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# MECHATRONIC CAPSTONE DESIGN COURSE

Kevin Craig

Department of Engineering, Hofstra University, Hempstead, NY, USA

## ABSTRACT

*Mechatronic system design is multidisciplinary and integration among the mechanical, sensor, actuator, electronic, computer, and control elements is essential. The integration is done simultaneously from the beginning and the design is model-based. Modeling, physical and mathematical, is the key in modern engineering practice. Before any hardware is purchased or built, a complete, computer virtual prototype is created to meet all performance specifications. Only then can an actual hardware prototype be built. Mechatronics students need to perform, need to experience, this process before graduation. It is all about the process, as they will be asked to apply the process to challenging problems. Modern machines are complex and computer-controlled, but most are made up of mechanisms. In this course, senior mechanical engineering students choose a mechanism to perform a certain task. They then apply the process to create the virtual and hardware prototypes to meet performance specifications, just like real mechatronics engineers.*

## KEYWORDS

*Mechatronic Design Process, Mechatronic System Design, Mechatronics Education, Senior Capstone Design, Virtual and Hardware Prototypes*

## 1. INTRODUCTION

Mechatronics is the best practice by engineers driven by the needs of industry and human beings. It is technology integration to achieve optimal system functionality, the synergistic integration of physical systems, electronics, controls, and computers through the design process, from the very start of the design process, thus enabling complex decision making. Integration is the key element in mechatronic design as complexity has been transferred from the mechanical domain to the electronic and computer software domains. Mechatronics is an evolutionary design development that demands horizontal integration among the various engineering disciplines, as well as vertical integration between design and manufacturing, and is what modern mechanical engineering needs to be.

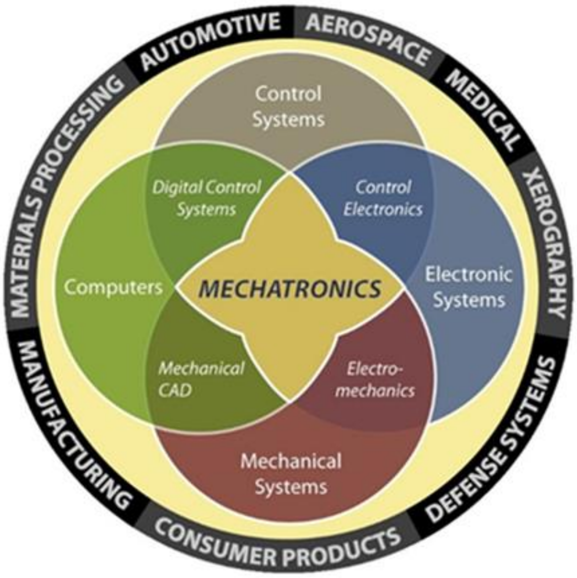


Figure. 1 Mechatronics Diagram

As a professor at Rensselaer Polytechnic Institute from 1989-2008, I created the mechatronics undergraduate and graduate programs there, and, in 1995, created the Mechatronics diagram (Figure 1), now used around the world to illustrate this multidisciplinary field.

Design, above all else, defines the difference between an engineering education and a science education. Design represents the bridge between theory and reality. It is the process by which our ideas enter and influence the world around us. Design distinguishes us as engineers. This one-semester, three-credit senior capstone design course for mechanical engineers is intended to be a challenging multidisciplinary design experience prior to graduation. This course builds upon the knowledge and skills that students have gained from other engineering courses taken as part of the mechanical engineering curriculum, in particular, the junior-level, four-credit required courses Modeling, Analysis, & Control of Dynamic Systems, Mechanical Engineering Design, and Mechatronic System Design. It provides a meaningful culminating experience that introduces students to the multidisciplinary, mechatronic aspects of design and to the essential model-based approach to design, rather than the design-build-test approach that is so common in a senior capstone design course. Under the guidance of the instructor, students develop an appreciation for the depth and breadth of knowledge and skills necessary for successful implementation of a significant development effort. The integrative and iterative aspects of a capstone design experience are emphasized. Students are required to apply their skills in multidisciplinary design, modeling, analysis, simulation, verification, and computer-control design, with electronics, sensors, actuators, microcontrollers, and real-time programming. Professional development in areas of team dynamics, interpersonal relationships, and technical communications are learned via active participation.

All mechanical engineering programs have a senior capstone design course. It is an ABET (Accreditation Board for Engineering and Technology) requirement. A review of senior mechanical engineering capstone courses around the country will uncover considerable differences. Among the differences are:

- The course is either a one-semester, three-credit course or a two-semester, four-credit to six-credit course.

- The design project is either purely mechanical or is multidisciplinary, with sensor, actuator and micro-computer control.
- The design project is industry-sponsored or is proposed by the student design team.
- Funding ranges from industry financial support up to several thousand dollars, to $400 - $1000 per 4-person team funded by the mechanical engineering department.
- The project can be virtual, i.e., a paper design and slide presentation are the end result, with or without a working virtual prototype. Or the project can include both a complete working model-based virtual prototype, followed by a working hardware prototype.
- The approach used is design-build-test, with little or no physical / mathematical modeling, or the design must consist of a model-based virtual prototype, either alone, or followed by a working hardware prototype.
- The design experience can be run as a formal class, with 3-4 person teams, or as an independent study activity with 3-4 person teams or individual projects.

