# Design and Development of a Multidisciplinary Industry Supported Course in Mechatronics

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## Abstract

This paper presents the development of an introductory mechatronics course, and evaluation of a pilot summer course by industry and government partners as well as alumni. Students in the pilot course were from a local community college who participated in a summer internship at Virginia State University (VSU) under the Louis Stokes Alliance for Minority Participation (LS-AMP) project. These students had completed their second year at the community college, and plan on pursuing a bachelor's degree in an engineering discipline. The course started with project-based teaching of fundamentals of electrical circuits, electronics, and instrumentation followed by introduction to mechanical design. It concluded with design projects using the skills that students learned from the aforementioned subjects. The projects aimed at promoting active learning, research, problem solving, and understanding the design process. The pilot course was used to evaluate the instructional materials to be utilized later in developing a new junior level course in the computer engineering and manufacturing engineering curricula. Feedback from constituents indicated that the proposed mechatronics course is well-suited for the engineering programs at VSU.

## Background

The need for multidisciplinary collaboration in engineering fields is evident in industry and government in general, and found most exemplified in today's manufacturing industries. Transformation is needed to ride the expected tide of change in the current manufacturing environment, particularly in the information technology and automation landscape. Multinational manufacturing companies strive to reduce computing costs; improve plant floor visibility; achieve increased efficient energy systems; and use IT hardware and software investments more effectively [1]. Manufacturing was an important base of the American economy beginning with the days of the Industrial Revolution. The United States served as the leading manufacturer in the world for years through strong investment in innovation and entrepreneurship. However, that commitment waned over many years. Today, there is a need to reinvest in manufacturing. This nation's ability to reassert itself as the world's leader in this sector is threatened by high operating costs, consequently providing a competitive edge for other countries [2]. Manufacturers are increasingly turning to automation as a means of reducing cost through higher production rates, quality, and safety. The concepts of Smart Factory, Digital

Manufacturing, and Industry 4.0 have been developed recently to help industries in this effort by digitization of the manufacturing sectors [3]. The functionality of conventional systems needs to be transferred from mechanical to electronics and software domains. Data collection from these systems will be essential for process monitoring and control, as well as integrating the entire manufacturing enterprise as one system for global competitiveness.

As manufacturing is moving far beyond its origins to come to grip with these new technologies, engineers must have the capability to solve industry problems using mechanical and electronic processes, as well as computer technology. There is a clear indication that the available labor force does not have the skills needed to address the digital manufacturing age. A report authored by Deloitte and The Manufacturing Institute [4] shows that 67% of manufacturers had a moderate to severe shortage of available, qualified workers. A similar report indicates that from 2009-2012, American manufacturing companies could not fill as many as 600,000 skilled positions, although the unemployment rate during this period was 10%-18% [5]. Virginia State University wants to educate engineers who are prepared to effectively solve problems in the new manufacturing arena. Developing engineering students who have strong multidisciplinary teamwork experience will go long way toward meeting this objective.

## Introduction

In 2001, Virginia State University established computer engineering, manufacturing engineering, and computer science programs, all currently ABET accredited. The programs are housed in the Department of Engineering and Computer Science. The computer engineering program focuses on design of computer-based data systems in general, and data acquisition systems in particular. The manufacturing engineering program emphasizes product development from the design stage to production and delivery to customers. While these programs ensure that students are able to work effectively in teams, multidisciplinary teamwork is not strongly emphasized in the curricula. In order to affect this needed collaboration change, ways are being sought to provide students with more opportunities to hone their teaming skills with students in other disciplines prior to graduation.

## Purpose

Students in all of the engineering programs are exposed to comprehensive projects during their senior year where they experience a multidisciplinary project. In the past, participants in the senior project course sequence formed teams with students within the same program. There was little or no cross-discipline interaction in the senior design course. During the 2016-2017 academic year, the engineering programs placed twenty-two computer engineering and manufacturing engineering seniors in one pool, and eight teams were formed to work on the following design projects: 1) Wireless Robot; 2) Wind Turbine; 3) Transferable Wheelchair; 4) Heart Rate Monitoring System; 5) Formula SAE (Society of Automotive Engineering) Steering Knuckle; 6) Footprints on the Net; 7) Security Breaching Robot; and 8) Desktop Robotic Arm. It was required that each team have at least one member from each of the engineering programs.

