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Innovation Plaza: Improving Teaching and Learning in Engineering Education

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INNOVATION PLAZA: IMPROVING TEACHING AND LEARNING IN ENGINEERING EDUCATION

by

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MECHANICAL ENGINEERING

THESIS

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DEDICATION

To my dearest husband and friend Ivan

To my precious daughters Alma and Diana

To my loving parents, Alma and Andres

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ABSTRACT

Innovation-Plaza at the University of New Mexico represents a significant advance in improvement in instruction, higher rates of student retention and graduation, and greater success for students traditionally underserved by engineering programs. Through the employment of improved teaching methods in several ECE courses; dual-credit courses for high school students; and outreach to public schools, industry, government and international organizations, Innovation-Plaza has already improved the prospects for academic and professional success for some students in the ECE program at UNM.

Expansion and dissemination of the innovations piloted in this program can serve an important role in improving the prospects for students traditionally underserved by engineering and other higher education STEM programs, change that is essential if the United States is to remain competitive with other nations in science and technology.

Given continued attention to the need to build on, replicate and disseminate successful aspects of the Innovation-Plaza program via improved pedagogy in ECE and other STEM courses; outreach to secondary school students, Hispanics, women, foreign students and other populations currently underserved by engineering and other STEM academic programs; and increased collaboration with educational institutions, governments, and industry, it can be expected that the Innovation-Plaza program will continue to experience growth and success in fulfilling its mission to better serve students in engineering and other STEM fields.

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Chapter 1

Student Learning Styles and Effective Instruction in Engineering

Introduction

Higher education institutions in the United States are striving to make engineering education more appealing and effective to a broad range of students. Engineering programs face great challenges in advancing students' knowledge and promoting the deep and well-integrated pedagogical concepts and skills that can lead to the successful application of that knowledge. The purpose of this study is to suggest means by which engineering programs can make stronger connections between applied learning and broad theoretical concepts in order to create an educational climate that is meaningful and effective for all students.

Learning Styles and Effective Instruction

Students differ from one another in many ways, including the types of instruction to which they respond most successfully. Student academic achievement is more dependent on the quality and effectiveness of instruction than on any other alterable factor [47] [63] [69]. Teachers' sensitivity to their students' various learning styles and their willingness to adapt instructional methods to effectively address them directly influences their students' success. In this way, teachers' views of their students and of their own roles as teachers have serious implications for the perceived place and purpose of engineering in post-secondary education.

In recent years, college engineering programs have suffered from steep enrollment decreases and unusually high rates of student attrition compared with many other academic fields. Seymour and Hewitt, in their study *Talking about Leaving; Why Undergraduates Leave the Sciences* [23], reported that many excellent students drop engineering classes because of dissatisfaction with instruction. They found that the grade distributions of students who leave engineering programs are essentially the same as those who remain. The primary factors cited by students who dropped out were irrelevancy of the curriculum to their goals, boredom, and the perception that their teachers were indifferent to them as individuals.

These problems are frequently exacerbated by the attitude of a significant proportion of engineering faculty who claim to view failure and attrition positively, believing that dropouts are students who lack the background in science and mathematics necessary to become engineers. Such teachers are often resistant to recommended changes in instructional methods, believing that the lecture and exam format that was good enough for them suffices for all worthy students.

Felder and Silverman [27] found that a mismatch usually exists between the learning styles of students and traditional teaching styles of engineering teachers. They further found that students who persist in engineering classes often can solve equations and put numbers into formulas, but cannot solve real world engineering problems independently or work collaboratively with others.

Though they found some highly interactive, hands-on classes in which engineering students performed at remarkably high levels, displaying first-rate problem-solving, critical and creative thinking skills, the same students did not do so in other, more traditionally taught classes. Faculty resistant to instructional change frequently complained that students, “Can memorize and plug numbers into formulas, but they don't know how to think!” yet failed to recognize a relationship between their instructional methods and their students' performance. Seymour and Hewitt [23] found most skill deficiencies observed in engineering graduates to be directly attributable to failures in instruction.

Felder and Brent [28] found that whether students thought critically and solved problems creatively, primarily depended on the methods and materials employed by their teachers. How much a student learned in class was governed in part by native ability and prior preparation, but mostly by the compatibility of the student's attributes and the instructor's teaching style.

Every student learns in a different way and every instructor teaches differently, yet a single approach has dominated engineering education, lecture, with student success or failure ultimately based on their ability to absorb information and reproduce it on an examination. This particular teaching method violates virtually every principle of effective instruction established by modern cognitive science and is unsuitable for most students.

For engineering instructors to be effective they must employ teaching strategies that address the various learning styles of their students [29]. Though it is not possible to tailor instruction to each individual student in a class, teaching should be focused on accommodating the needs of as many students as possible. The best way to do this is by using a variety of instructional methods and designing lessons that address several different learning styles. Methods and materials in engineering classes should address varying student needs by including hands-on problem-solving exercises; theoretical and real-world applications of principles of math and physics; visual and aural input in the form of high quality readings, recordings and video; and both individual and small group work.

According to Gardener's Multiple Intelligence (MI) Theory, intelligence is more than only just IQ score, it has to do with determining individual capacities for problem solving and creativity [7]. The eight comprehensive intelligences are linguistic, logical-mathematical, spatial, bodily-kinesthetic, musical, inter-personal, intra-personal and naturalistic. Every person has several intelligences but one or two of them are dominant. Table 1 describes the different intelligences, their characteristics and the careers to which people are attracted depending on their dominant intelligences.

Intelligence	**Characteristics**	**Common Career**
Linguistic	A deep understanding of words, the capacity to use words effectively, orally or in writing	Poet, lawyer, politician, linguist, librarian, speech pathologist, journalist
Logical-Mathematical	An ability to understand numbers and logical concepts, and understanding of abstract analysis and functions, possession of highly developed	Auditor, accountant, mathematician, mathematician, scientist, statistician, computer