## 2. MECHATRONIC MACHINE DESIGN

A modern mechatronic machine is like the human body. The actuators are the muscles that make things happen. The sensors are the senses that tell us what is happening. The links and joints of the mechanisms are the legs, arms, hands, and joints of the human body, and the microcontroller, which performs the complex decision making it has been programmed to do, is the human brain. Mechanisms have been around for millennia dating back to the Egyptians. Up until 30 years ago, the design of mechanisms was purely mechanical, often with mechanical cams, but, in the present mechatronic age, the design is multidisciplinary, i.e., mechanical, electrical, electro-mechanical, hydraulic, and pneumatic, all computer-controlled, with electronic cams and complex motion profiles (See Figure 2).

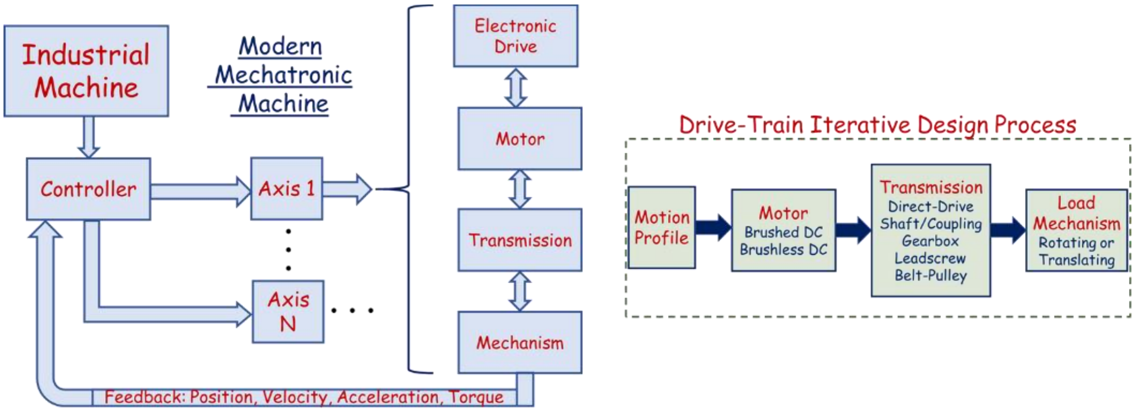


Figure 2. Modern Mechatronic Machine and Drive-Train Iterative Design Process

What does it mean to mechatronify a mechanism or machine [1]? In life, how you do something is more important than what you do. Mechatronics is more than just adding a sensor, an actuator, and a computer control system. They must be added in an integrated way from the very start of the design and, just as importantly, using a model-based design process that takes advantage of analysis techniques and simulation software and leads to optimum designs without trial and error. Combining old inventions with new technology fosters innovative ideas, but it is the process that transforms these ideas into reality.

A mechatronic approach to the design and implementation of any mechanism has been developed that reflects both the traditional mechanism analysis and synthesis methods together with the best industry practices, e.g., Rockwell Automation, Procter & Gamble. It is shown in the flow chart

(Figure 3) [2]. It is through this process that innovative ideas become a reality. Sweating the details with a combination of knowledge, old and new, process, and determination will make innovation happen.

System requirements dictate a desired end-point trajectory. The motion can be defined as an electronic cam, characterized by different profiles and maximum values of velocity, acceleration, and jerk, which will affect the level of mechanical stress, vibration, and noise in the motor, transmission system, and mechanical load. It is essential that the desired motion profile be chosen first because the required torque vs. speed curve to size the motor depends on it. In addition, the motion profile has relevant implications on the tracking errors through the control system. A kinematic (geometry of motion) model of the mechanical system is then developed, and through inverse kinematics, the required motor motion profile is determined. The torque-speed requirements for the motor are determined by first developing a kinetic (geometry plus all torques and mass moments of inertia) model of the complete mechanical system and then applying an appropriate feedback control system to that model. A computer simulation (e.g., MatLab Simulink) of the mechanical and control systems will result in the necessary torque-speed curve of the load to size the motor. Candidate servo motors (e.g., brushless DC motor) can now be identified. Additional requirements, e.g., cost, energy efficiency, and load-to-motor inertia ratio, will shorten the list. The chosen motor, including any flexible couplings or gearing, becomes an integral part of the system and its properties must be included in the system model. The control system will have to be tuned or even modified because of the motor addition. A computer simulation will reveal new torque-speed requirements for the system. Is the motor's torque-speed capability satisfactory? Is the control system stable? Does the system meet application-specific requirements regarding time response, relative stability, and steady-state error? If the answer to any of these questions is no, iteration is required. A model-based design approach, together with computer simulation, will lead to an optimal motor selection with all the benefits that implies.

