Project Description
Building Sustainability into Control Systems Courses

1. Introduction and Motivation

Defining the problem

Adequately preparing future engineers to play crucial roles in solving complex problems related to energy and sustainability is a growing need. Traditional teaching methods that emphasize theory over practice leave engineering students little opportunity to develop practical problem solving skills and lead to lack of student motivation and retention (Sheppard, et al., 2008; Seymour and Hewitt, 1997). The field of control systems is especially challenging for students trying to comprehend the abstract concepts involved and for faculty attempting to convey the material effectively. Presenting opportunities in the curriculum to see the application and relevance of engineering theory to the real-world can engage students in the learning process.

In order to attract and retain student interest in engineering and science, engineering educators must increase awareness of the importance of engineering and science to society (NAE 2009). If students, especially women and other underrepresented minorities, were more able to clearly see the societal relevance of science, technology, engineering, and mathematics (STEM), they would be less likely to abandon these careers for those they perceive as more personally fulfilling (Baker, et al., 2007; Seymour and Hewitt, 1997). Environmental sustainability and energy efficiency are becoming increasingly vital to the stability of the US economy (NAE 2005; Sheppard, et.al., 2008). The fields of energy and sustainability are especially effective at eliciting student interest (Tankersley, 2009) and are already raising interest in science and engineering in schools nationwide. Sustainable building initiatives play a key role in reducing energy consumption and the role of building automation and control systems cannot be understated. The complexity and interdisciplinary nature of these problems requires educators teach students to approach problems with a *systems* perspective (NAE 2004). Providing case-based and hands-on experiences helps students relate the theory they are learning to the real-world and gives them skills necessary to approach more complex systems.

Envisioning the goal

An important aspect of transforming engineering education is to clearly identify the skill sets, knowledge base, and qualities we need in our next generation of engineers to tackle the future's energy sustainability challenges. Key attributes of the Engineer of 2020 include strong analytical skills, practical ingenuity, and a commitment to lifelong learning (NAE 2004). One major goal of creating a new learning environment is to promote acquisition of these skills. The proposed work seeks to achieve this goal by incorporating case studies and hands-on laboratories where students approach real-world problems with a unifying building systems theme.

The motivation behind this proposal is summarized below:

1) Improve student motivation and retention by providing case-based and hands-on learning experiences; and
2) Provide students with practical problem solving skills useful to both industry and academia and necessary for addressing 21^{st} century sustainability challenges.

2. Background

The Mechanical Engineering (ME) faculty at Cooper Union is uniquely positioned to develop a set of new building system case study materials and control systems laboratory experiments that will work towards these intended outcomes.

The Cooper Union for the Advancement of Science and Art is a highly selective institution in New York City, renowned for its commitment to undergraduate education in engineering, art, and architecture, disciplines that have sustained the world's cities throughout history. Established in 1859 by the philanthropist, inventor, and industrialist Peter Cooper, it is among the nation's oldest and most distinguished centers of higher learning. Its uncommonly rigorous admissions process rewards all students with full four-year scholarships. The mission of the Albert Nerken School of Engineering is to prepare "the leadership engineer" to have such attributes as a systems perspective, strong technical skills, and an entrepreneurial spirit. The Nerken School annually enrolls around 500 undergraduates, of which about one-third are women. This is a percentage significantly higher than the national average for engineering schools.

As a vehicle to put focus on issues of sustainability, The Cooper Union Institute for Sustainable Design was formed in 2008 to facilitate interdisciplinary research and scholarship in creating sustainable environments and disseminate information to enhance the public understanding of green building design and construction. Part of the mission is to serve as a resource center and connecting hub for staff, faculty, and students in the Schools of Engineering, Architecture and Art, wanting to explore these critical topics, within the Cooper Union curricula and beyond. Students at Cooper Union become particularly engaged in ongoing energy projects, such as the green roof and thermoelectric project sponsored by ConEdison, the AIChE Chem-E-Car Competition, the Formula SAE Hybrid, and other sustainability and energy reclamation projects.

The ME Department at Cooper Union has formulated broad objectives that underscore our continued shift toward a modern, hands-on pedagogy. The department adapted its mission to incorporate the faculty's idea that engineering pedagogy should be centered around the student whose skill set has to evolve with the changing climate of the engineering field. The faculty must also be examples of life-long learners who adapt to the students' future needs.

> Our Mission: *Cooper Union's Department of Mechanical Engineering will produce broadly and rigorously educated graduates, able to practice professionally, pursue advanced studies, and innovate in a wide range of fields. Together with our faculty and staff, our students will develop a commitment toward lifelong interdisciplinary learning, fulfill their potential for responsible leadership, and inspire others to continuously pursue excellence by example.*

Small class sizes at Cooper Union ensure great interaction between professor and student, with full-time professors with Ph.D.'s predominantly teaching the core classes. Continuous efforts by the faculty, staff, and students to explore innovative pedagogies through real-world problem solving and novel teaching methods are ubiquitous throughout Cooper Union. This commitment is evident in the design-centered learning model, which attempts to strike the appropriate balance between technical rigor, creative problem-solving, and professional skills that include project management, teamwork, and technical communication.

This faculty represents an energized, collaborative group of young educators (four of the six full-time, tenure-track positions in the department were filled in the past five years), with top instructional credentials and strong professional experience at the beginning of shaping their research and academic programs, under the mentorship and guidance of experienced senior faculty. While the proposed work specifically focuses on redesign of the systems and control curriculum, the new instructional approach is based on input from all mechanical engineering faculty members and is part of a broader plan to assess and continually improve the ME program as a whole.

The ME Program is the product of a comprehensive re-evaluation of practices in the department, the need to redefine undergraduate mechanical engineering education, and a systematic approach to continued improvement through assessment and evaluation. To explore and implement strategic actions leading to program improvement, the department formed a "Transition Committee." The charge of the committee is to critically assess all facets of the ME program, to develop recommendations for program improvement and to develop a transition plan to incorporate these changes. The goal of the ME program is to develop a cohesive progression of core concepts and professional skills that allows flexibility for the development of individual interests. Though the existing ME curriculum provides a solid ME background through a collection of courses, observations based on years of experience interacting with students and alumni have identified specific professional skills that the faculty aims to develop in its students throughout the curriculum. While the work proposed specifically focuses on the systems and controls courses, the effort to incorporate building/HVAC systems case studies and hands-on laboratories is part of a larger, collaborative initiative to make positive curricular changes.