Intelligence	Characteristics	Common Career
	reasoning skills	analyst, technician
Spatial	An ability to manipulate and mentally rotate objects, a sensitivity to the relationship between color, line, shape, form and shape	Engineer, surveyor, architect, urban planner, graphic artist, interior decorator, photographer, pilot
Bodily-Kinesthetic	An ability to manipulate objects skillfully, using both fine and gross motor movements, highly developed coordination, balance, strength and flexibility	Physical therapist, dancer, actor, mechanic, carpenter, forest ranger, jeweler
Musical	A sensitivity to rhythm, pitch, tone and melody, sensitivity to a music instrument	Musician, piano tuner, music therapist, choral director, conductor
Interpersonal	An ability to perceive and make distinctions in the moods, characteristics, intentions, temperaments, motivations and feelings of others, a sensitivity to those distinctions, acknowledge by treating each individual with their personal distractions in mind	Administrator, manager, personnel worker, psychologist, nurse, public relations person, social director, teacher
Intrapersonal	Highly developed self-knowledge, defined as having accurate knowledge of one's dreams, goals, strengths, limitations, moods, anxieties, desires, and motivations	Psychologist, therapist, counselor, theologian, program planner, entrepreneur
Naturalistic	An intense interest in the plant and animal species of the world, a highly developed ability to observe patterns in nature and catalog natural material, such as animals, rocks and minerals, a high interest in the well-being of the environment	Botanist, astronomer, wildlife illustrator, meteorologist, chef, geologist, landscape architect

Table 1.1: MI Theory. Intelligences, Characteristics and Common Careers [7]

Perhaps the best-known approach to experiential learning is that of the Kolbs [41]. Their model defines learning as, "the process whereby knowledge is created through the transformation of experience. It is based on six propositions that set forth their active, transactional view of learning:

1. Learning is best conceived of as a process, not in terms of outcomes.
2. Learning is a continuous process grounded in experiences.
3. Learning requires the resolution of conflicts between opposed modes of adaptation to the world.
4. Learning is a holistic process of adaptation.
5. Learning results from synergistic transactions between the person and the environment.
6. Learning is the process of creating knowledge.

The Kolbs' learning model is also based on the existence of four interrelated learning modes, as seen in the figure 1.1.

The Experiential Learning Model classifies students as having a preference for Concrete Experience (CE) vs. Abstract Conceptualization (AC) and Reflective Observation (RO) vs. Active Experimentation (AE) (see Figure 1). CE and AC refers to how people think or feel about things. CE learners involve themselves fully in a subject without bias while AC learners think about and critique new information. AE and RO refers to how a person approaches a task, AE learners like to learn by doing things while RO learners prefer to learn by observation. Felder and Brent [29] describe these four types of learners in table 1.2.

In 1988 Richard M. Felder and Linda K. Silverman [26] proposed some learning-style dimensions based on Kolb's theories. Their hypothesis was that learning and teaching styles should be the same in order for learning to take place. When a mismatch of teaching style and instruction occurs, it is very difficult for the students to

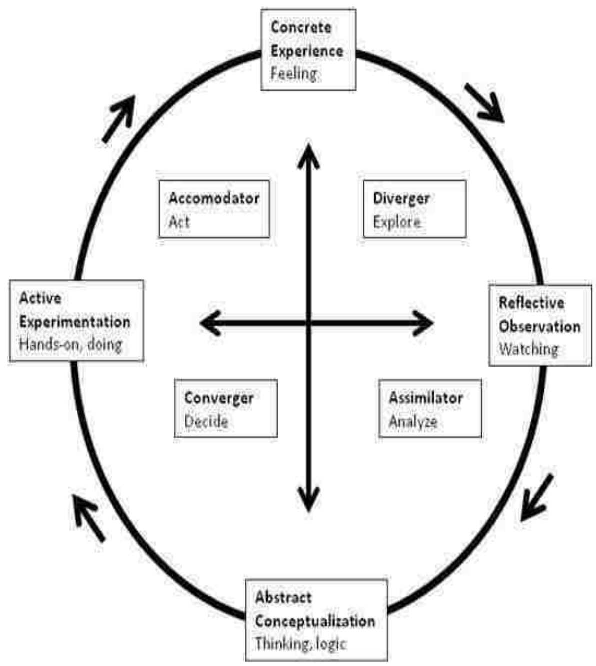

Figure1.1: Kolb's Experiential Learning Model [46]

learn new material during class or to be engaged in the lesson. Their proposed model has five dimensions with two subdivisions each:

1. perception: sensory and intuitive,
2. input: visual and auditory,

3. organization: inductive and deductive,

4. processing: active and reflective,

5. understanding: sequential and global,

Learner	**Characteristics of Students**	**Instructor should function as a**
Diverger (AE & RO)	-Responds well to explanations of how material or lesson relate to experience, interests and future careers -Characteristic question: Why?	Motivator
Assimilator (RO & AC)	-Respond to information presented in an organized, logical way and like to reflect -Characteristic question: What?	Expert
Converger (CA & AE)	-Respond to having opportunities to work on well-design tasks and learn by trial-and-error -Characteristic question: How?	Coach (provide guidance and feedback)
Accomodator (AE & CE)	-Like to apply course material in new situations to solve real life problems. -Characteristic question: What if?	Problem-based-learning is the ideal strategy for these students

Table 1.2: Kolb's Types of Learners [29]

While traditional engineering classes usually address only two of the five categories (auditory and sequential), classes can be restructured to address all five. Table 3 describes the characteristics of learners according to their learning style:

Dimension	Learning Style
Perception: ways in which people tend to perceive the world.	***Sensing Learners:*** observers, gather data through senses, like facts and experiments, dislike surprises, are patient with detail but dislike complications, good at memorizing facts, careful but slow
	Intuitive Learners: indirect perception of the speculation, imagination and hunches, prefer principles and theories, like innovation and dislike repetition, are bored by detail and at grasping new concepts, better at symbols than sensing learners
Input: ways in which people receive information, there are three ways, visual, auditory and kinesthetic (taste, touch and smell)	**Visual:** preference to what they see, pictures, diagrams, charts, lines, movies, demonstrations
	Auditory: these learners remember what is said to them, the discussions, verbal explanations, what they hear
Organization:	**Inductive:** progression that proceeds from particulars to generalities, need motivation for learning, need to see the phenomena before understanding the theory
	Deductive: progression that proceeds from the general to the particular, it might be part of the solution process but it is never the entire process
Processing: the complex mental processes by which information is converted into knowledge can be conveniently grouped, active is not opposite of reflective	**Active Experimentation:** testers, feel comfortable doing something with the external world, like experimentation, work well in groups, evaluate ideas, design and find solutions and are decision makers
	Reflective Observation: introspection, examine the information, need time to think after information is presented, tend to be theoreticians and mathematicians
Understanding: how the information is presented, most classes present the content in a	**Sequential:** can work with material if they understand it partially, may be strong analysts, learn best when easier information is presented first

Dimension	Learning Style
sequential order making it difficult for global learners to keep the pace of the class	**Global**: unable to solve simplest problems but make sudden intuitive leaps and might not be able to explain how they came up with the solution, may be strong at synthesis, sometimes do better jumping directly to most difficult material

Table 1.3: Dimensions of Learning Style [26]

The learning styles that are not addressed in traditional lecture classes are sensory, intuitive, inductive, active and global. Felder and Silverman [26] proposed a way to reach all the different learning styles and effectively address diversity in the classroom without leaving anyone out. Students who could be excellent engineers drop out of school and the best way to avoid that is to adopt teaching methods that address all learning styles.