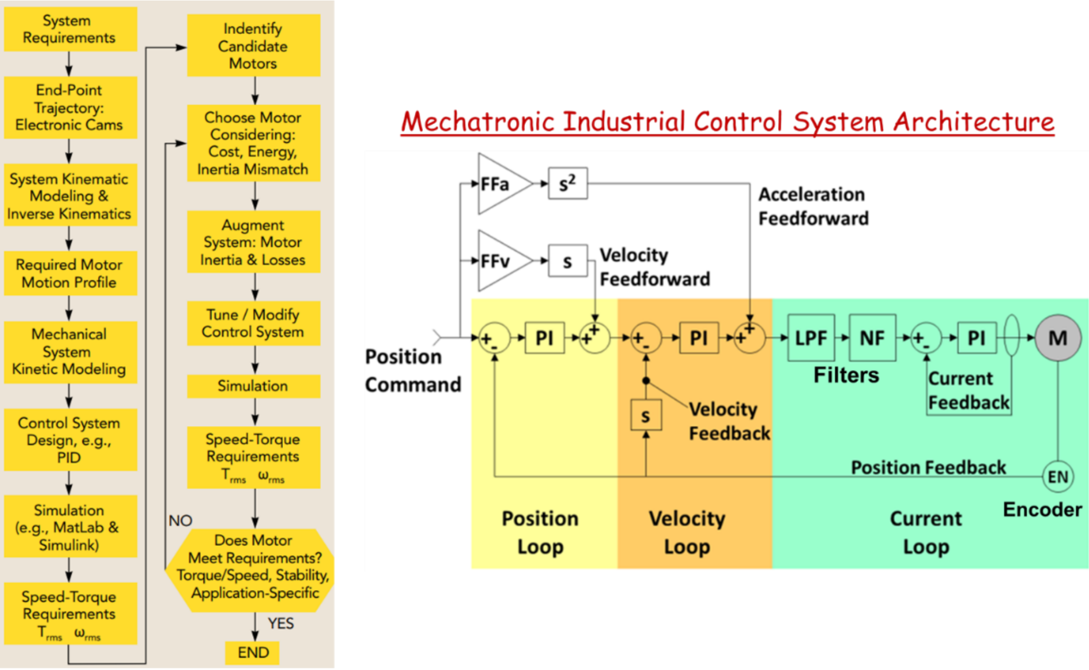


Figure 3. Mechatronic Mechanism Design and Control System Architecture

## 3. SLIDER-CRANK CASE STUDY

Let's use as an example a mechanism developed by Leonardo da Vinci over 500 years ago and now found in engines, automation applications, and miniature devices around the world – the slider crank. Let's illustrate how to mechatronify this Renaissance mechanism.

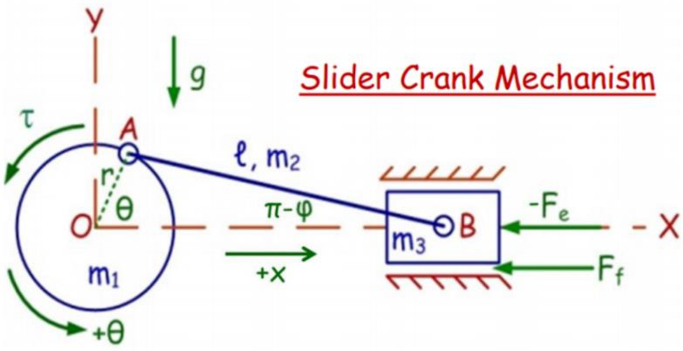


Figure 4. Slider Crank Mechanism

Shown is a diagram of a slider-crank mechanism (Figure 4), consisting of a flywheel-crank, a connecting rod, and a slider, all assumed to be rigid. The external forces / torques acting are the servo-motor torque τ (and also motor friction torque, not shown), the slider friction force $F_f$, and the external force $F_e$. It is a special case of the four-bar linkage where one crank is infinite in length, such that its end point (point B) has rectilinear motion. It is a one-degree-of-freedom system, as only one coordinate is needed to completely describe its motion. The constraint equation relating angles θ and φ is r•(sin θ) = ℓ•(sin φ). Kinematic analysis (i.e., the geometry of motion) can be carried out graphically yielding great insight. However, a mathematical solution is much more effective for mechatronic system design and optimization. This analysis can be performed either by trigonometry or by complex numbers. Positions, velocities, and accelerations of key points are obtained, as well as the angular velocities and angular accelerations of the rigid bodies. Kinetic analysis can be accomplished by drawing free-body diagrams showing gravitational forces, contact forces / torques, and also the inertia forces / torques, and then summing forces / moments, as needed. This is known as the D'Alembert approach to applying the Newton-Euler Equations, and forces / torques at all joints can be determined. The system equation of motion is directly obtained by the application of Lagrange's Equation $\frac{d}{dt}\frac{\partial T}{\partial \dot{\theta}} - \frac{\partial T}{\partial \theta} + \frac{\partial V}{\partial \theta} = Q_\theta$ using the generalized coordinate θ, where V is the system potential energy, i.e., $V = \frac{1}{2} m_2 g r \sin\theta$, T is the system kinetic energy, i.e., $T = \left(\frac{1}{2}\bar{I}_1\left(\frac{d\theta}{dt}\right)^2\right) + \left(\frac{1}{2}\bar{I}_2\left(\frac{d\varphi}{dt}\right)^2 + \frac{1}{2}m_2\bar{v}_2^2\right) + \left(\frac{1}{2}m_3\bar{v}_3^2\right)$, and $Q_\theta$ is the generalized torque due to torques that do work, i.e., $Q_\theta = \tau - \left(F_e + F_f\right)\left(r\sin\theta\right)\left(1 + \frac{r}{c}\cos\theta\right)$ with $c = \sqrt{\ell^2 - r^2\sin^2\theta}$. The resulting equation has the form $M(\theta)\frac{d^2\theta}{dt^2} + N\left(\theta, \frac{d\theta}{dt}\right) = F(\theta)$.