The Chair of the Department of Engineering and Computer Science oversaw and coordinated all projects, and six faculty members from computer and manufacturing engineering programs provided direct supervision for the projects. The Chair had weekly classroom meetings with students in the senior project course, and bi-weekly meetings with the faculty supervisors. This experience clearly indicated that in order to improve the multidisciplinary quality of the senior projects, students should be exposed to the engineering multidisciplinary project environment prior to their senior year.

## Audience

Introduction to Mechatronics is developed to be a project-based, first semester junior level course. The course is designed to enhance the engineering related multidisciplinary experiences of students majoring in computer engineering, manufacturing engineering, electronics engineering technology, and mechanical engineering technology.

## The Mechatronics Course Description

The mechatronics course is an introduction to designing mechatronic systems that includes integration of mechanical and electrical engineering principles within a unified framework. Topics covered in the course include low-level interfacing of software with hardware; use of graphical programming tools to implement real-time computation tasks; digital logic; analog interfacing; measurement and sensing; and controllers. The course includes significant hands-on experiments as well as a final team project.

## The Course Design

An introduction to mechatronics course was taught in the summer of 2017 as a pilot to five community college students who were participating in an internship at VSU, under the National Science Foundation (NSF) supported Washington-Baltimore-Hampton Roads Louis Stokes Alliance for Minority Participation (WBHR-LSAMP) program. These students have future plans of continuing their education in either engineering (mechanical, electrical, computer, and manufacturing) or physics. The course consisted of lectures; laboratory experiments on circuits, rapid prototyping, PLC, and data acquisition with LabVIEW; and projects. Participants completed two team projects related to the manufacturing area, one of which was on an "Experimental Kinematic Study of Slider Crank Mechanism" that was designed to convert straight-line motion to rotary motion or rotary motion to straight-line motion. Students were challenged with the process control aspect and collecting data from sensors to evaluate the dynamic characteristics of the mechanism. The other project was on "Robotic Reverse Engineering" to reverse engineer a desktop robotic arm in such a way that to perform pick and place functions, and improve the functionality on the original design using techniques and software that were taught in the program. Students presented their projects at the WBHR-LSAMP Annual Summer Research Symposium on Thursday, July 27, 2017 at Morgan State University in Baltimore, Maryland.

The course was designed to have six student outcomes as follows: 1) an ability to apply knowledge of mathematics, science, and engineering to mechatronic system responses; 2) an ability to design and conduct a procedure for test and validation of a mechatronic system, as well as to analyze and interpret data; 3) an ability to design an electro-mechanical system, component, or process to meet desired needs; 4) an ability to function on multidisciplinary teams; 5) an ability to communicate effectively; and 6) an ability to use laboratory tools and software. These student outcomes were carefully selected in consideration of the knowledge and attributes needed in subsequent courses.

**Term Project Requirement**

A team project will have of two or three members. Each team must propose a project that does the following:

1. designs a practical device to solve an engineering problem;
2. develops a problem statement which the need and criteria for acceptability; and
3. includes, at a minimum, a start switch, a stop switch, an actuator, a sensor, data collection, theoretical calculations, and procedures for error analysis.

**Method of Assessment**

A survey instrument was developed to assess several aspects of the course including 1) student learning outcomes; b) course learning modules; and c) term project requirements. Students were asked to rate the importance of the competencies as they related to their academic goals, while faculty and industry partners rated the relevancy of competencies to that desired by industry. A scale of 1 to 5 was used with the designations as follows: 1= Not Relevant at All; 2= Somewhat Relevant; 3= Relevant; 4= Very Relevant; and 5=Extremely Relevant. The three components used in the survey are provided in Tables 1 through 3 along with details for each component.