Kolb's inventory has been administered in several research studies to undergraduate engineering students at different universities to determine the learning styles of engineering students. Figure 1.2 displays a comparison of the results.

Most of the students' learning styles are those of assimilators or convergers. The assimilator asks "what?" and the converger "how?" [40]. Assimilators are abstract conceptualizers and reflective observers. They prefer to think before they act and learn better in a highly structured classroom. Teaching strategies like demonstrations and lectures are helpful for them. Convergers like to try out their ideas to see if they work. They like to understand how to make things efficient and enjoy acting independently [46].

Most professors in engineering programs primarily depend on lectures and reading to convey content [26], which favors assimilators, but may discourage convergers. Students with differing learning styles may feel lost in such classes. When a mismatch in the teaching style of the instructor and the learning style of the student exists, research suggests that students will not succeed. An effective instructor of engineering will utilize teaching strategies that are oriented to all of the different learning styles of the students.

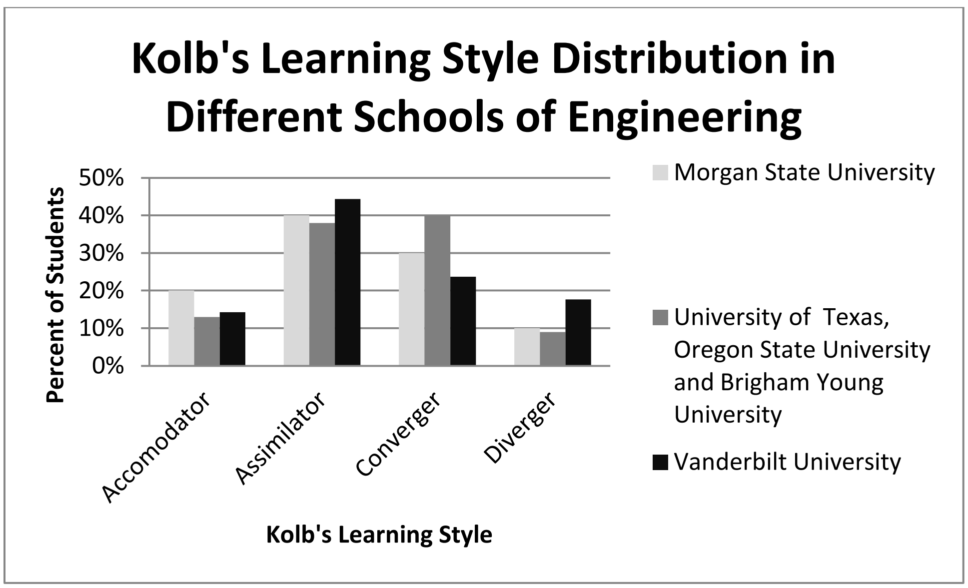

Figure 1.2: Kolb's Learning Style Distributions [41]

These teaching techniques include relating material presented in class to previously learned content and to personal experiences; preparing students in advance for what will be covered during the semester; balancing concrete and abstract concepts (facts, principles, hypothetical experiments, mathematical models); teaching problem-solving techniques; using posters, graphs, charts, pictures and films; providing time for students to reflect and brainstorm in groups; assigning drill exercises; allowing students to work cooperatively on homework; and applauding creativity.

Finally, it is important for every student to be aware of the various learning styles and to identify those that characterize their preferred modes of learning. Students must be encouraged not to limit themselves and to be aware of and attempt to strengthen their abilities in each learning style, but a clearer understanding of their individual strengths and preferences will help them succeed academically.

Conclusion

The introduction of effective research-based improvements in pedagogy that take students' individual learning styles and preferences into account and exploit them effectively can transform instruction and greatly improve student success. An emphasis on expanding the range of modes of lesson delivery, individualized support for students, and new avenues for hands-on application of concepts has been crucial to the success of Innovation-Plaza at the University of New Mexico.

Chapter 2

Overcoming Barriers to Recruitment, Retention and Graduation of Traditionally Underserved Engineering Students

Introduction

While the individual learning styles of students are important factors in academic performance, gender and ethnicity are also powerful determinants of academic success in engineering. Our engineering workforce is crucial to America's innovative capacity and global competitiveness, yet women are vastly underrepresented in engineering jobs and among engineering degree holders despite making up nearly half of the college-educated workforce in the United States.

Overcoming Barriers

Although women attend college in numbers approximately equal to men, only one out of twelve engineering students is female. Stereotypes exist about girls not having innate mathematical ability and disliking engineering. In 2011, of 83,000 engineering degrees granted in the United States, only 18.4 percent were received by women [82].

Despite decades of active recruitment, women remain underrepresented in engineering, both in the United States and globally [33]. Women leave engineering at all stages of their careers—as undergraduates, graduate students, professionals, and in the transitions between each stage, a phenomenon described as the leaky pipeline. Despite the fact that males and females are nearly equally represented in high school engineering classes (56% vs. 44%) the pipeline turns into a “gaping hole” when they reach college [52]. Women comprise only 18% of engineering undergraduate degrees and only 11% of the engineering workforce [44].

The underlying causes of this disparity between men and women are numerous, complex, and pervasive. However, a recent meta-analysis of research on the gender gap in STEM [34] found bias, stereotype threat, and social factors as prime driving forces contributing to the loss of women from STEM fields. In fact, recent work by Moss-Racusin [57] found science faculty across disciplines and regardless of gender exhibited an unconscious gender bias against undergraduate women, underscoring the pervasive and persistent nature of cultural stereotypes regarding women in science.

In examining hundreds of studies, Catherine Hill, AAUW’s Director of Research, and Christianne Corbette, a research associate – found eight major factors that helped depress the numbers of girls and women in STEM careers: beliefs about intelligence, stereotypes, self-assessment, spatial skills, the college student experience, few role models among university and college faculty, implicit bias, and workplace bias [34].