This proposal aims to address a critical subset of the larger vision developed by the ME faculty at Cooper Union with the following specific objectives:

1) **Increase appreciation for the importance of sustainable system design by creating new case-based learning experiences that take advantage of the systems in a new state-of-the-art, "green" academic building, and**
2) **Improve student learning of control systems by developing laboratory experiences that connect course theory to building systems theme, thereby eliciting student interest and engagement in the learning process.**

The systems and controls curriculum at Cooper Union consists of two consecutive, required courses, Systems Engineering (ESC161) and Feedback Control Systems (ME151), taught at the sophomore and junior levels. ESC161 is an introductory course to mathematical modeling and systems analysis taught in the Spring semester. Students learn to develop models of mechanical, electrical, electromechanical, fluid, and thermal systems and solve for the system's response. Although students are introduced to simulation techniques in ESC161 using Matlab® and Simulink®, students continue to have difficulty relating how systems analysis theory applies to the real-world. Numerical simulation helps students understand first and second order system response, but it does not show *actual* systems responding in *real-time*. The ME151 course content includes principles of feedback control and linear systems analysis including root locus and frequency response methods. The systems and control material is especially challenging for mechanical engineers due to the rigorous mathematics and abstract concepts; often students get lost in the theory.

A brief comparison with other institutions reveals different approaches to teaching the systems and control material. One approach (followed by University of Illinois at Urbana-Champaign and Stanford) covers modeling and dynamic systems analysis in one required course and covers all control related material in another elective course. A second approach requires one course where control principles are introduced first and provide motivation for control-oriented models and analysis. The University of California (UC) Berkeley and UC Santa Barbara follow this approach. A middle ground approach between these two consists of a required course where the focus is on systems modeling and a few control concepts are introduced at the end of the semester. Georgia Tech, University of Michigan, and Midwestern State University follow this approach. Cooper Union is somewhat unique in that two separate courses are required for systems and feedback control. Two required courses allow ample time to review the mathematical tools (differential equations, Laplace Transforms, complex variables, etc.) necessary for rigorous systems analysis and still provides time to allow students to explore what real-world phenomena these models can explain and how they can be used to solve control problems of importance to industry and society. Dr. Baglione feels that it is essential to provide control-oriented motivation for developing models of systems early on. Nonetheless, the curricular materials will be scalable and modular such that they can be adopted by schools with different approaches to teaching control systems. Since students are familiar with typical home heating and refrigeration systems, introducing the motivation for control systems using basic HVAC system analogies is an ideal way to make the progression from open loop control, automated on-off control, and ultimately closed loop feedback control. A new "green" academic building at Cooper Union can be leveraged as a learning laboratory for students to connect theory to professional practice.

The new academic building (41 Cooper Square) is a state-of-the-art academic building, the first of its kind, designed by the 2005 Pritzker Prize-winning architect Thom Mayne. 41 Cooper Square is the first laboratory building in New York City on track to receive the Leadership in Energy and Environmental Design (LEED) Platinum certification. A sample of energy efficient subsystems and conservation strategies are as follows:

- State-of-the-art radiant heating and cooling ceiling technology conserves energy and increases efficiency
- An outer layer of semi-transparent mesh screen, modulates solar input, helps regulate building temperature, minimizes energy use, and promotes natural ventilation
- Carbon dioxide detectors throughout the building automatically dim power and ventilation when rooms are unoccupied, thereby saving on energy and costs
- A layer of low-maintenance plantings cover the deck surface of a green roof, which helps minimize the city 'heat island' effect, storm water runoff, noise, summer air conditioning costs, and winter heat demand

- Low-flow plumbing devices combined with rainwater collection systems – which irrigate the green roof and provide water to toiler fixtures on two lower level floors and two floors above grade – saves more than 600,000 gallons of water annually
- Use of a computer-integrated Building Management System (BMS), to control, monitor and manage actual energy consumption
- Implementation of two energy-efficient cogeneration systems is underway – in the new academic building at 41 Cooper Square and the college's historic Foundation Building. These systems are expected to dramatically reduce overall electrical demand from the grid, while cutting the college's greenhouse gas footprint by a projected 30%
- An atrium and interior space design that maximizes the use of natural daylight – 75% of all spaces have access to daylight
- Enhanced commissioning, which verifies that the building's energy-related systems are installed, calibrated and perform according to the project requirements and basis of design, to optimize sustainable performance, energy savings, and occupant comfort. The commissioning agent will continue to be available to assist with this educational effort.

The goal of this current effort is to leverage the new building to increase student appreciation of the real-world relevance of the control systems principles they learn. Alongside the traditional lecture-style approach to learning theory, students will be exposed to a series of building systems case studies and process control experiments that are strategically integrated within the controls curriculum to enhance the hands-on and experiential learning in key conceptual areas.

The primary objectives of the proposed work are to:

1) **Incorporate real-world, case-based learning opportunities by integrating building systems sustainability into the control systems curriculum, and**
2) **Develop active, hands-on process control laboratory experiments that supplement traditional classroom learning.**

The specific deliverables are:

- Assessment of the student learning outcomes that result from the these new case-based learning and laboratory learning approaches, and
- Development and dissemination of the curricular materials developed.

<u>Integration of real-world, case-based learning</u>

Traditional lecture-based instruction is deductive, beginning with theory and progressing to application of the theory. With the traditional approach, students often fail to see the relevance of the theory they are learning until they apply it. Although professors see how the material fits in the bigger picture, students often view material as disjointed. Inductive instruction, where new information is presented in the context of situations and problems to which the student can relate, is linked to better cognitive learning and increased motivation (Prince and Felder, 2006). Case-based instruction methods can lead to inductive learning and provide a positive and engaging experience but only if they are properly designed and used to improve student learning (Prince and Felder, 2006; Gallucci, 2006). Three principles established to about how students learn STEM fields will be taken into account when developing and presenting the building system case studies proposed here (NRC 2005). First, students come to the classroom with alternative conceptions that are resistant to change and that may need to be addressed and explored within the context of the case study. Second, students require a conceptual framework, i.e., "students gain perspective about the importance of a topic if they see it as a part of a meaningful whole" (Gallucci, 2006). Third, students learn by taking control of their own learning through metacognitive approaches. As such, students need to be engaged in questioning and monitoring their own thinking during case study progression since ultimately the goal is to not simply teach content, but to provide students with the skills to become more effective learners.