**Table 1. A: Student Learning Outcomes**

| |
|---|
| A1) An ability to apply knowledge of mathematics, science, and engineering to a mechatronic system responses |
| A2) An ability to design and conduct procedure for test and validation of a mechatronic system, as well as to analyze and interpret data |
| A3) An ability to design an electro-mechanical system, component, or process to meet desired needs |
| A4) An ability to function on multidisciplinary teams |
| A5) An ability to communicate effectively |
| A6) An ability to use laboratory tools and software |
| Additional Comments |

**Table 2. B: Course Modules**

| Course Modules | Contents |
|---|---|
| Module 1-Circuits | B1) DC: Voltage, current, resistors, capacitors, inductors, ohm law, series circuits, parallel circuits, KVL, KCL |
| | B2) AC: Frequencies, periodic and non-periodic signals, impedance, diodes, Rectifiers |
| | B3) Laboratory Experiments: Proper usage of laboratory equipment, series, parallel, series-parallel circuits, power dissipation, rectifiers, AC-DC conversion |
| Module 2-PLC | B4) Boolean system, logic gates, counters, PLC and ladder logic, timer, counter PLC experiment |
| Module 3-Prototyping | B5) Intro to NX PLM, Developing G-Code, Experiment with 3D printers and CNC Machining |
| Module 4–Mechatronics System | B6) Sensors: Capacitive, resistive, and inductive sensors |
| | B7) Actuators: DC motors, linear, belt, gears, force, torque, speed, motor selection |
| | B8) Drivers and Controllers: Driver selection, PWM, PID Controllers |
| | B9) Data acquisition and interpretation |
| | B10)Signal Conditioning: Grounding, amplifiers, filters(hardware and software) |
| | B11)Simulation |
| | B12)Software: Graphical programing, high level language |
| | B13) Test and Validation |
| Additional Comments | |

**Table 3. Term Project Requirement**

| |
|---|
| C1) Team Composition |
| C2) Project Components |
| Additional Comments |

## Results and Analysis

Fifteen engineers from industry and governmental agencies completed the survey, of which six of them were VSU alumni who graduated more than four years ago. The participating organizations were the Commonwealth Center for Advanced Manufacturing (CCAM); Alstom; Northrop Grumman Corporation; Lockheed Martin; DuPont; Callisto Integration; Norfolk Naval Shipyard; National Security Solutions; Defense Supply Center; Defense Logistics Agency; and the Virginia Department of Transportation. Three participating students returned their surveys, fully completed, while two students returned partially completed surveys which are ignored in

this study. Three manufacturing engineering, three computer engineering, and two engineering technology faculty shared their feedback as well.

## Quantitative Analysis

Table 4 provides a summary of the statistical analysis performed using the feedback data from industry partners, faculty, and participating students. Figures 1 and 2 depict this same data in graphical form giving the means and standard deviations of the responses, respectively.

**Table 4. Summary of Statistical Analysis Results**

| Responses | | Course Outcomes | Term Project | Course Modules | | | | Overall Modules | Overall Results |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Circuits | PLC | Prototype | Mech. Sys. | | |
| Industry | Mean | 4.167 | 4.500 | 4.267 | 4.067 | 3.933 | 4.250 | 4.215 | 4.276 |
| | Standard Dev | 0.978 | 0.500 | 1.083 | 1.236 | 1.181 | 0.968 | 1.040 | 0.987 |
| Faculty | Mean | 5.000 | 4.813 | 4.292 | 4.375 | 4.250 | 4.406 | 4.365 | 4.488 |
| | Standard Dev | 0.520 | 0.390 | 0.735 | 0.696 | 0.968 | 0.765 | 0.773 | 0.699 |
| Students | Mean | 5.000 | 4.500 | 2.444 | 2.333 | 5.000 | 4.208 | 3.718 | 3.873 |
| | Standard Dev | 1.247 | 1.118 | 1.257 | 1.886 | 0.000 | 1.117 | 1.484 | 1.409 |