Because most engineering faculty are males, it is difficult to know if the uneven gender distribution of students in higher education engineering programs is more a problem of a lack of academic and professional role models for female students, a mismatch in the teaching/learning style of the classroom that favors males, or deep-seated prejudices against women in the field that manifest themselves in lower expectations for women on the part of peers, professors and themselves [32].

Research on self-stereotyping, the most insidious form of bias, has revealed that women's scores on mathematics and science assessments are higher when they are tested alone or with other women, and drop by as much as fifty percent when a male is present [73]. Considerable social pressure is brought to bear against women who express an interest in STEM fields by peers and teachers who both consciously and unconsciously promote the stereotype that women lack the native ability in mathematics and science possessed by men.

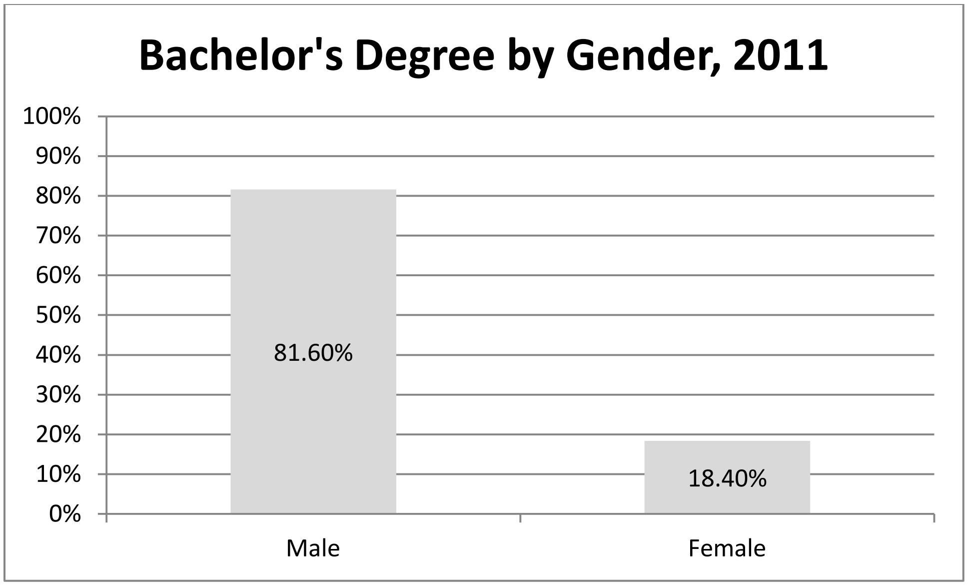

Figure 2.1: Engineering Bachelor's Degree by Gender [82]

Cultural bias regarding women in STEM fields can produce anxiety or lack of confidence which might be a factor determining why some women who enter engineering programs with superior academic credentials do not perform as well as less qualified men and have a higher probability of dropping out [32]. Though the belief that men have greater innate scientific ability than women is not supported by the evidence, it persists in some countries.

In many instances, the gender gap in engineering education is attributed to disparities in mathematical preparation and ability. While a strong and persistent belief in a gender achievement gap in mathematics has prevailed for decades [26], evidence for its existence is less conclusive [37]. In a meta-analysis of six large survey studies, Hewlett [35] documented a small mean difference in mathematics achievement between men and women and modest differences in variance. More recent data in the United States refute a mathematics gender achievement gap, at least in the general populace grades two through eleven, as found by Hunt [37].

Analyses of international data reveal significant variability between nations in the presence and effect size of a mathematics and science gap [62]. Gender stereotypes regarding mathematics and science ability, though deeply rooted in the United States, are less common in many other parts of the world. The 2003 Trends in International Mathematics and Science Study (TIMSS) revealed nearly equal scores in most of the thirty-four countries where it was conducted, with girls significantly outperforming boys in seven nations, and boys significantly outperforming girls in five nations.

In science and mathematics tests administered in 2012 by the Organization for Economic Cooperation and Development to 470,000 fifteen-year-old students in sixty-five countries around the world, girls generally outperformed boys, though not in the United States, Canada or the United Kingdom where their scores were, on average, five percent lower than those of boys. In Russia, China, and the Middle East, which have a much higher proportion of women in science and engineering education is the most effective means by which women can achieve independence and social mobility, girls scored an average of eight points higher than boys.

This variability suggests that sex differences in mathematics and science achievement are shaped by socio-cultural factors rather than innate cognitive differences related to sex. The gender gap in mathematics and science performance favoring boys disappears or is reversed in societies where gender stereotypes regarding mathematics and science ability do not exist and there are ample female role models for girls to emulate. This is supported by research by John Bargh and associates [13] in which half a million Implicit Association Tests completed by citizens of 34 countries revealed that nation-level implicit gender stereotypes predicted nation-level sex differences in 8th-grade science and mathematics achievement. Self-reported stereotypes did not provide additional predictive validity of the achievement gap, suggesting that implicit, unconscious stereotypes and sex differences in science participation and performance are mutually reinforcing, contributing to a persistent gender gap in science engagement in some countries, including the United States.

Stereotypes that men are naturally more talented and interested in mathematics and science are thought to influence the science, technology, engineering, and mathematics aspirations and achievements of males and females. For example, women who endorse such stereotypes report less interest in mathematics and science, and are less likely to pursue a mathematics or science degree. Also, reminding women of the "mathematics = male" stereotype, or just unobtrusively highlighting their gender, is sufficient to weaken their performance on a subsequent mathematics or engineering examination compared with a control group. This phenomenon, termed stereotype or social identity threat, is thought to occur via increased anxiety, and increased cognitive load created by such anxiety, that one's own behavior will potentially confirm a stereotype about one's group [73].

Stereotype threat, described as a "risk of confirming … a negative stereotype about one's group" [73], may undermine achievement in the STEM classroom. Stereotype threat is not limited to gender and can apply to many intrinsic characteristics, including race, ethnicity, income level, and academic ability [72]; however, its most widespread impact is on the performance of women in undergraduate STEM programs.

The subject's perception of stereotyping is complex and highly contextualized, triggered by a survey item [73], the gender of the instructor, or instructional practices [42], and can undermine academic success in several ways. Stereotype threat can produce stress and induce anxiety, causing a student to become more self-conscious about her performance and to actively try to suppress those emotions, which may tax working memory and lead to decreased performance [68]. Prolonged exposure to stereotype threat can result in "disidentification," wherein a student stops associating with a given stereotyped group and avoids situations likely to be perceived as threatening [74] [8]. In engineering, stereotype threat contributes to the leaky pipeline, causing attrition of women from the major.