Once the kinematic and kinetic analyses are completed, the desired end-point trajectory must be defined, and then, through inverse kinematics, which includes here the crank and connecting rod lengths, the necessary motion profile for the actuator is computed. This is accomplished by trajectory planning. This profile needs to be defined in a way to avoid or reduce the mechanical vibration and stress on components and actuators, as well as to reduce overshoot response and excessive position error during motion. This is accomplished by electronic cams. The inverse kinetic analysis, which includes masses, center-of-mass locations, and mass moments of inertia, is used to generate the required actuator torque / force for the motion profile, and results in a speed / torque-force diagram on which to base actuator selection. The chosen actuator now becomes part of the system, and, with the updated system, a control system, with feedback and feedforward control, is designed, which then results in a new speed / torque-force profile. The entire system should now be simulated, with the addition of any parasitic effects, for design validation.

To create a mechatronic machine requires an integrated approach and a process that results in a complete virtual prototype before any work is done to create the actual working prototype. Once the virtual prototype – complete with models of the mechanical elements, electronics, controller, microcomputer, sensors, and actuators – is shown to work as desired, then work towards building the actual prototype can begin. When completed, the working prototype should work as expected, the first time power is turned on. That is called model-based design and it is the cornerstone of modern engineering practice.

## 4. SENIOR CAPSTONE DESIGN COURSE

The mechatronic mechanism design process was implemented, and a slider crank was built to accomplish a prescribed task. This process is essential to modern engineering practice and this case study was used as a guide in Mechanical Engineering Senior Capstone Design during the fall 2018 semester. The four-bar linkage is probably the most common mechanism in the world and is used in a great variety of applications. Twenty-eight senior ME students, working in teams of 4, were assigned a four-bar mechanism application: aircraft landing gear, quick-return mechanism, pick-and-place mechanism, robot gripper, straight-line mechanism, flipping mechanism, and windshield wiper, and then proceeded through a process to create a virtual prototype and then, a working prototype. Pictures appear in the Appendix.

**Process Steps:**

- Define project specifications. These are continually reviewed and updated.
- Create the motion profile.
- Model the mechanism forward and inverse kinematics.
- Model the inverse kinetic system to determine the speed-torque requirements and select a motor.
- Model the forward kinetics with the selected motor included in the model.
- Design a feedback control system to perform the desired motion.
- Reevaluate the motor selected.
- Create and simulate the complete virtual prototype with mechanics, sensors, motor, electronics, and controller included.
- Once satisfied with the performance of the virtual prototype, work on the actual working prototype can begin using fundamental machine-design principles.
- When the actual working prototype is completed, its performance is compared to the predications from the virtual prototype. Discrepancies are resolved.

The motors used were brushed dc motors (with and without a gear box) equipped with optical encoders. The controller was designed in MatLab Simulink, tested on the Simulink nonlinear virtual prototype, and then implemented on the working prototype using a H-bridge and Lab VIEW with the NI myRIO controller (Figure 5).

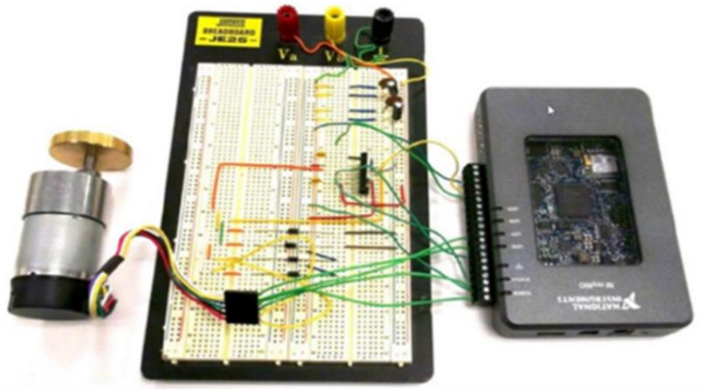


Figure 5. Motor + H-Bridge + MyRIO

The students experience what they will actually be asked to do as practicing engineers. Students maintain a bound design notebook, one per team, in which all information, including minutes from meetings, reference material gathered, and all technical work performed. If it is not in the notebook, from the instructor's point of view, it does not exist. The course milestones are shown in Table 1.

**Table 1**

| **Course Milestones** | **Due Dates** |
|---|---|
| Form Teams & Develop Challenge Concept | Week #1 |
| Virtual Prototype Demonstration and Presentation | Week #7 |
| Working Prototype Demonstration and Presentation | Week #14 |
| Final Presentation with Virtual & Working Prototypes and Design Notebook | Exam Week |

The course learning objectives, major deliverables, course organization, course policies, grade summary, and weekly team tasks are shown below.

**Course Learning Objectives:**

1. To provide the student with an experience that requires active student participation.
2. To enhance the student's skills in engineering design methodology, including research, modeling, analysis, computer simulation, virtual and real prototype testing, and participation in design reviews.
3. To simulate the advanced product development process used in industry including the incorporation of customer requirements, performing a state-of-the-art search, keeping an engineering notebook, and organizing a commercial presentation of the work.
4. To illustrate the interaction between competing technical and non-technical issues and the role of compromise, constraints and the interplay of potential benefits versus risks.
5. To provide the student with exposure to various phases of the design process, from the specification of requirements and constraints to product realization. All phases of new product development are practiced: concept formulation, technology search, preliminary design and layout, virtual prototyping, detailed design, fabrication, parts procurement, assembly, testing, and documentation.

6. To help develop an understanding of the planning, coordination, cooperation, and communication required in a team effort.
7. To have the student understand what is required to meet a firm technical deadline where funds and technical assistance are limited: scheduling work, developing contingencies, specifying, procuring and incorporating purchased parts, identifying and using available fabrication and test equipment.
8. To allow for innovation.
9. To allow the student to apply the skills learned in previous engineering courses to a challenging project.