Case-study type approaches have been proven to promote student engagement in mechanical engineering courses. Two case studies – one based on the catastrophic failure of a hydro-electric due to the "water hammer" effect and the other on the Three Mile Island disaster – were implemented into a systems modeling course at Purdue (Yadav, et al., 2010). An expansion of the case-study approach was also written and implemented in the context of a real-world environment – in this case the facilities plant for the University of Minnesota Mankato (Tebbe, 2007). The Cooper Union also plans an expanded case study approach that weaves in the importance of sustainable building systems and hands-on experiments that connect the control systems theory to "industry focused" problem-solving.

Development of active, hands-on experiments

Many have argued that engineering education remains too theoretical and not hands-on enough (Sheppard, et al., 2008; Basken, 2009). In addition, ABET criteria (ABET 2006) address hands-on skills in criterion (b), "the ability to design and conduct experiments and interpret data." Exposing students to real-life engineering applications also further enhances ABET criteria (c), "an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability," and (h) "the broad education to understand the impact of engineering solutions in a global, economic, environmental and societal context." Through regular surveys and industrial advisory board meetings at Cooper Union, alumni and employers consistently stress the importance of hands-on ability. In an IEEE Control Systems Society survey, industry and university respondents agreed that there should be increased emphasis on "hands-on experience" and "industry focused" design in controls curricula (Cook and Samad, 2009). It is crucial to provide hands-on learning opportunities for students to reinforce fundamental engineering concepts and to help develop skill-sets founded in scientific inquiry. A goal of the faculty is to a find the appropriate balance between theory and hands-on experimentation in teaching fundamental dynamic systems and control concepts. A key finding of *How Students Learn* (NRC 2005) suggests that students need a strong foundation in concepts and tools to organize and manipulate factual knowledge yet they need not be taught all there is to know about any topic or set of topics. Rather, engaging students in reflective scientific practice helps students learn about science both *as* and *by* inquiry (NRC 2005). Our goal as educators is to create curricula and instructional materials that engage students in the learning process. The experiments developed as the posed work will demonstrate to students that the implications of systems engineering concepts are far reaching and can have a significant impact on energy consumption and our environment.

Further research from *How Students Learn* suggests classrooms should be learner-centered, knowledge-centered, assessment-centered, and community-centered (2005). Engineering students, especially women, tend to drop out not from a lack of knowledge or proper preparation but rather from lack of confidence (Seymour and Hewitt, 1997). In fact, while Cooper Union attracts and admits more female engineering students than the national average, the results of a survey and study presented by the assessment coordinator for this proposal, presents evidence that a higher rate of females drop out at Cooper Union, even though there is no significant gender difference in GPA (del Cerro and Duncan, 2002). The results of the survey suggest that women leave Cooper Union because they fail to meet their own expectations after setting higher standards for themselves. Particularly since hands-on experiences can lead to feelings of intimidation and negative experiences for some students (NAE 2004), the faculty plans to create an environment that is supportive and flexible to different learning styles of different student populations. A recent study on the role of support and confidence in female engineering student retention and success found that students feel more confident when they are working on problems they see in the real-world (Marra, et al., 2009). The Marra study also found that women and minority students often felt excluded in engineering learning environments, and therefore it is imperative that engineering curriculum changes focus on inclusiveness (2009). A broader motivation of creating this learning environment is to foster a collaborative setting, with a high degree of faculty interaction with students, which has been proven to positively affect the learning process and increase retention (Seymour and Hewitt, 1997). Increased collaboration amongst all constituents - faculty, student, staff, alumni, and industry - will help effectively integrate these case-based and hands-on experiences into the curricula within Cooper Union and beyond. It is also imperative that the hands-on experiences are inclusive and provide support for those that may feel intimidated by hands-on assignments and excluded during project work (e.g. women, other underrepresented minorities, those with less prior hands-on experience). Students that are intimidated by lab work will do so in cooperative, non-competitive environment with support of faculty that are present and engaged. The assessment plan discussed later in this proposal will specifically addresses whether the proposed learning approach increases confidence and self-efficacy for women and other underrepresented students.

3. Research Plan

The premise behind the project is to engage students by exposing them to application of the systems theory they are learning in *their* environment. Since all academic buildings have heating, ventilation and air conditioning (HVAC) systems and their design encompasses many systems engineering aspects, why not leverage these systems to enhance student learning and understanding. The basic equipment in 41 Cooper Square includes pumps to move fluids through the radiant panel heating coils, fans to distribute and condition air, flow control valves to regulate flow through heat exchangers, instrumentation needed for feedback control of their operation, and so on. These complex systems, normally hidden, will be made available for students to explore systems engineering concepts.

The format of the curricular material developed will be a combination of short case studies and process control laboratory assignments with background material and short related assignments to bring students up to speed on all the relevant information and relate the material to theory. The case studies and assignments will ultimately be internet accessible and well-documented with photos, video interviews, descriptions, and data for analysis, such that other schools may adopt the case studies and/or experiments or use them as a framework for developing similar case studies using their own building systems. It is also important to note that the curricular materials that will be developed as part of this proposal will be scalable and modular such that they can be accommodated to fit different types of engineering programs, e.g. both small and large, and those that have different approaches to teaching control systems courses.

The progression of weaving the building systems theme into the controls system curriculum is loosely based on Bloom's taxonomy and the levels of intellectual behavior important in learning (1956) and Kolb's experiential learning sequence (1984). Designing a sequence of activities around the learning cycle is complimentary to different learning styles (Felder and Brent, 2004). The project objectives loosely follow a sequence that involves (1) introducing a problem and providing motivation by relating it to students' interests and experiences (the focal question is *why?)*; (2) presenting pertinent facts, experimental observations, theories and principles, and problem-solving methods (the focal question is *what?)*; (3) providing guided hands-on practice in the methods and types of thinking the lessons are intended to teach (the focal question is *why?)*; and (4) encouraging exploration on consequences and applications of the newly learned material (the focal question is *what if?)* (Felder and Prince, 2006).

Objective #1: Introduce Building Systems

The first objective is to grab attention and give students a big picture understanding of building systems. The energy usage of a residential and commercial building as a percentage of total energy consumed will reveal to the students the importance of sustainable building to the future. A concise overview of the purpose of HVAC systems as well as conventional HVAC systems will be presented in new curricular materials. While the content of the material is not new, it is necessary to present the material in a concise format in the context of a systems engineering course such that the introduction of case-based instruction does not detract from traditional control systems theory. HVAC systems will be presented in terms of basic control system terminology, such as controlled variables (e.g., discharge air temperature), sensors (e.g., thermistors), actuators (e.g. valves), and a controlled agents (e.g. chilled water). Since students are often familiar with typical home heating and refrigeration systems, introducing feedback control theory using basic HVAC systems analogies and the problem of designing sustainable systems is an ideal way to integrate inductive learning (which according to Biggs helps them to make connections to their existing knowledge structures (1996)).