Empirical work focused on ways to reduce or eliminate the effects of stereotype threat has revealed a number of simple yet effective measures to serve at-risk populations by altering test-taking instructions [4]. Social psychologists have also reduced the effects through mediation of contextual and societal factors related to stereotypes. Individuation has proved effective by explicitly distinguishing between a stereotyped individual and the stereotype to minimize identification [5] and allowing stereotyped students to work together, distance themselves from the stereotype in question, while remaining engaged in the task or course [4]. Finally, because women are more likely to endorse the stereotype that science is for men when suitable female role models are largely absent, simply increasing the visibility of and engagement with positive female role models has proven effective [56]. In fact, simply having a competent woman administer a mathematics exam was sufficient to reduce the achievement gap in one study [49].

Values-affirmation tasks have recently received a great deal of attention for their ability to reduce or eliminate stereotype threat. In this type of intervention, individuals take 10–15 minutes to write about values that are personally important but unrelated to the course. Such writing tasks appear effective in reducing or eliminating stereotype threat for African Americans and women [55] with effects that may persist over time. Although short and simple, values-affirmation writing tasks draw directly on students' experiences to actively engage each student as an individual and may promote deep processing to effect powerful results. Thus, although simple, values-affirmation writing tasks have the potential to profoundly impact students experiencing stereotype threat [81].

The Carnegie Mellon University School of Computer Science was able to expand its undergraduate major from 7 percent female to 42 percent female in the span of five years by doing more to actively recruit female applicants, changing admission requirements to include less prior experience with programming, and changing the "peer culture" of the major. A study that looked at physics department with larger-than-average female enrollments, as well as at historically black colleges and universities and women's colleges, found that active recruiting, departmental social activities, informal mentoring groups, and hands-on labs that provide personal support and reinforcement to individual students can help attract and retain female majors [55].

More broadly, what many studies have found was that the climate of the department makes a significant difference in who is attracted to the engineering major, who chooses to persist and eventually graduates. The active recruitment of students is necessary, and inviting students to take an introductory course or to consider engineering as a profession is an important first step. Another important step is to reform the teaching of intermediate advanced courses so that, looking ahead, female students understand that their work will be noticed, supported and valued throughout the program [55] [3].

The scarcity of women in engineering programs reflects a significant wasted opportunity to benefit from the capabilities of talented individuals, whether male or female. Although women have begun to enter some science fields in greater numbers, their mere increased presence is not evidence of the absence of bias. Rather, some women may persist in academic science despite the damaging effects of unintended gender bias on the part of faculty. Similarly, it is not yet possible to conclude that the preferences for other fields and lifestyle choices that lead many women to leave academic science even after obtaining advanced degrees are not themselves influenced by experiences of bias, at least to some degree. To the extent that faculty gender bias impedes women's full participation in science, it may undercut not only academic meritocracy, but also the expansion of the scientific workforce needed for the next decade's advancement of national competitiveness.

Although 36% of Hispanic students entering college declare their intention to major in a STEM field, only one of five of them go on to earn a degree, a higher rate of attrition in STEM than any demographic other than women. The high dropout rate, which reflects a lack of support for Latinas/os in science, technology, engineering, and mathematics, is wasteful of a vast pool of interest and talent. Although the number of Latinas/os participating in some form of higher education has more than doubled over the past two decades, Latinas/os participation in STEM has not experienced the same gains.

In 2012, 70% of Hispanic high school graduates attended college, a higher percentage than any other ethnic category, however; more than half of those students withdrew from college before the end of their first year. Although Hispanic constitute 21% of the college-aged population, 18 to 24, only 8% of bachelor's degrees, 3.5% of master's degrees, and 4.4% of doctorates in STEM fields are awarded to Latinas/os. This is not due to a lack of interest. Latinas/os who attend college enter STEM majors at higher rates than Anglos, but experience a higher rate of dropout. Much needs to be done to build on the popularity of STEM among Hispanics, provide the support necessary to enable them to persist to graduation and increase the number of Latinas/os STEM undergraduate and graduate degree holders.

With large amounts of federal funding being channeled to Hispanic Serving Institutions (HSI), colleges of all sizes and levels of selectivity are beginning to engage in instructional reform efforts to improve retention and graduation rates of Latinas/os students. One of the most successful approaches is benchmarking. This involves determining how higher education institutions can adopt new programs, form learning communities, sponsor peer tutoring, provide supplemental instruction, or any of a number of "high impact" pedagogical strategies that have attracted attention in recent years.

There are three forms of benchmarking that have shown to be effective. The first strategy is performance benchmarking, in which colleges set and monitor performance goals using graduation rates and other indicators of educational achievement, disaggregated by race and ethnicity. The second strategy is diagnostic or "best practices" benchmarking, in which colleges compare practices on their campus with programs and policies in use at other colleges that have proven exemplary in terms of effectiveness, innovation, or orientation to ensuring the equitable participation of underserved groups. The third strategy is process benchmarking, in which faculty and administrators make guided site visits to exemplary institutions in order to learn about the steps they would need to take in order to adopt the observed exemplary practices on their own campuses.

By examining new ideas that have been effectively tested in other institutions, particularly in K-12 education, HSIs are gradually introducing positive changes on their own campuses in curriculum, pedagogy, and student services. There is a great deal of interest in discovering, disseminating, and measuring the effectiveness of exemplary practices that are effective not only in improving the performance in STEM programs of Hispanic students, but of women and other underserved or badly served populations.

One of the most innovative and effective means by which HSIs have plugged the leaky engineering pipeline between secondary school and college is to offer dual-credit courses. High school students who make an early start on prerequisite and introductory engineering courses are more likely to persist in college, to earn higher grades, and to graduate. This is especially true if the dual-credit courses are offered on the college campus, where the influence of more mature college students and the "grown up" feeling of being in college inspires many secondary students to higher levels of academic achievement than might be possible in the high school setting [36].

One particularly successful dual-credit program in engineering was sponsored in Florida public schools and universities by the Career and Professional Education (CAPE) Act which provides funding for training of students in high school to earn state-approved industry certifications that are critical to Florida employers. The legislation requires districts to provide academically rigorous courses that meet or exceed state-adopted, subject-area standards; lead to industry certification; and, where appropriate, result in postsecondary credit. The legislation also required districts to set up career and professional academies to offer this coursework, and to ensure standards-based instruction by industry-certified faculty [28].