### Major Deliverables

1. The engineering details of a concept design (physical and mathematical modeling, model analysis and verification, virtual prototype, computer-aided design drawings, electrical schematics, performance test results) as described in an engineering notebook with a presentation.
2. A working prototype which the team members design, fabricate, test, and demonstrate at a design exposition.

### Course Organization

- The course consisted of two mandatory 85-minute sessions each week for all students. The first session each week was spent in a classroom setting during which the instructor covered fundamental engineering content essential for successful completion of the challenge. In the second session each week, each team worked together and with the instructor, as well as discussed and presented their work in a mini-design review format to the other teams.
- Students were organized into four-person multidisciplinary teams during the first period of the course.
- During the first period, each team was assigned a four-bar mechanism design challenge. The system necessarily was dynamic with sensors, electronics, actuators, and computer control as integral parts of the design, i.e., a mechatronic system.

### Class Attendance, Participation, Preparation, and Conduct

- Design is not a spectator sport. Active participation is required for a meaningful capstone experience. Students were expected to attend and participate in all class sessions and make relevant contributions in team meetings outside of regularly scheduled class time. Active participation and initiative were critical parts of the student’s individual success and that of the team.
- Attendance at all classes was mandatory.
- Student participation in class was strongly encouraged.
- Preparation for class was essential.
- All course notes / announcements were posted on the course web site.
- Students were expected to conduct themselves in a professional manner at all times with integrity, honesty, and respect for others.

### Grade Summary

| | |
|---|---|
| Virtual Prototype & Presentation | 40% |
| Working Prototype & Presentation | 40% |

| | |
|---|---|
| Design Notebook | 20% |
| Total | 100% |

**Weekly Team Tasks**

**Table 2**

| Team Tasks | Week # |
|---|---|
| Form 4-Person Teams; Select & Research 4-Bar Mechanism Task; Set Up Design Notebook | Week #1 |
| Define Mechanism Performance Requirements & Motion Profile for the Selected 4-Bar Mechanism Task; Perform Forward and Inverse Kinematic Analysis & Implement in Simulink | Week #2 |
| Perform Forward & Inverse Kinetic Analysis using Newton-Euler Approach; Determine Equation of Motion using the Lagrange Approach; Implement in Simulink | Week #3 |
| Determine Motor Speed-Torque Requirement; Identify Candidate Brushed DC Motors; Choose Motor & Justify | Week #4 |
| Augment System with Motor (Inertia and Friction); Design Controller using MatLab; Implement Closed-Loop System in Simulink; Reevaluate Motor Selection | Week #5 |
| Complete the Virtual Prototype Design & Prepare Presentation & Report; Order Motor | Week #6 |
| Virtual Prototype Presentation and Report | Week #7 |
| Develop Mechanism Detailed Design using Machine Design Principles | Week #8 |
| Detailed Design & Build | Week #9 |
| Detailed Design & Build | Week #10 |
| Detailed Design & Build | Week #11 |
| H-Bridge Set-Up; LabVIEW Real-Time Programming; System Closed-Loop Testing | Week #12 |
| Complete the Actual Prototype Build & Test; Prepare Presentation & Report | Week #13 |
| Actual Prototype Presentation and Report | Week #14 |

**Course Evaluation**

Twenty-seven students evaluated the course. (Questionnaire and results are in the Appendix). The questionnaire had an overall quality question plus three parts. In Part A, students rated their ability to apply knowledge and tools required for industry; in Part B, students rated which skills were most useful for a practicing engineer; and in Part C, students ranked how the course prepared them for the future. Parts A and C applied specifically to the course. A rating of one meant the course strongly achieved the goal, while a five meant the course did not. The overall course quality was rated 1.63. Students strongly agreed that the course will help them meet industry needs, that the professor helped achieve the course goals, and that they feel confident applying engineering design principles and processes to solve a new engineering problem.

## 5. CONCLUSION

A new approach to mechanical engineering capstone design has been described and implemented. All seven four-person teams designed a four-bar mechanism for an assigned application. This allowed the instructor to teach fundamentals of kinematics and dynamics of mechanisms, both forward and inverse, in particular, the four-bar mechanism. Nonlinear kinematic and dynamic analyses, both forward and inverse, were performed in Simulink. Control design was performed using MatLab, computer simulations were performed for the virtual prototype using Simulink, and the real-time control was programmed using LabVIEW with the NI myRIO controller. Students selected the brushed DC motors for their applications, developed the power electronics, interfaced the incremental optical encoder, and programed the real-time control code. A prerequisite for this course is the standard junior-level Machine Design course. In that course students learn about theories of failure, stress, strain, and deflection, as well as how to size a shaft and select bearings, couplings, and gears. They now put that into practice, as the mechanical design of the mechanism (links and bearings), support structure, and motor coupling was performed using these machine design principles. Performance requirements were continuously evaluated and updated. See mechanism pictures in the Appendix. Students had the opportunity for a hands-on, real-world mechatronic design experience, just as they will be expected to perform after graduation as real practicing engineers.

## REFERENCES

[1] Craig, K., "Mechatronify Common Mechanisms," Design News, August 2012.

[2] Craig, K., "Modeling and Simulation for Motor Selection," Design News, June 2011.