Next resources will be provided to offer various insights to the problem without a direct solution for the problem. Students need to learn how to approach industry problems that are complex, ill-structured, have conflicting goals, and do not have a clear solution (Jonnasen, Strobel, and Lee, 2006). The curricular materials will include material related to important HVAC systems such as chillers and boiler plants, air handling units, etc. A combination of resources will be developed to supplement the traditional lectures, including background reading material on these systems, videos, Matlab/Simulink models and simulations, homework problems, and links websites and other materials relevant to the case study problem.

Objective #2: Learn and Integrate Building Management System (BMS) into Learning Environment

The next objective of the project is for the project participants to attain an awareness of this complex engineering system in which we work. We plan, in consultation with the Cooper Union building facilities manager (Jody Grapes), planning director (Clark Wieman), and with major contributors in the building design and commissioning (IBE Consulting Engineers, Sciame, Siemens, Synergy Engineering, etc.), to become trained in the vast network of hardware and software required to meet the physical needs of the building. A key element to developing these case studies is developing a firm understanding of the energy model that accompanied the design of the HVAC hardware and control systems. Key players in the project will undergo training in these systems, conduct interviews, and synthesize the material for inclusion in the background material and case studies. While the major objectives of this project involve creating and evaluating new curricular materials and strategies, since building systems are complex and interdisciplinary by nature, the project requires that the PI gain new knowledge outside her area of expertise. A portion of the budget is therefore allocated for faculty and students involved in the project to acquire new HVAC systems, energy modeling, and LEED training as well as for consulting services for subject matter experts. Initial consultations with these key players have already taken place and openness and readiness to participate have been expressed.

The ultimate objective is to engage students to monitor energy usage and control systems data from the Building Management System (BMS) and *apply* energy efficiency and control concepts from their coursework. To prepare students for this we will develop organized tours of building systems that we will give to students taking the feedback control systems course. We will tap into the steady stream of data from the sensors located throughout the building and develop a means of cataloging and analyzing the data. A method for comparing the actual energy consumption with an estimate of what would have been required had various energy conservation measures *not* been made will be developed. A running tally of energy requirements and associated costs will produce an appreciation for the enormity of these costs, just for one relatively small building in Manhattan, and how even a modest energy conservation measure can add up to substantial savings in fossil-fuel consumption, associated CO_2 emissions and cost.

<u>Objective #3: Provide Hands-on Experience with Systems and Controls Instrumentation</u>

Having seen the big picture and arousing a curiosity as to how things actually work, the students will be introduced to the various system components and instrumentation, and how they are synthesized to perform as a system in the actual building. The plan is to create experimental hands-on and laboratory experiences that simultaneously isolate components and subsystems and complement the traditional teaching pedagogy with the aim to give students a working knowledge of how fundamental control system principles apply to real systems. Operating principles of each component will be established by acquiring sample building components, where appropriate, or smaller-scale bench top versions (e.g., pumps, motors, heat exchangers) and/or instrumentation (i.e., thermistors, differential pressure sensors, variable air volume (VAV) valves, pneumatic control valves, etc.) with which students can interact.

Students will perform bench top process control laboratory experiments so that they can examine response characteristics and control of fluid, thermal, and pneumatic systems real-time in a risk-free setting. Students will learn to apply on-off control and proportion-integral-derivative (PID) tuning to control flow and level in a liquid-level system, to control temperature in a heat exchanger and radiator/fan system, and to control pressure from controlled pressure source with pressure vessel (capacitance) and varying flow paths (resistances). Three process control (PROCON) test rigs from Feedback Inc. exist and are currently used in the Feedback Control (ME151) course. Preliminary work on integrating these test rigs into the systems and control curriculum at Cooper Union was presented at the 2009 ASME World Congress (Baglione 2009). The PROCON test rigs include trainers for level and flow, temperature, and pressure process control. The advantage of the PROCON rigs is they allow students to interact with an actual industry standard ABB controller.

The PROCON trainers interface with Feedback's Discovery software and come complete with on-screen background reading, laboratory assignments, and questions. While the PROCON test rigs offer significant potential, one drawback is that the out-of-the-box experiments are currently redundant and not suitable for inclusion in a typical mechanical engineering control systems course progression. If students were to follow the as-supplied laboratory experiments from the Discovery software, the students would spend excessive time becoming familiar with the test rigs and on topics such as calibration. While it is imperative that students understand the processes that they are trying to control, the laboratory procedures and questions need to be redesigned to remove redundancy. Teaching students the importance of calibrating equipment before running an experiment is critical; yet it is not necessary in a control systems course to teach the underlying principles behind calibrating each and every transducer, especially in the context of a control systems course, this content would be better suited for a course dedicated to experimentation. Concentrating on fundamental process control principles (e.g., how different types of systems respond and how to tune a controller) and their relation to real-world systems would be a better use of precious laboratory time. For example, the Level/Flow Rig currently has ten calibration and familiarization experiments requiring approximately 6-10 hours of laboratory time before the students run any closed loop control experiments. It is unrealistic to dedicate this much laboratory time to topics outside the scope of basic control systems. Unfortunately, the design of the assignments do not give users sufficient background information and requires that the students jump around to different assignments of interest which can be confusing. Furthermore, better alignment of the sequence of experiments with lecture topics would help students see more clearly the connection between theory and practice. At least one professor who teaches undergraduate control system courses and has PROCON rigs from Feedback Inc. in his laboratory (Prof. Dale McDonald at Midwestern State University) concurs with this assessment and thus has resorted to only using the PROCON rigs for student demonstrations where students do not get to interact with the controller hands-on. Prof. McDonald is interested in collaborating on future PROCON development work and will serve as an external evaluator for this aspect of the project (refer to letter of support).

Efforts are currently underway to redesign the experiments, however, the ABB controller at Cooper Union is obsolete. As a result, the faculty is writing new laboratory assignments in MS Word documents, which does not allow the students to directly interface to the PROCON trainers and controller via the computer. The proposal requests funding (50% of which will be cost-shared by the ME Department) to upgrade to the latest controller from Feedback Inc. which will enable us to upgrade to the latest software. New software to be released in the Summer 2010 - Discovery Tools and Discovery Course Manager - allow full editing of the supplied material and the creation of new content and additional assignments. The plan is to develop one to two introductory assignments with a building systems focus followed by experimentation of the closed loop systems for each of the three PROCON test rigs. The edited versions of the Discovery software will be shared with other users that have expressed similar concerns with the previous versions of the as-supplied course material and a forum will be developed to exchange PROCON curricular material and ideas for improving the PROCON laboratory assignments. Ultimately redesigning the curriculum to streamline the laboratory experiments and to demonstrate real-world applications gives students the opportunity to acquire valuable practical skills and to fully appreciate the relevance of dynamic systems and control concepts.