Now in its seventh year, the CAPE program has produced findings that are promising, in terms of student engagement, performance and preparation for college and careers. High school students who took at least one technology course, and at least one industry certification exam, had better attendance and higher grade point averages (GPAs) compared to students of similar demographics who took no technology courses or exams in this same period. Moreover, students who took at least one technology course, and at least one industry certification exam, earned admission to four-year colleges and universities at a higher rate than students who took no technology courses or industry certification exams [28].

The positive relationship between dual-credit technology coursework and student outcomes in post-secondary education has been clearly demonstrated with those who participated in dual-credit technology courses and certification programs enjoying higher GPAs, persistence and graduation rates in STEM programs. However, given that attendance, GPA and admission to four-year colleges and universities are important measures of high school success—and strong, research-based predictors of postsecondary academic success—this relationship warrants attention and further exploration [28].

Florida's efforts to strengthen CTE mirrors a national movement in this direction, which was underscored in the 2006 reauthorization of the federal Carl D. Perkins Career and Technical Education Improvement Act. In addition, technology corporations have been instrumental to help fund technology courses that lead to industry certifications from industry providers, including Adobe Systems, Apple Computer, Cisco Systems, Microsoft and Oracle Corporation [28].

Students typically must complete at least 150 hours of instruction in a one-year class with an industry-provided curriculum to be eligible to take a certification exam. Students must pass the exam to earn certification. Some industry providers offer multiple technology courses—or sequences of courses of increasing difficulty—that prepare students to earn multiple certificates. Florida has articulation agreements with postsecondary institutions, which provide students with college credit for some industry certifications and "establish educational pathways to promote student movement up the college and career ladder" [28]. A planned sequence of academic coursework can help students attain industry-recognized certifications and transition successfully to postsecondary education.

Students who took at least one dual credit technology course and opted to enroll in college were more likely than other students of similar demographics to enroll full-time. Students who took technology courses, earned industry certifications and college credit appear to have a more purposeful and focused plan for their postsecondary years than many other students. Further longitudinal data is needed to examine the relationship between dual-credit technology courses, college admission rates and enrollment status, and high school and college graduation rates. However, it seems clear from the Florida example that such programs do lead to higher rates of college admission, particularly at four-year institutions, and improved attendance and academic performance [28].

Nationally, the numbers of Latinas/os students receiving STEM bachelor's degrees increased by 80% between 1995 and 2007. During the same period the number of Latinas/os completing Master's and doctoral degrees grew by 105% and 144%, respectively; however, Latinas/os continue to be severely underrepresented among STEM degree recipients at all levels. Given that advanced degrees are typically required for entry into STEM professions and faculty positions, greater efforts must be made to support and improve these trends [22].

Conclusion

Increasing participation of Latinas/os and other underrepresented groups in STEM education at all degree levels is not just a matter of fairness and social equity, but of workforce need. The Bureau of Labor Statistics projects employment in STEM occupations will increase by 21.3% from 2008 to 2018—more than double the growth in other occupations (U.S. Department of Labor, 2009). Latinas/os are the fastest growing demographic group and are projected to be 25% of the U.S. population in 2020. By 2025, the majority of the U.S. population will be members of ethnic "minority" groups [80]. Given these demographic shifts, it is critical that underserved populations, particularly women and Latinas/os are educated to contribute to a diverse STEM workforce.

Chapter 3

Innovation Plaza: Reaching Across Borders to Improve Instruction and Increase Student Success

Introduction

Innovation-Plaza is an initiative spearheaded by the Electrical and Computer Engineering Department (ECE) at the University of New Mexico (UNM). The program's intent is to give students more opportunities to see topics presented in real world contexts in their engineering courses, applying concepts through hands-on experimentation rather than simply listening to lectures, seeing demonstrations in a laboratory, or manipulating virtual models on computers. Students from high school and university undergraduates participate in hands-on, interactive projects with real-world applications, conduct independent and group research projects, and become proficient relating abstract concepts to the concrete methods and tools currently employed in industry.

Innovation-Plaza

The first undergraduate course adopted by Innovation-Plaza was ECE 446 and 446L, Design of Feedback Control Systems, in Spring 2013. This is an upper division course that is usually taken by engineering students during their final semester in the Bachelor's degree program. It has been reported by students and professors to be an especially challenging class that requires mastery of difficult concepts. Innovation Plaza hoped to improve student performance in ECE 446 by combining it with a hands-on laboratory course in Feedback Control Systems.

Students in ECE 446 are required to participate in class and a two-part laboratory. In the first part of the lab they become familiar with and learn to program LabVIEW Environment using the Control Design and Simulation Toolkit, learn the basics about the CompactRIO Module and Design and implement a virtual controller using labVIEW. In the second part of the lab, which takes place in the Innovation-Plaza laboratory, they learn to control a National Instruments DC Motor Control Trainer (DCMCT) that can be configured in a variety of ways. This hands-on work in robotics helps students to apply their knowledge of Control Systems to real world applications and they program the DCMCT to perform a variety of tasks.

The instructor of ECE 446 has high expectations for students, demonstrated by the statement "ECE 446 has ambitious goals!!" written in the syllabus (Appendix A). These goals and expectations are then described in specific terms, making the course requirements clear:

1. Design and experimental verification of feedback control systems

1. Learn how to analyze and design digital control systems
2. Study state feedback, output feedback, and LQR
3. Give an introduction to nonlinear control systems
4. Design PID controllers
5. Apply the concepts learned on real-world nontrivial control problems
6. Introduce Hybrid and Networked Control Systems

Pedagogical research shows that teacher expectations affect student achievement and attitudes. In an effective classroom, high expectations are communicated through policies and practices which focus on academic goals [14]. The stated goals of the course demonstrate that not only will a variety of concepts be covered, but diverse teaching strategies will be employed to assure that different learning styles will be addressed. In an academic field in which a tradition of lecturing prevails, the Innovation Plaza redesign of ECE 446 demonstrates a sensitivity to and knowledge of active, high-impact pedagogy [43].

STEM education can be improved by providing students with the opportunity to take part in hands-on experiences in which concepts are applied to real-world problems [27]. ECE 446 not only employs these highly effective strategies, but motivates students by making these connections clear. The syllabus clarifies the instructor's commitment to relating course content to students' career goals and interests, stating:

> "Feedback control systems are found everywhere. They are found in aircrafts, cars, robots, and manufacturing systems, to mention a few. These

> systems are equipped with microcontrollers, sensors, and communication devices and interact with uncertain dynamic environments. This course will help you learn the concepts and master the tools that will enable you to design and develop effective feedback control systems" (p. 1).