## AUTHOR

Kevin Craig attended the United States Military Academy at West Point, NY, earned varsity letters in football and baseball, and graduated with a B.S. degree and a commission as an officer in the U.S. Army. After serving in the military, he attended Columbia University and received the M.S., M.Phil., and Ph.D. degrees. While in graduate school, he worked in the mechanical-nuclear design department of Ebasco Services, Inc., a major engineering firm in NYC, and taught and received tenure at both the U.S. Merchant Marine Academy and Hofstra University. While at Hofstra, he worked as a research engineer at the U.S. Army Armament Research, Development, and Engineering Center (ARDEC) Automation and Robotics Laboratory. He received the 1987 ASEE New Engineering Educator Excellence Award, a national honor. In 1989, he joined the faculty at Rensselaer Polytechnic Institute (RPI). At RPI, he served as Director of Core Engineering, the first two years of the School of Engineering, and as Chair of the Engineering Science Interdisciplinary Department. As a tenured full professor of mechanical engineering, he taught and performed research in the areas of mechatronic system design and the modeling, analysis, and control of multidisciplinary engineering systems. With significant continuous funding from both industry and government, he developed the Mechatronics Program at RPI, which included an extensive teaching and research laboratory and several undergraduate and graduate courses in mechatronics. He collaborated extensively with the Xerox Mechanical Engineering Sciences Laboratory (MESL), an offshoot of Xerox PARC, during this time. During his 18 years at RPI, he graduated 37 M.S. students and 20 Ph.D. students. While at RPI, he authored over 30 refereed journal articles and over 50 refereed conference papers. Emphasis in all his teaching and research was on human-centered, model-based design, with a balance between theory and best industry practice. At RPI, he received the two highest awards conferred for teaching: the 2006 School of Engineering Education Excellence Award and the 2006 Trustees' Outstanding Teacher Award. From 2007 to 2014, he wrote a monthly column on mechatronics for practicing engineers in Design News magazine. Over the past 30 years, he has conducted hands-on, integrated, customized, mechatronics workshops for practicing engineers nationally and internationally, e.g., at Xerox, Procter & Gamble, Rockwell Automation, Johnson Controls, Brady Corp., Pitney Bowes, and Siemens Health Care in the U.S., and at Fiat and Tetra Pak in Italy. He is a Fellow of the ASME and a member of the IEEE and the ASEE. After a national search, in January 2008, he was chosen to be the Robert C. Greenheck Chair in Engineering Design, a $5 million endowed chair, at Marquette University. His mission was to integrate multidisciplinary design and discovery learning throughout the entire college, in all years and in all departments. He transformed students, faculty, curricula, and facilities throughout the college and created a new engineering education mindset and culture for innovation. He was given the 2013 ASEE North-Midwest Best Teacher Award and the 2014 ASME Outstanding Design Educator Award, a society award. He graduated his 21st Ph.D.In the fall of 2014, he returned to the Hofstra University School of Engineering and Applied Science as a tenured full professor of mechanical engineering. He is the Director of the Mechatronics Laboratory, which he created with $1M funding from NYS / Hofstra, and also the Director of the Center for Innovation, a new center he created to collaborate with business and industry to foster innovation, where all intellectual property (IP) belongs to the sponsor. Recent clients include ThermoLift, P&G, and Toro. He has taught graduate courses as an Adjunct ME Professor at both Stony Brook University and NYU Tandon School of Engineering.

## APPENDIX

Mechanical Engineering Senior Design Questionnaire

1- Strongly Agree 2- Agree 3-Neutral 4-Disagree 5-Strongly Disagree

The purpose of this course is to develop in the student the attributes of a professional engineer in the application of their undergraduate engineering, mathematics, and science knowledge to the solution of a real-world engineering challenge using the model-based, integrated design approach, i.e., virtual prototype to working prototype, that is the hallmark of 21st-century engineering practice.

_____ This course accomplished this goal.

**Part A**

This course has provided me with:

_____An ability to apply knowledge of mathematics, science, and engineering.
_____An ability to design and conduct experiments, as well as analyze and interpret data.
_____An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, social, political, ethical, health and safety, manufacturability, and sustainability.
_____ An ability to function on multidisciplinary teams.
_____ An ability to identify, formulate, and solve engineering problems.
_____ An understanding of professional and ethical responsibility.
_____ An ability to communicate effectively.
_____The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.
_____ A recognition of the need for, and an ability to engage in, life-long learning.
_____ A knowledge of contemporary issues.
_____ An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

**Part B**

The following skills and knowledge, and their corresponding growths, are essential to a career as a practicing engineer.

_____ Communication

_____ Teamwork
_____ Project Management
_____ Problem Solving
_____ Organization
_____ Leadership
_____ Statics / Dynamics
_____ Strength of Materials / Machine Design
_____ Modeling, Analysis, and Control of Dynamic Systems
_____ Electromechanics
_____ Electronics
_____ Fluid Mechanics
_____ Thermodynamics
_____ Heat Transfer
_____ Computer Graphics (e.g., Solid Works)
_____ MatLab / Simulink
_____ LabVIEW
_____ Real-Time Computer Programming