<u>Objective #4: Present Opportunities for Synthesis and Evaluation of Building Systems</u>

The building system case studies and process control curricular experiments developed will not only supplement classroom learning and provide opportunities to develop professional skills; they will culminate in more advanced project-based, research oriented learning opportunities related to the design of “green”, sustainable buildings. This will address the appeal and retention aspect of engineering students by providing them with opportunities to apply engineering knowledge learned in the classroom to problems in their own environment. The faculty hopes that after students see real HVAC systems and are exposed to the importance of sustainability in building design, some will pursue more advanced projects in these areas. The building systems at 41 Cooper Square and components and instrumentation offer immense opportunity in the form of Senior Capstone Design projects or other undergraduate or Masters-level research projects.

Although not proposed directly here, planned student projects include reconfiguring the process control test rigs to perform efficiency studies and demonstrate “green” design concepts. One example involves redesigning the secondary flow for the heat exchanger in the Temperature Process Rig from open circuit to closed circuit and assessing the performance and environmental impact for different configurations. Another project will entail coupling the Level/Flow and Temperature Rigs to facilitate the investigation of dual-loop control concepts. Other advanced studies will use the PROCON test rigs to explore model-based design and control concepts.

41 Cooper Square includes many innovative features and energy saving tactics that will be exploited to teach students the ability to approach more complex, interdisciplinary real-world systems. The Building Management System (BMS) will be utilized to analyze the performance history and optimize the efficiency of specific building systems or the system as a whole. The Cooper Union building uses enthalpy-based economizer control on the air-handling units to minimize the energy consumption of the overall system. Another advanced feature of 41 Cooper Square includes a Cooling Plant Optimization Package (CPOP), an integrated software program that is supported by a distributed processing network of stand-alone controllers that incorporate Direct Digital Control (DDC) technology. The CPOP software networks primary DDC control panels for the following equipment in the central cooling plant: chillers, pumps, cooling towers, valves, and related mechanical equipment, to optimize energy savings of the chiller plant as a whole. Studies to further understanding of the underlying mechanical and electrical components and processes being controlled in the chiller plant can lead to broader interest in researching and developing new designs and control systems that are more efficient. The implementation of a cogeneration system in 41 Cooper Square, a project that is currently underway and scheduled for completion by November 2010, offers further opportunity to integrate innovative "green" technology into the learning environment. In addition, Cooper Union will have an operational cogeneration plant in its historic Foundation Building operational by August 2010. Both systems will be extensively monitored, with collected data available for both building operations and academic research and analysis. Due to the interdisciplinary nature of environmentally sustainable design, advanced projects will also provide an avenue for increased collaboration between different faculty members in the mechanical engineering department, within the different departments in the School of Engineering and between the School of Engineering and School of Architecture.

Including the building systems at 41 Cooper Square as a learning and research resource will give students a sense of ownership in the learning process and engage them to pursue life-long learning. Relating the projects to *their* building will foster personal satisfaction. Given that "green" engineering practices are becoming increasingly important, the faculty hopes that students will find solving problems with societal relevance personally fulfilling. Whether students ultimately pursue careers in industry or academia, their exposure to sustainability in design and engineering at an early undergraduate level encourages these future engineers to be good stewards of the environment.

4. Assessment Plan

The assessment plan includes assessment of the student learning outcomes as well as external evaluation of the pedagogical and technical content of the curricular materials developed.

Student Learning Outcomes

The PI has identified specific, measurable student learning outcomes (SLOs) that the proposed work aims to address:

1. Students will be able to describe the basic principles of operation of central HVAC systems including centrifugal chillers, heat exchangers, and air handling units;
2. Given an actual HVAC system, students will be able to identify the control goals, the process variables to be controlled, the controller inputs and outputs and the corresponding sensors and actuators;
3. Students will able to characterize the proportional, integral, and derivative terms in a controller and tune controller parameters to control level-flow, temperature, and pressure control systems;
4. Students will be able to design a system, component, or process to meet desired needs with particular emphasis on minimizing the environmental and energy consumption impact.

Gerardo del Cerro will serve as the assessment coordinator of the student learning outcomes. Gerardo del Cerro holds Ph.D.'s in the social sciences from the New School for Social Research in New York and the Universidad Autónoma de Madrid. He is a graduate of Harvard Business School's Executive Program on Performance Measurement for Effective Management of Non-Profit Organizations. Professor del Cerro has taught in Spain and in the United States and has contributed several publications to the field of evaluation research. Between 1997 and 2002, he was Project Area Leader for the Gateway Engineering Program of the U.S. National Science Foundation and advised organizations in Spain, Russia, Japan, and South Korea on social science methods for program and organizational planning and evaluation. Gerardo del Cerro serves as Director of Institutional Research and Assessment at The Cooper Union and is a Visiting Professor at the Massachusetts Institute of Technology.

Our assessment plan follows three paradigms:

1. It is ***value-added***, as it uses a pre-/post- evaluation method of student learning gains via a direct value-added method, and via an NSF standardized survey, the SALG (Student Assessment of Learning Gains).
2. It is ***mixed-method***, because it uses quantitative (observational checklist or scoring rubric of teacher/assessor observations of student behavior) and qualitative (focus group, semi-structured interviews, or ethnography) evaluation techniques.
3. It is ***performance assessment*** – it uses a scoring rubric based on Bloom's taxonomy to code and register student behaviors and closely follows the design of the project from inception.

Value-added evaluation

Value-added assessment, and especially *direct value-added assessment*, is one of the most fruitful and effective ways to measure student learning (AASCU 2006). It measures and compares what students know and can do at two points in time – in the case of our proposal before and after students are exposed to the case-based, hands-on learning experience. The student learning outcomes of this proposal will be turned into questions for the survey instrument to be designed for this direct value-added evaluation. The survey will ask students to provide ratings to a number of ***factual*** statements describing what they know and can do. Additionally, we will use the SALG to measure student ***perceptions*** of their learning gains. The SALG (http://www.salgsite.org/) is an online survey that measures student perceptions of their learning gains due to any components within a course or project. Faculty can modify a template to match any and all features of their projects, have their students take the survey on-line, and have the data returned to them as either raw data or with simple statistical analysis. By employing these two surveys, one standardized and one locally developed, we will obtain a very clear picture of the value added to student learning by the project outlined in this proposal.