A commitment to motivating and supporting students begins on the first day of class, when the students receive the syllabus and immediately understand that their learning will be meaningful and important and that they will have the opportunity to apply what they learn in hands-on work in the Innovation-Plaza laboratory.

Design of Feedback Control Systems utilizes good pedagogy because the course presents information in an organized, logical way, supporting learning through laboratory applications of concepts, differentiating instruction with a combination of lecture, seminar, individual and group work. Pedagogical research has shown that instructors cannot reach all students with one-style-fits all methods. Differentiated instruction emerged as a fully developed model nearly two decades ago [77] and has grown in popularity ever since. The goal of a differentiated classroom is "to maximize student growth and individual success by providing many avenues for students to learn and demonstrate mastery of content." Differentiated instruction can significantly improve student achievement by reaching multiple intelligences [29].

Even though a single best way to teach does not exist, in 2006 Dr. Dee Silverthorn described several of the most effective best practices in his article "Teaching and Learning in the Interactive Classroom". Silverthorn explains how professors report low attendance in classes because students no longer depend on the instructors for the acquisition of information. Students have the ability to memorize facts, but science education should emphasize a better understanding of conceptual principles. The only way of serving the students better is using a variety of teaching strategies and making the classroom interactive [70].

Creating a successful classroom requires five steps: develop clear objectives, identify essential content, decide what students can learn on their way, use class time for practice and ungraded assessment and finally make sure the graded assessment matches class activities [70]. ECE 446 is an interactive classroom because it successfully employs the five steps and it also complements learning with hands-on laboratories.

The relationship between Silverthorn's five-step successful classroom model and ECE 446 is described below:

1. *Develop clear objectives*. In the ECE 446 class the objectives of the class are accessible to the students. The instructor uses Blackboard (UNM Learn) to post all the information, lecture notes, slides, and homework solution.

2. *Identify essential content*. It is important that the students not only memorize, but also understand and apply the concepts to be able to remember them. In ECE 446 students use technology during class (Matlab/Simulink/StateFlow and LabVIEW) to apply the concepts learned on real-world problems.

3. *Decide what students can learn on their own*. By having the expectation that students will learn material on their own, most students will learn the basic material on their own. The instructor assigns reading assignments to make the students learn facts about a topic before class.

4. *Use class time for practice and ungraded assessment*. Attendance is expected every class, students are responsible for all material covered in class and they know that the material covered every class is important. The learning that takes place during class is relevant; they will apply it in the homework and exams. The instructor has effectively employed electronic "clickers" to engage student participation and interest and to measure and share information with students about their learning.

5. *Make sure the graded assessment matches class activities*. If students think assessments are not fair, or class will not prepare them to pass them, they might stop coming to class. For ECE 446 attendance is not mandatory, but students attend the class because they learn material that is relevant, and will help them pass the class.

The addition of a new laboratory component to ECE 446 is an important improvement in instruction. In the labs the instructor scaffolds the material, making learning more effective and lasting by presenting complex and difficult concepts through tasks that are accessible, manageable and within each student's "zone of proximal development" as described by Vygotsky [66] [79]. Students learn the Design Process Feedback Control System through a LabVIEW programming process that is learned and applied step by step.

In the first lab session the students become familiar with a LabVIEW environment (Graphical Programming), the function and icons; and create simple functions. In the following five labs the students gradually learn the design process working individually and in groups with support from the instructor. As shown in figure 3.1, the instructor clearly displays the objectives of the lab project on the board, using different colors for enhanced comprehension, and inserts LabVIEW icons into the presentation to guide students, in learning and applying the programming system.

In order to make learning more meaningful for students the instructor explains the objectives for the entire semester during the first meeting and answers students' questions about the goals of the laboratory class. In Lab 2, the instructor guides the students by continually providing them with visual material to help them understand which part of the design process they are learning, as shown in figure 3.2, and its place in the entire process. Students can access a slide that describes the specific part of the process that they will cover that day, annotated, highlighted and explained. The same procedure is used for labs 3 and 4 as shown in figures 3.3.

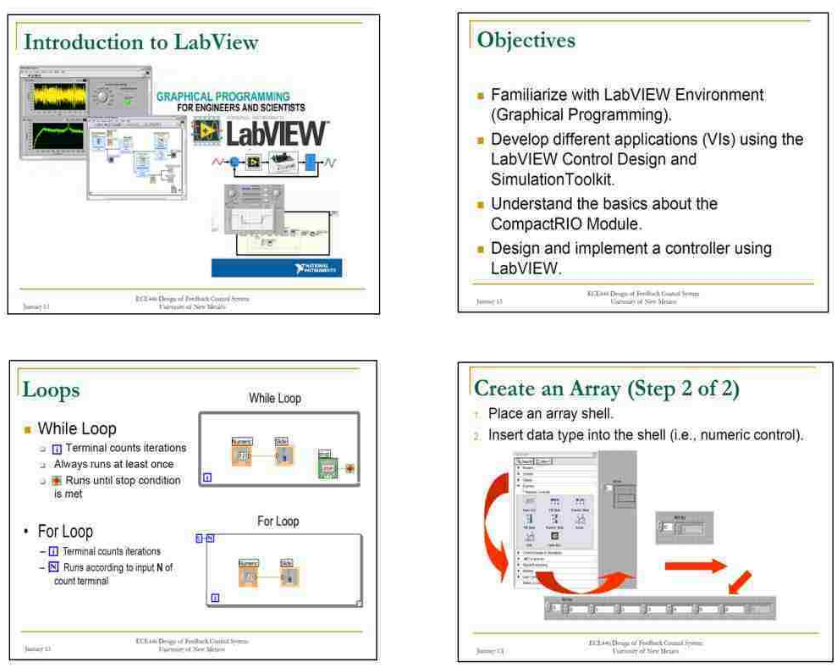

Figure 3.1 Laboratory 1 (Appendix B)

In the last two lab sessions, students are required to design a virtual instrument (VI) using LabVIEW and to present and discuss it. During these two sessions they use the tools they have mastered during the previous labs and apply their knowledge. Students solve problems and use analytical skills to create a program. Students generate their solutions using a program language.