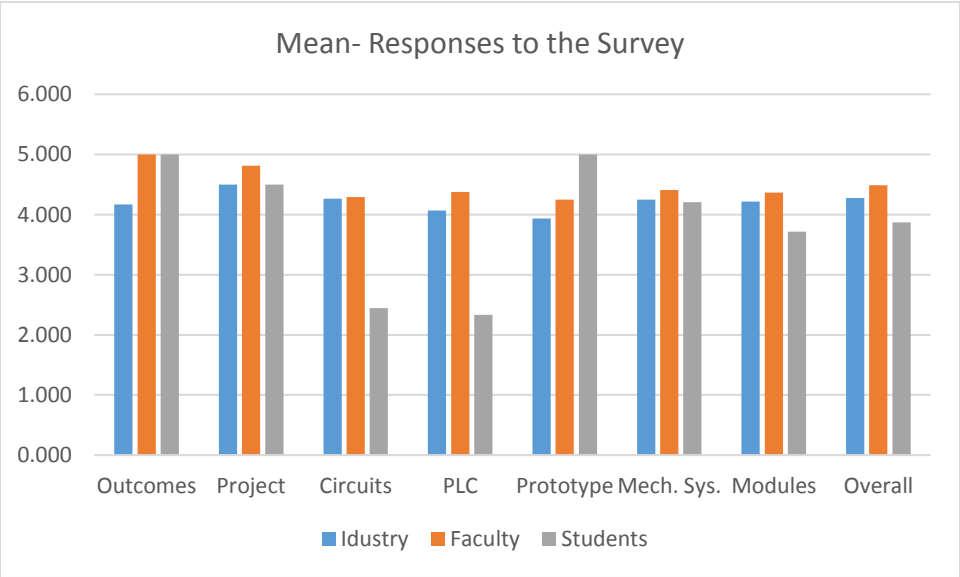


**Figure 1: Mean-Responses to the Survey**

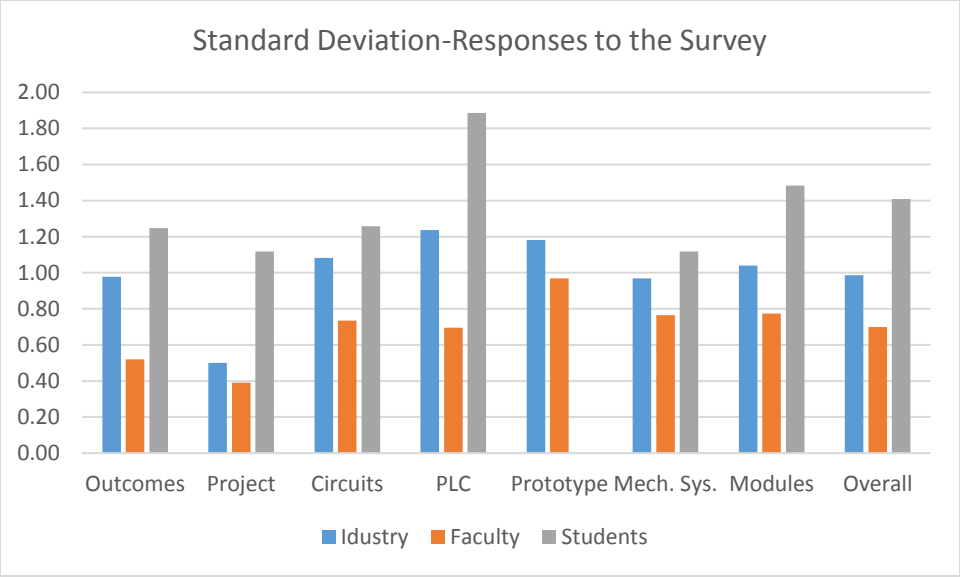


**Figure 2: Standard Deviation-Responses to the Survey**

The statistical results indicate that the feedback from faculty is more uniform with a standard deviation of 0.699 compared to industry/government and students' responses. The faculty felt that this course is more in line with academic curricula of affected programs at VSU. The students' feedback is the least uniform with a standard deviation of 1.409. This is understandable since they have the least experience in understanding the competencies that are desired by industries. Since a wide range of industries were surveyed, their responses exceeded our expectation on uniformity of feedback with a standard deviation of 0.987. In particular, one of the respondents was a network engineer who understood the value of the course; however, he rated '1' for most of the course modules and stated that "Contents rated a "1" aren't relevant to my field of engineering as I don't design electro mechanical systems or design them on a granular level." When his response is removed from the data, the overall mean of industry responses is 4.388 with a standard deviation of 0.782 which is much closer to the faculty responses. Industry favored the term project higher than faculty and students. On the other hand, the students liked prototyping the most.