Mixed-method evaluation

In addition to the two surveys mentioned above as a form of student self-assessment, we plan to use a mix of quantitative and qualitative approaches to evaluate our project where students are assessed by instructors rather than themselves. Hein (1987) recommends a variety of approaches be used in assessing hands-on learning, including observing students at work, examining the things they manipulate, and evaluating engineering-related drawing and writing. Other assessment techniques include group discussion, journaling, and student interviews (Gaffney, 1992; Tippins and Dana, 1992). Some assessment tasks should be done by student teams to help build group skills (Small and Petrek, 1992). It is often beneficial to have students score their peers' group work (Culp and Malone, 1992).

While it would be desirable to employ a wide panoply of evaluation techniques that would help us untangle the innovative character of our proposed project in a comprehensive and systematic way, we must consider limitations of time and resources as well, and thus we propose to use the following mixed-method approach.

a) Quantitative techniques – an observational checklist (or scoring rubric) whereby the instructor will be able to assess and quantify student behavior as it relates to the project at hand.
b) Qualitative techniques – the use of semi-structured interviews or focus groups to probe results from student surveys will help us clarify the nature and extent of student learning gains as well as the characteristics of student behavior during the project.

Performance assessment

Instructional activities that use concrete manipulatives in engineering education – such as hands-on experimentation in project-based learning (PBL) modes or case-based learning experiences – help teachers address a broad range of conceptual and engineering knowledge, organizational skills, and personal attitudes. Assessing learning goals across this broad spectrum requires "a repertoire of assessment strategies that promote the fit between learning styles and desired educational outcomes"

(Flick, 1993, p. 6). The benefits of case-based approaches include enhanced student participation in the learning process (active learning and self-learning), enhanced communication skills, addressing of a wider set of learning styles, and promotion of critical and proactive thinking. Case-based approaches also facilitate the development of many of the "soft skills" demanded from engineering graduates, as embodied in the ABET EC 2000. Examples include effective teaming skills, project management, communications, ethics, engineering economics, etc. (Hadim and Esche, 2002).

Performance assessment suits the nature of our proposed project very nicely as it highlights the behavioral components of student learning, which can be developed and observed in a case-based learning experience and then coded and registered in a scoring rubric. We follow Oehlers (2006) development of a framework of three fundamental priorities that are essentially a condensation of the six cognitive skills recognized by the classic Taxonomy of Educational Objectives (Bloom's Taxonomy, 1956). The fundamental priorities developed by Oehlers are as follows: **Learn to think**: Namely, the ability of students "to use their imagination and to develop thought processes that can be used to solve problems." **Learn to learn**: This refers to the ability of "gathering whatever knowledge is available that can be used to eventually solve the problem." **Learn fundamental principles**: Instead of "imparting information," courses must teach students "the fundamental principles governing engineering behavior."

Oehlers proposes structuring the assessment similarly to the design and experimentation process itself – that is, as a sequential progression of stages building upon one another. For any given project or case-based learning experience, a table of prioritized goals can be laid out, and "generally speaking, the priorities should be achieved in sequential order" by students working on the project. The grade for any given project depends on how many stages have been satisfactorily completed by the student. The important thing is that, ultimately, this alternative assessment procedure prioritizes in sequential order the concepts that govern the ability to solve problems and so helps to quantify the students' ability to solve problems.

Amidst all of the assessment techniques proposed here, we plan in particular to assess the impact of the proposed inductive and hands-on teaching methods on different student populations. The assessment data will be studied a number of ways to assess if any differences exist in the *actual* and *perceived* learning gains amongst female and underrepresented minorities. Through focus group and targeted student surveys we will determine if the case-study and hands-on approaches affect confidence and self-efficacy. Also assessor observations during the hands-on laboratory experiences will help to determine differences in student behavior and learning style as well as which types of faculty-to-student or student-to-student interactions can lead to increased confidence and self-efficacy and positive learning outcomes in female and underrepresented students.

5. Previous Work and Preliminary Results

The mechanical engineering faculty at Cooper Union continually express a desire to expand the hands-on, experiential component of learning in the curriculum. Student course evaluations echo this sentiment and indicate a desire for students to experience more hands-on laboratories. At the end of the Spring 2008 ESC161 course, student were asked on a scale of 1 (Strongly Disagree) to 5 (Strongly Agree), where a rating of 3 indicated a neutral opinion, whether they felt "the course had an appropriate balance of theory and practice" and whether "incorporating laboratory work into this and future courses would be beneficial to the learning process." The student survey results suggested a neutral opinion of the balance between theory and practice ($\bar{x} = 3.3, s = 1.1$). Students agreed on a desire to incorporate more laboratory work into the systems and control curriculum ($\bar{x} = 4.1, s = 0.97$). Based on this feedback and on personal experience with how the controls systems material was presented to her during her undergraduate experience, Dr. Baglione redesigned the Feedback Control Systems course (enrollment of 23) in the Fall 2008 semester to incorporate a significant laboratory component. Dr. Baglione presented the curricular changes to ME151, preliminary results, lessons learned, and future plans for improving the systems and control curriculum at the 2009 ASME International Mechanical Engineering Congress and Exposition.

The class was sub-divided into small group and were personally guided through the experiments. The experiments included four DC motor experiments using a trainer from National Instruments and Quanser as well as eleven level/flow control and temperature control using the PROCON rigs. For the Fall 2008 semester the students were asked to read background material that was provided with the PROCON rigs and Discovery software before the laboratories. The students followed the experiments from the PROCON Discovery software and answered questions that were included in the as-supplied teaching materials for homework with a few additional questions added by the professor. While student survey results from the ME151 Fall 2008 semester revealed a more positive attitude towards the course balance between theory and practice when compared to the Spring 2008 ESC161 results, the shortcomings of the as-supplied teaching materials was evident. Survey results generally indicated that students liked the laboratory experiments and generally agreed "the emphasis on the laboratory experiments complimented the course theory" ($\bar{x} = 4.1, s = 0.61$). Several student suggestions for improving the laboratory component of the ME151 course involved redesigning the focus of the experiments, reducing the number or non-relevant experiments, and redistributing the workload. In addition, the students would have liked to have seen in advance how the experiments related to actual industry problems. For the Fall 2009 semester Dr. Baglione reduced the total number of experiments on the PROCON rigs from eleven to five by removing some of the redundancy and skipping some of the assignments. However, without the editable version of the Discovery software skipping, the students were forced to skip around to different assignments in order to get the necessary background information to perform the experiments. This made the students' experience with the PROCON rigs awkward and disjointed and furthermore it was impossible to add new content to try to relate the experiments to actual real-world scenarios. The proposed work attempts to address these shortcomings.