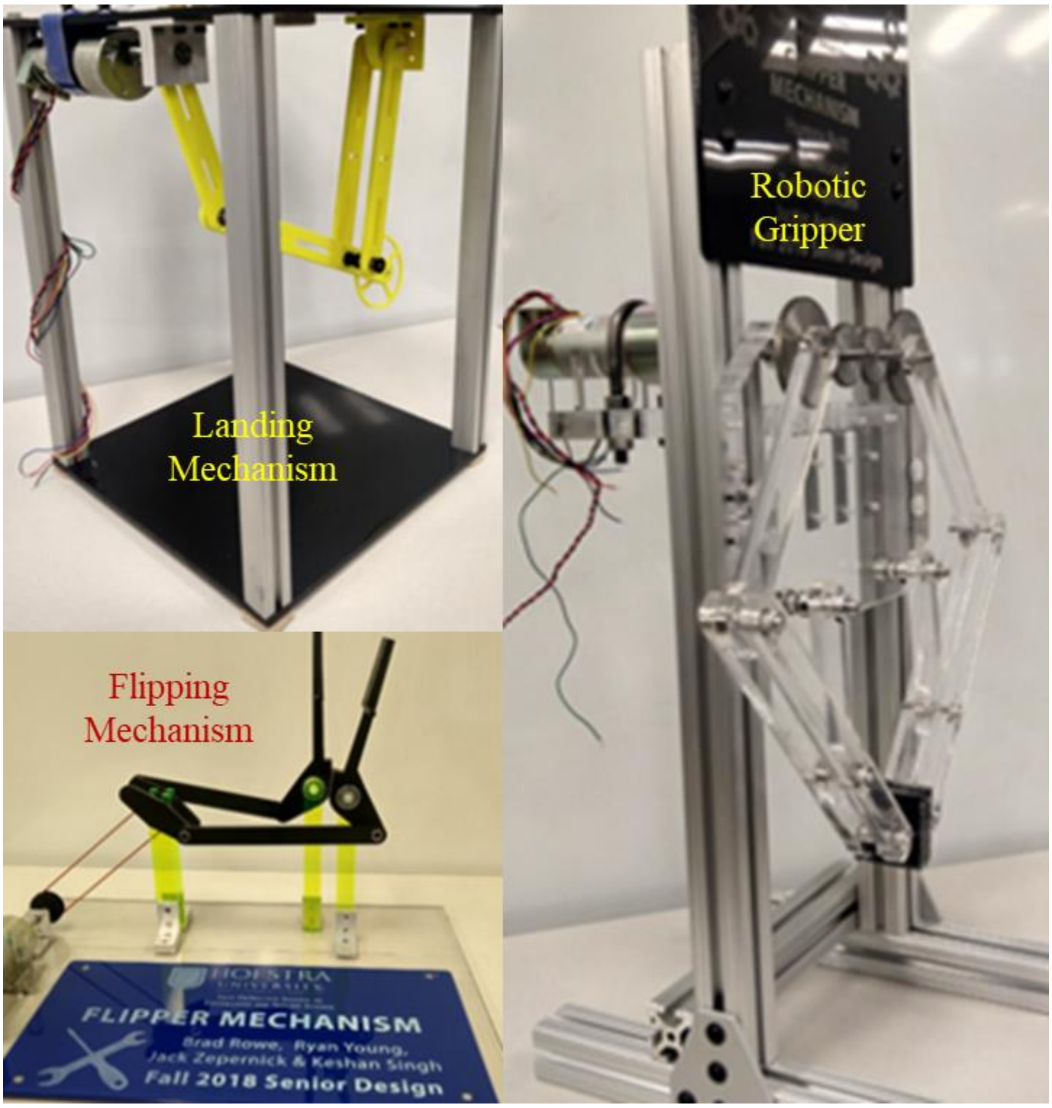
**Part C**

_____ This course will help you to meet industry needs.
_____ This course resulted in improved student learning.
_____ The professor in this course helped achieve the course goals.
_____ You feel confident in applying engineering design principles and processes in the solution of a new engineering problem.
_____ The approach used, i.e., to teach subject matter (e.g., mechanisms) and then use that knowledge in the current design process, was very effective.