There were three components to the course. Tables 5 through 7 show the mean responses to each element of the survey of student learning outcomes, course content, and term project, respectively. The alphabetic notation such as A1, B1, and C1 refer to the subcategories under each of components A (Student Learning Outcomes), B (Course Modules) and C (Term Project Requirement) as described previously under the Method of Assessment section.

**Table 5- Statistical Analysis Results- Student Learning Outcomes-Mean**

| Respondents | A1 | A2 | A3 | A4 | A5 | A6 |
|---|---|---|---|---|---|---|
| Industry | 4.467 | 4.400 | 3.933 | 4.400 | 4.400 | 4.400 |
| Faculty | 4.750 | 4.875 | 4.750 | 4.500 | 4.375 | 4.625 |
| Students | 3.667 | 4.333 | 4.333 | 3.667 | 4.000 | 4.000 |

It seems that industry and government desires competencies in an ability to apply knowledge of mathematics, science, and engineering to mechatronic system responses, whereas students viewed this competency least related to their future professional goals.

**Table 6- Statistical Analysis Results-Course Contents-Mean**

| Respondents | B1 | B2 | B3 | B4 | B5 | B6 | B7 | B8 | B9 | B10 | B11 | B12 | B13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Industry | 4.33 | 4.27 | 4.20 | 4.07 | 3.93 | 3.80 | 4.07 | 4.20 | 4.67 | 4.27 | 4.27 | 4.07 | 4.67 |
| Faculty | 4.25 | 4.13 | 4.50 | 4.38 | 4.25 | 4.75 | 4.63 | 4.50 | 4.00 | 4.38 | 4.38 | 4.25 | 4.38 |
| Students | 2.33 | 2.67 | 2.33 | 2.33 | 5.00 | 5.00 | 4.00 | 4.00 | 4.00 | 3.33 | 4.00 | 4.67 | 4.67 |

Industry responses indicated that they give high importance to an engineer who is skillful in collecting data and able to interpret them. On the other hand, students believe that prototyping and understanding sensors applications are most related to their professional goals.

**Table 7- Statistical Analysis Results-Term Project-Mean**

| Respondents | C1 | C2 |
|---|---|---|
| Industry | 4.47 | 4.53 |
| Faculty | 4.75 | 4.88 |
| Students | 5.00 | 4.00 |

Industry, faculty, and students rated term project somewhat high. Because of this, more time will be allocated for term projects, and their complexity will be examined closely.

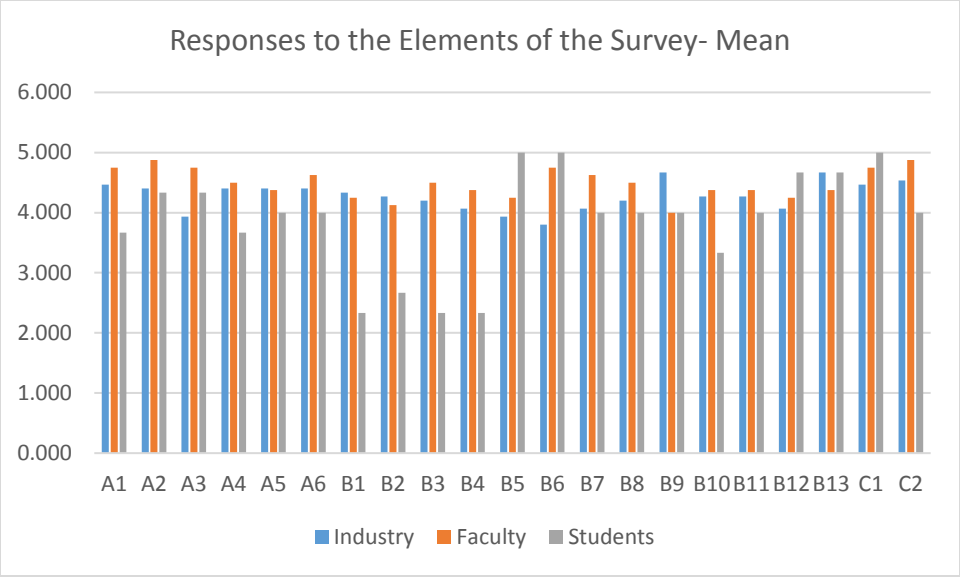


**Figure 3: Responses to the Elements of the Survey-Mean**

Figure 3 portrays the means from all categories of respondents for the student learning outcomes, course modules, and term project. This provides a complete view of the statistical results.