To address the practical component of the learning experience, Dr. Baglione took 39 students from the ME151 course on a tour of various building mechanical rooms and the BMS control room at the conclusion of the Fall 2009 semester. Dr. Baglione arranged four tours with 9-10 students per tour. Either an engineer from Siemens or the building commissioning engineer accompanied Dr. Baglione on the tours since the building just opened in September 2009 and this was the first time student tours were given. Interacting with engineers who worked directly on the implementation of the HVAC systems at 41 Cooper Square proved an invaluable learning resource for both faculty and students. The students saw various HVAC equipment, including two centrifugal chillers and corresponding condenser water pumps, a plate and frame heat exchanger that supplies hot water to the radiant panels, and four air handling units used to condition and circulate air. In the BMS control room the students saw the graphical interface to the subsystems from the tour and how building facilities personnel can use the BMS to control, monitor and manage actual energy usage real-time. As a subsequent homework assignment, the students were asked to turn in three short, type-written paragraphs describing at a high-level the plants, the process variables, the controller inputs and outputs, and the actuators for the three subsystems they experienced on the tour. When asked whether they "found the HVAC systems and BMS tour to be valuable," the students generally agreed ($\bar{x} = 3.8, s = 0.87$).

Most students enjoyed stepping out of the traditional classroom setting and seeing real-world control systems. Some of the students' comments indicated a desire to have been introduced to the HVAC subsystems that they were going to see before taking the tours. The proposed work attempts to remedy this shortcoming and maximize what the students get out of the tours by developing online background material that the students will be assigned to read before taking the tours. Furthermore, the proposed work aims to integrate HVAC system curricular material earlier in the semester alongside traditional lecture topics with supplementary assignments to give students a more holistic view of the application of control systems to the energy management of buildings. Developing an online repository of information (e.g., interviews of commissioning engineers, load balancers, etc.) will serve as a historical archive such that students and faculty at Cooper Union and beyond can continue to access the wealth of knowledge extracted from the many constituents involved in the HVAC system design and implementation well after new building wraps up the commissioning phase.

6. Dissemination and Future Plans

The work proposed here is designed to not only positively impact students at Cooper Union, but to be generally applicable to engineering programs as a whole. As such we will be following an "open-source" ideology of dissemination. The ME Faculty at Cooper Union plan to disseminate this work through the following key pathways:

1) American Society of Mechanical Engineers (ASME) and American Society of Engineering Education (ASEE) conference presentations / workshops and journal articles. In fact, Dr. Baglione presented a

conference paper entitled "Incorporating Practical Laboratory Experiments to Reinforce Dynamic Systems and Control Concepts" at the 2009 ASME International Mechanical Engineering Congress and Exposition. The paper presents the preliminary results of the re-design of her Feedback Controls courses to include a significant laboratory component. In addition to conference an journal papers, at the conclusion of this project, Dr. Baglione plans to collaborate with Dr. McDonald to organize a workshop at a future ASME International Mechanical Engineering Congress and Exhibition in the Engineering Education and Professional Development: Dynamic Systems and Control Track to encourage a more free flow exchange of ideas amongst other educators.

2) A public website link with curricular plans, course material, and assignments on the National Science Digital Library (NSDL) website (http://nsdl.org). The material will include the building systems case studies developed and background information including photos, video interviews, descriptions, and data for analysis, such that other schools may adopt the case studies and/or experiments or use them as a framework for developing similar case studies of their own.

3) A public website link with PROCON laboratory assignments and edited versions of the Discovery software. The Feedback Inc. US Customer Service Manager, Ron Butterfield, estimates that 100 colleges and universities currently own PROCON test rigs. Contact has already been established with some of these schools and an effort will be made to establish further contact. An online forum to exchange PROCON curricular material and ideas for improving the PROCON laboratory assignments to encourage future use of the PROCON rigs to enhance student learning will be developed.

4) ASME Metropolitian Section Collaboration and Sustainability in Engineering Education Symposium. As faculty advisor to Cooper Union's ASME student chapter, the PI is closely involved with the Metropolitan Section of ASME. Cooper Union hosts numerous ASME Met Section events. The PI is in close contact with the Met Section Executive Committee, which includes many metropolitan area engineers from industry, and is responsible for planning events and activities. The Met Section includes eight colleges and universities, including City College of NY (CCNY), Columbia, Manhattan College, NYU Polytechnic, SUNY Maritime, College of Staten Island, and NYC Technical College, many of which are developing sustainability initiatives and programs. Such programs include CCNY's new program in Sustainability in the Urban Environment and the construction of Columbia's new interdisciplinary science building, the Northwest Corner Building that also boasts many sustainable design elements. The PI is in contact with the other Met Section Faculty Advisors and will host a Met Section Symposium to share results of the work in this proposal and exchange ideas for collaboration amongst the different schools. Collaboration is already underway with Dr. Mohammad Naraghi, Professor of Mechanical Engineering at Manhattan College, who has developed a new "Energy Dynamics of Green Buildings" course (2009), to share course material and offer mutual feedback. Dr. Naraghi is developing a new textbook, for which Dr. Baglione will provide feedback, and Dr. Naraghi has offered to use Cooper Union's case study material in his course and provide feedback on the curricular material developed as part of this project. Dr. Naraghi will also serve as an external evaluator for aspects of this project.

5) Dissemination via PlaNYC Consortium. Broader dissemination of curricular materials, and inter-school collaboration, will be pursued through Cooper Union's participation in a consortium of colleges and universities in the Mayor's Challenge, an initiative managed by New York City's Office of Long Term Planning and Sustainability. The Mayor's Challenge is part of the PlaNYC effort to reduce greenhouse gases by 30% by the year 2030. The 15 colleges and universities participating have signed onto an accelerated plan to meeting that reduction goal by 2017. Models of 41 Cooper Square energy use, as well as current and proposed upgrades of Cooper Union's Foundation Building, indicate that Cooper Union will surpass the 30% goal, with the implementation of energy-saving strategies HVAC systems in both buildings, including the completion of two cogeneration plants currently under construction. As part of this work, Cooper Union faculty and students will develop a deeper understanding of these energy models with the intent of sharing this knowledge for teaching and collaboration purposes as well as tracking model output to actual building performance.