Mechanical Engineering Senior Design Questionnaire

1- Strongly Agree 2 - Agree 3- Neutral 4 - Disagree 5 - Strongly Disagree

| Course Questionaire # | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | Mean | Mode | Low | High |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Course Question** | 2 | 2 | 5 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 2 | 2 | 2 | 1.630 | 2 | 1 | 5 |
| **Part A** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Question # 1 | 1 | 2 | 4 | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 1.519 | 1 | 1 | 4 |
| Question # 2 | 2 | 2 | 4 | 2 | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 3 | 1 | 1 | 1 | 2 | 1 | 1 | 3 | 1 | 1 | 2 | 2 | 2 | 1 | 3 | 1 | 1.889 | 2 | 1 | 4 |
| Question # 3 | 1 | 2 | 4 | 1 | 2 | 2 | 2 | 1 | 3 | 2 | 2 | 1 | 2 | 1 | 1 | 3 | 1 | 1 | 1 | 3 | 2 | 2 | 3 | 1 | 2 | 2 | 2 | 1.852 | 2 | 1 | 4 |
| Question # 4 | 1 | 2 | 2 | 1 | 3 | 2 | 1 | 2 | 1 | 3 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 2 | 5 | 2 | 1 | 2 | 1 | 1 | 1.704 | 1 | 1 | 5 |
| Question # 5 | 1 | 2 | 3 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 2 | 3 | 1.444 | 1 | 1 | 3 |
| Question # 6 | 1 | 3 | 5 | 2 | 3 | 3 | 1 | 3 | 1 | 3 | 2 | 1 | 1 | 2 | 1 | 3 | 1 | 2 | 3 | 3 | 2 | 2 | 1 | 1 | 2 | 1 | 1 | 2.000 | 1 | 1 | 5 |
| Question # 7 | 2 | 2 | 3 | 1 | 3 | 1 | 2 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 4 | 2 | 1 | 1 | 2 | 1 | 1 | 5 | 2 | 1 | 2 | 1 | 1 | 1.778 | 1 | 1 | 5 |
| Question # 8 | 2 | 3 | 5 | 3 | 3 | 2 | 3 | 2 | 3 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 3 | 1 | 3 | 4 | 3 | 3 | 1 | 2 | 1 | 2.185 | 3 | 1 | 5 |
| Question # 9 | 1 | 2 | 2 | 3 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 4 | 2 | 3 | 2 | 1.741 | 1 | 1 | 4 |
| Question # 10 | 1 | 4 | 4 | 3 | 3 | 5 | 3 | 3 | 3 | 2 | 5 | 1 | 2 | 1 | 2 | 2 | 1 | 1 | 3 | 1 | 1 | 3 | 3 | 4 | 2 | 3 | 4 | 2.593 | 3 | 1 | 5 |
| Question # 11 | 1 | 2 | 4 | 2 | 2 | 2 | 1 | 2 | 1 | 2 | 2 | 1 | 2 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 2 | 1.630 | 2 | 1 | 4 |
| **Part B** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Question # 1 | 1 | 4 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1.185 | 1 | 1 | 4 |
| Question # 2 | 2 | 4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1.185 | 1 | 1 | 4 |
| Question # 3 | 2 | 4 | 2 | 3 | 1 | 1 | 1 | 3 | 2 | 2 | 1 | 3 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 2 | 2 | 2 | 1 | 1 | 2 | 1.741 | 1 | 1 | 4 |
| Question # 4 | 1 | 4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.148 | 1 | 1 | 4 |
| Question # 5 | 1 | 4 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1.185 | 1 | 1 | 4 |
| Question # 6 | 1 | 4 | 3 | 1 | 1 | 2 | 1 | 1 | 3 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 2 | 1 | 2 | 1 | 1 | 2 | 1.556 | 1 | 1 | 4 |
| Question # 7 | 3 | 4 | 3 | 1 | 2 | 2 | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 3 | 2 | 1.556 | 1 | 1 | 4 |
| Question # 8 | 3 | 4 | 4 | 1 | 2 | 2 | 3 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 2 | 1 | 2 | 2 | 1.704 | 1 | 1 | 4 |
| Question # 9 | 3 | 4 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 1.556 | 1 | 1 | 4 |
| Question # 10 | 3 | 4 | 2 | 2 | 3 | 2 | 2 | 3 | 2 | 3 | 2 | 3 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 3 | 1 | 2 | 1 | 1.926 | 2 | 1 | 4 |
| Question # 11 | 2 | 4 | 2 | 3 | 3 | 2 | 3 | 2 | 2 | 3 | 2 | 3 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 2 | 3 | 1 | 2.000 | 2 | 1 | 4 |
| Question # 12 | 4 | 4 | 4 | 3 | 3 | 2 | 3 | 4 | 2 | 3 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 2 | 2 | 3 | 3 | 2 | 3 | 2.333 | 3 | 1 | 4 |
| Question # 13 | 3 | 4 | 4 | 3 | 3 | 2 | 3 | 4 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 2 | 3 | 3 | 2 | 3 | 2.185 | 1 | 1 | 4 |
| Question # 14 | 4 | 4 | 3 | 3 | 3 | 2 | 3 | 4 | 1 | 2 | 2 | 2 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 2 | 2 | 3 | 2 | 2 | 3 | 2.222 | 3 | 1 | 4 |
| Question # 15 | 2 | 4 | 1 | 1 | 1 | 2 | 3 | 1 | 2 | 2 | 1 | 4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.481 | 1 | 1 | 4 |
| Question # 16 | 3 | 4 | 1 | 1 | 1 | 2 | 1 | 1 | 3 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 4 | 3 | 2 | 2 | 3 | 2 | 1.778 | 1 | 1 | 4 |
| Question # 17 | 3 | 4 | 1 | 1 | 2 | 2 | 1 | 1 | 3 | 2 | 1 | 4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 4 | 3 | 2 | 2 | 2 | 3 | 1.889 | 1 | 1 | 4 |
| Question # 18 | 2 | 4 | 2 | 1 | 2 | 2 | 1 | 3 | 2 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 3 | 1 | 2 | 1 | 1 | 1 | 1.630 | 1 | 1 | 4 |
| **Part C** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Question # 1 | 3 | 3 | 5 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 1 | 3 | 2 | 1 | 2 | 3 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 3 | 2 | 2 | 1 | 1.926 | 2 | 1 | 5 |
| Question # 2 | 3 | 3 | 5 | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 1 | 2 | 2 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 1.630 | 1 | 1 | 5 |
| Question # 3 | 4 | 5 | 4 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 2 | 1.593 | 1 | 1 | 5 |
| Question # 4 | 2 | 4 | 4 | 2 | 1 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 1.815 | 2 | 1 | 4 |
| Question # 5 | 2 | 4 | 4 | 1 | 3 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 3 | 1.630 | 1 | 1 | 4 |


Landing Mechanism
Robotic Gripper
Flipping Mechanism
HOFSTRA UNIVERSITY
FLIPPER MECHANISM
Brad Rowe, Ryan Young, Jack Zepernick & Keshan Singh
Fall 2018 Senior Design