Survey Responses and Actions Planned

Twenty-nine comments were received. Most of the respondents believed that the proposed mechatronics course is a very good idea. They provided several suggestions for course improvement, some of which are as follows:

1. "Although this course does mention the use of Allen Bradley PLC instruction, it would also be useful to touch on industrial wiring, specific to the use of terminal blocks and other DIN mounted hardware and components that are commonly used with these PLC's. The significance is that this hardware looks markedly different that circuit board components which are commonly taught in mechatronics, and offer different capabilities."

   **Action**: This will be incorporated in the lesson plan for the PLC module.

2. "While working in the industry, I have run across many types solenoid valves. Perhaps, our students could benefit from being more familiar with electromechanical fluid control valves."

   **Action:** Application of solenoids in general will be considered in the course. Consideration is being given in designing a lab experiment that covers electromechanical fluid control valves.

3. "These modules are very good. They are all definitely necessary and relevant. It is very important to have a thorough introduction on both sides of engineering involved. However, is there enough time for all of the contents to be taught in just one semester? Should this be broken down to two semesters? For example: If this is the first time the student is taking a course that involves Pspice, Matlab and 3D printers, then there should be plenty of time offered for experiments and trial and error."

   **Action**: At this time, this is a one semester course. This suggestion will be revisited after the course is taught at least one time during the academic year.

4. "In my opinion, since this is an introductory course, instead of having the students propose a design, give them a list of ideas and have them pick which one interests them the most. Also, how much time do they have to work on the project? How big is this project? I think that should be specified to give students a clear idea of what to expect."

   **Action**: This suggestion will be revisited prior to the course being taught.

5. "Cover safety guidelines about power tools before performing the lab."

   **Action**: The programs already cover safety guidelines.

6. "Adding sampling theory, anti-aliasing, sensor's calibration, sensors using laser, etc. will enhance this course."

   **Action**: This suggestion will be revisited after the course is taught at least one time during the academic year.

7. "Limit team composition to 2 participants if possible but force teams to work on projects that must "mate" to each other per functional specifications. This will insure that individual contributors actually contribute while also forcing the various teams to interact with students on different teams."

   **Action**: This suggestion will be revisited after the course is taught at least one time during the academic year.

8. "Consider including the following as part of minimum requirements: PLC programming (with a PID loop included?), Written Test & Validation procedure, User interface? (might be asking too much)."

   **Action**: This suggestion will be revisited after the course is taught at least one time during the academic year.

9. "Team Project: Incorporate quality planning that focus on setting quality objectives and specifying necessary operational process requirement. Introduce students to use some

commercial specification and standards (ASME. SAE, etc.) to their design. Include also inspection requirements and quality acceptance and reject criteria on their design project."

**Action**: This will be incorporated in the lesson plan and term project

10. "The circuit module should be a pre-requisite, it should not spend so much time in the mechatronics class."

    **Action**: This suggestion will be done.

11. "Mechatronics does provide students a broader engineering perspective which is quite helpful. Care needs to be given to focus on the "engineering" aspect of mechatronics rather than the "technology" aspect."

    **Action**: This suggestion will be done.

12. "Team project requirement does not mention on multidisciplinary even though Student Outcome indicates "An ability to function on multidisciplinary teams."
    PID Controllers need more time. Probably, Module 1 needs to give up some time to PID lecture. I think all engineering and technology students know most of Module 1."

    **Action**: This suggestion will be done.

## Conclusion

An analysis of the survey and feedback comments from industry and government, alumni, faculty, and students suggest that this course is well suited for engineering and engineering technology programs at VSU. Some of the suggestions from industry partners will be integrated in lesson plan. There were suggestions that are not feasible to incorporate at this time; however, those suggestion will be revisited after the course is taught for the first time.

## Acknowledgements

This work was supported in part by the HBCU-UP of the National Science Foundation under NSF Cooperative Agreement No. HRD-1036286. Any Opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect those of the National Science Foundation.

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