Future work includes broadening the curricular changes and expanding the sustainability and building systems theme into other disciplines. While the proposed work primarily consists of developing curricular material related to controls systems aspects of sustainable building systems, the complex and interdisciplinary nature of these systems presents numerous opportunities for increased collaboration both within the School of Engineering and between Engineering and the Schools of Architecture and Art, around the New York Metropolitan area, and across the nation. One vision of the new building is to serve as an environment to enhance existing collaborations and stimulate new ones.

Furthermore, it has always been Cooper Union's mission to serve its community and society by providing a forum for exchanging ideas, resources and information. Another idea being generated expands on incorporating the building management system (BMS) into case studies and organized tours. The idea involves developing and implementing interactive kiosks where students and other visitors can interact with a plethora of BMS data. Allowing different audiences to interact with information such as real-time energy consumption, utility costs, weather and load trends, and a running tally of the energy and CO_2 savings due to the building's energy saving tactics would cultivate an appreciation for the importance creating sustainable environments.

7. Review Criterion

Intellectual Merit

The systems in the new LEED academic building at 41 Cooper Square will provide rich opportunities for teaching and learning, as well as the unifying theme behind the case studies and hands-on experiments proposed. This project will adapt what is known about how students learn to develop effective case-based learning materials for mechanical engineering control systems curricula. Case studies can lead to better cognitive learning and increased student engagement in the learning process. Connecting the control systems course theory to a unifying building systems theme helps students see the relevance of abstract control system concepts and motivates students to become active learners. Developing a concise set of hands-on experiments in a supportive environment will give students the confidence and skills to approach complex, real-world problems with a systems perspective. Integrating the sustainability aspects of Cooper Union's new academic building at 41 Cooper Square into the engineering learning environment is a unique way to elicit student interest and motivation. Educating future engineers to consider "green" design and sustainability is timely and relevant given the challenges that face engineers in the next century.

Broader Impact

Given the growing interest in sustainability in the New York metropolitan area and across the country, the proposed case-based and experimental curricular materials are applicable well beyond Cooper Union. Multiple means of dissemination will ensure that other programs can exploit the unique opportunities a new "green" LEED-certified academic building provides. The case studies and hands-on experiments will be modular and scalable to different control systems teaching approaches. The experiments will give students the opportunity to apply fundamental control systems concepts while deliberately integrating valuable professional skills. Other engineering programs that are amenable to building systems and sustainability can use the case study materials and experiments directly or use them as a blueprint to develop their own facility-oriented, inductive teaching materials. The dissemination of curricular materials and assessment of the learning outcomes will occur via conference and journal publications, via web-based resources and via local and national workshops. Cooper Union's unique urban setting and proximity to other academic institutions provide a framework to enhance existing collaborations and stimulate new partnerships both locally and nationally.

The high proportion of women in the engineering student body at Cooper Union facilitates exploration of the impact of the proposed inductive and hands-on teaching methods on efforts to attract and retain underrepresented groups in mechanical engineering. Ultimately integrating case-based and hands-on learning will reveal the societal relevance of engineering and provide students with the necessary skills to tackle complex engineering problems. Providing realistic, hands-on experiences to students in a collaborative, supportive setting has the potential to promote student confidence and self-efficacy, essential traits required to address complex problems in an unfamiliar environment. A key outcome of this effort will be to examine the role of first-hand experiences and curricular improvements in attracting and retaining diverse students traditionally underrepresented in mechanical engineering.

8. Proposed Timeline

Task	Year 1			Year 2		
Objective #1: Introduce Building Systems	Sp	Su	F	Sp	Su	F
Prepare preliminary overview of building systems (chiller plant, boiler plant, and air handling units) and control systems terminology	•					
Seek feedback from subject matter experts to refine overview and develop detailed background material (detailed descriptions of how components and systems work, photos, diagrams, video interviews, etc.)		•	•			
Develop internet portal for case studies and background material		•	•	•		
Objective #2: Learn and Integrate BMS into Learning Environment	Sp	Su	F	Sp	Su	F
Conduct interviews with facilities manager, building designers and commissioners	•	•				
Refine and implement organized building tours for students		•	•			•
Undergo training and develop understanding of BMS data stream for controls systems and energy analysis		•	•		•	•
Prepare and conduct student surveys and pre- and post- assessment of student learning outcomes		•	•			•
Objective #3: Provide Systems and Control Hands-on Experience	Sp	Su	F	Sp	Su	F
Acquire sample components and instrumentation	•	•				
Upgrade to new PROCON controller and learn new Discovery software configuration utilities	•	•				
Develop and assess new PROCON Pressure Rig Experiments		•	•			
Develop and assess new PROCON Level/Flow Rig Experiments			•	•		
Develop and assess new PROCON Temperature Rig Experiments				•	•	
Develop online forum to exchange and improve PROCON material					•	•
Objective #4: Synthesis and Evaluation of Building Systems	Sp	Su	F	Sp	Su	F
Explore opportunities and encourage advanced sustainability student projects and collaboration	•	•	•	•	•	•
Disseminate project results and determine future work					•	→

9. Qualifications of Principal Investigator

Melody Baglione, Assistant Professor, teaches courses in the areas of mechanics and systems and control. Melody brings with her 7+ years of industry experience, primarily in automotive powertrain systems. With her professional experience, Melody tries to present examples where classroom theory is applicable to the real-world. Melody was awarded the "Student's List for Exemplary Teaching" by the Cooper Union Engineering Study Council and Student Body in December 2010. She is currently developing and integrating undergraduate laboratory experiments in her courses as well as creating new project and research opportunities in the area of Dynamic Systems and Controls. Melody is developing and cultivating expertise in building sustainability and HVAC systems. This is evident in her many informal interactions with key contributors in building systems design (e.g., architects, mechanical, electrical, and plumbing (MEP) engineering firms, load balancing consultants, building automation and control system contractors, commissioning engineers, operations managers, and so on). In addition, she has participated in numerous events such as the Institute for Sustainable Design lecture series, Siemens Laboratory Energy Savings Seminars, and workshops (e.g., Sustaining the Sustainable: Performance Integrity for Life Cycle of a Building, Innovative Sustainability Curricula, and Expandable Methodologies and Experiments for Teaching, Critical Learning, & Engagement of Engineering Mechanics and Controls Education, etc.).

10. Results of Prior NSF Support

Melody Baglione, NSF Graduate Research Fellowship, 2002-2007