the term

The designated ECE faculty member will contact the external evaluator to set up the timetable for the *external assessment* of the project. The evaluator will be provided the course information for the courses to be taught during the term. This course information will comprise course syllabi with the listing of course outcomes, topics covered, *key assignments*, and their relationship to course and learning outcomes similar to those currently in use by the ECE department.

During the term

The faculty assigned to teach the revised courses will collect the objective evidence for their course. This will comprise student performance assessment on *key assignments* using the EAMU performance vector as the rubric. The course instructor will also track student performance through the *formative component o*f the FCAR. The designated ECE faculty member will prepare the mid-term (after 7 to 8 weeks into the term) *progress report* to be provided to the external evaluator. This report will contain the *internal assessment* of each course taught.

End of the term

The following tasks form the components of this stage.

(a) The designated ECE faculty member will schedule the visit of the external evaluator to the department

(b) The evaluator will conduct interviews with the course instructors

(c) The evaluator will interview the students who took each of the revised courses.

(d) The evaluator will prepare the *external assessment report*.

This report will document the strengths and weaknesses of the centralized golf cart project platform and its components vis-à-vis the ECE curriculum. The faculty in the department will meet to generate action items for the revisions to be made to each course based on the *external assessment report*. This establishes the process of course and curriculum revision that ensures currency of the project within the framework of STEM engineering education.

Project Dissemination

The broader impact of this project is achieved through the dissemination of the *integrated project* set up and learning outcomes assessment for each re-structured ECE laboratory course. The components of the dissemination plan are as follows:

Technical documents, Laboratory Manuals, Websites
The technical documents will provide the specifications and operational guidelines for each *integrated project* set up. The laboratory manual for each course[18] will provide step-by-step instructions on the use of the *integrated project* set up in that laboratory course. The *integrated*

project set up will also be posted to academic websites such as the *Developer Zone* page of the National Instruments website (www.ni.com/academic) where the company highlights innovative use of their products.

Engineering education
The integrated project set up and learning outcomes assessment from each laboratory course will be disseminated through paper presentations[19-22] at conferences on engineering education such as the [Frontiers in Education (FIE) and the American Society for Engineering Education (ASEE)], seminars and workshops on STEM education, as well as in journals of engineering education e.g. *IEEE Transactions on Engineering Education*.

Section 5: Current status of the Project Platform

The restructure of the courses in the ECE curriculum at our institution has commenced and the following milestones have been achieved.

- Laboratory design, testing, and validation of the sensor, power management, and drive boards for the electric golf cart have been completed
- PCB design of each board completed
- Backplane/chassis layout completed
- Professional PCB manufacture (boards, backplane) initiated

In preparation for the assembled project platform to be functional in May 2014, the department has been offering new courses in topics related to *Electronic System Integration* and *Electric Drives* for the EE option (juniors and seniors), as well as *Rapid Prototyping with FPGA* and *Real-Time Embedded Systems* for the CE option (juniors and seniors). For instance, the course on *Electronic System Integration* engages the student in drive board designs for the centralized golf cart platform which they simulate the design in Pspice, complete the PCB layout, and build the in-house PCB using the PCB Maker in our System Integration laboratory.

The students who take these courses are assessed on specific course outcomes which are mapped to the ABET student outcomes. The ECE Department expects the first round of project and student assessment after the Fall 2014 term (December 2014). In addition, each ECE faculty member is revising the content of the course taught by them to include theory, structured lab exercises, and unstructured projects (where applicable) as related to the centralized project platform. The restructured courses will be offered starting the Fall 2014 term (August 2014).

Section 6: Conclusions and Future Considerations

The use of a centralized engineering project platform such as the electric golf cart is expected to strengthen the infrastructure of ECE education through the use of structured and unstructured integrated projects in the core and elective courses of the ECE curriculum.

Comprehensive curriculum integration will create and strengthen undergraduate engineering education as follows:

(a) Establish the laboratory facilities to deliver integrated skills

(b) Adopt integrated projects across the ECE curriculum to enhance student learning

Although research has shown the advantages of incorporating integrated projects into an ECE curriculum, it is not yet widely accepted or practiced. The implementation of this curriculum model and the careful assessment of its effectiveness will serve to guide others in best practices through the dissemination of our experience. The assessment of student learning in the integrated projects environment will lead to rubrics for project evaluation, survey questionnaires for learning outcome, and the dissemination of the project set up and learning outcomes through presentations at conferences, seminars and workshops on engineering education (e.g. *FIE*, *ASEE*), and articles in journals of engineering education (e.g. *IEEE Transactions on Education*).

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