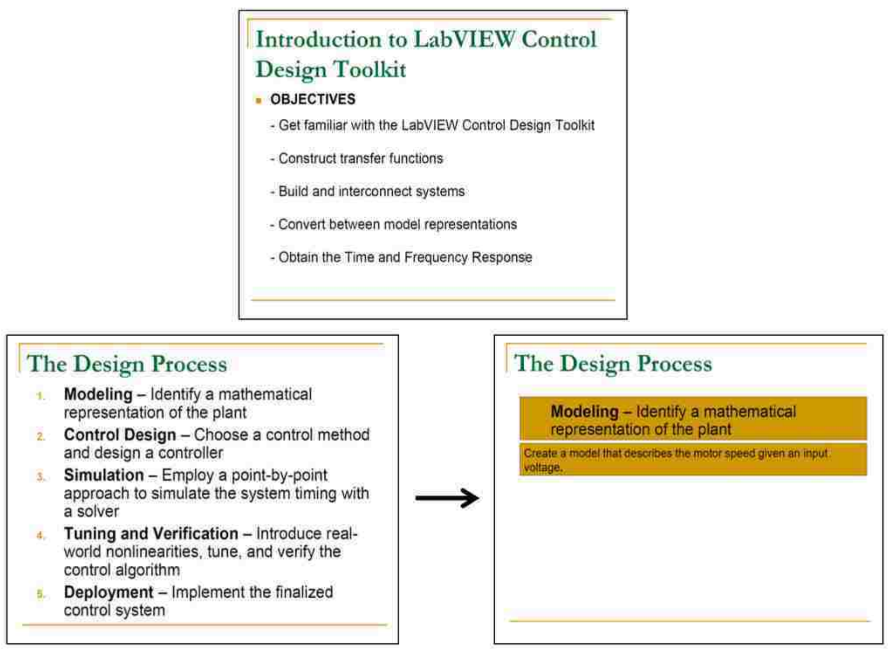

Figure 3.2. Laboratory 2 (Appendix B)

The greatest challenge facing students at this point is not only understanding syntax or concepts, but the elements of effective program planning [39]. In ECE 446L students learn to design VIs step by step, planning and designing instruments each time. Ismail, et al. identified four main problems students have when they have to create programs. These are: a lack of skill in analyzing problems, ineffective use of problem representation techniques for problem solving, ineffective use of teaching strategies for problem solving and coding and difficulty in mastering programming syntax and functions.

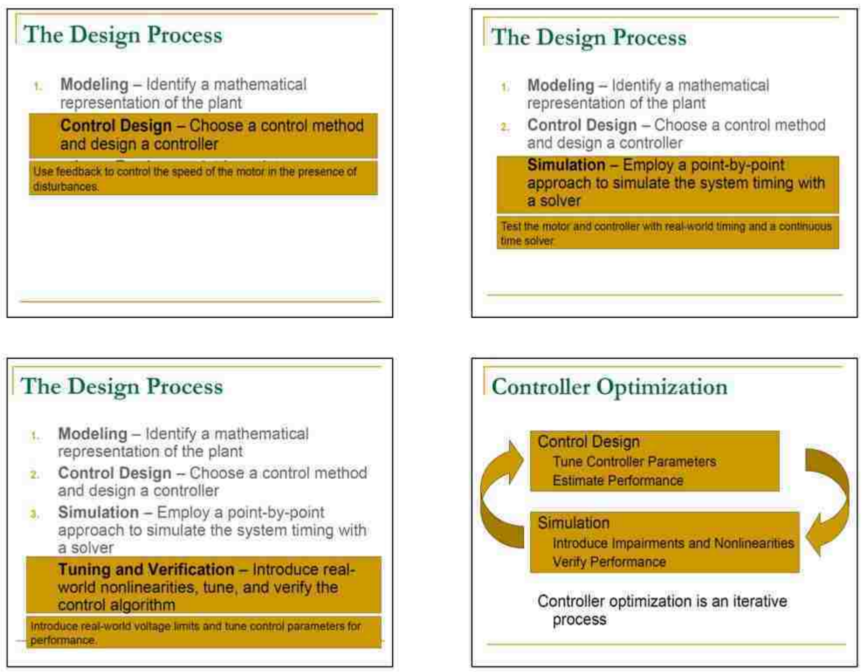

Figure 3.3. Laboratory 3 (Appendix B)

Students taking ECE 446L are presented with a Prelab problem in every session where they are required to access prior knowledge and practice problem-solving skills. During the prelab students use Matlab to apply the concepts. The prelab also functions as a pre-assessment tool for the instructor and assists in identifying areas that require review or a new approach to instruction.

Murray, et. al. have written of effective means of teaching control concepts and tools, saying that engineering programs must:

> Invest in new approaches to education and outreach for the dissemination of control concepts and tools to nontraditional audiences. As a first step toward implementing this recommendation, new courses and text books should be developed for experts and non-experts. Control should also be made a required part of engineering and science curricula at most universities including not only mechanical, electrical, chemical and aerospace engineering, but also computer science, applied physics and bioengineering. It is also important that these courses emphasize the principles of control rather than simply providing the tools that can be used for a given domain. An important element of education and outreach is the continued use of experiments and the development of new laboratories and software tools. This is much easier to do than ever before and also more important. Laboratories and software tools should be integrated into the curriculum" (p. 23) [58].

When students take ECE 446L, each lab session is divided in two different parts. During the first part of the session, students pursue virtual projects designed by the instructor of the lab. In the second part, students interact with innovative equipment designed by Quanser. In this part of the lab students experiment with the QNET vertical take-off and landing (VTOL) , the QNET DC Motor Control Trainer for NI ELVIS and the QNET Mechatronic Sensor Trainer for NI ELVIS shown in figure 3.4, 3.5 and 3.6. The experiments cover current control, modeling, flight control, PID Control, position and speed control, experimentation with different sensors among others. In order to carry out the laboratory, students must be familiar with transfer function fundamentals and LabVIEW programming.

Figure 3.4. QNET Vertical Take-off and Landing Trainer (VTOL)

Each session in the student workbook employs several different instructional strategies to facilitate more efficient and productive student learning and to support a variety of learning styles. The tasks and materials included in each practice are background information, pre-lab questions or exercises, experiments and a final lab report.

The first part of each workbook exercise is the background section that provides all the necessary theoretical concepts for the experiment and builds prior knowledge to lead to constructive learning. Use of prior knowledge helps students synthesize new knowledge [38]. New knowledge should connect meaningfully to what students already know [47]; therefore, the background section is an extremely powerful tool. During each lab session students link new experimental and prior background knowledge.

Figure 3.5 QNET DC Motor Control Trainer DCMCT

Figure 3.6 QNET Mechatronic Sensor Trainer (MECHKIT)

The next section consists of Pre-lab questions or exercises that help the students get ready for the lab session. It can be assigned as homework or solved during the lab session, generating an interactive opportunity prior to the lab. The questions or exercises are useful for the students because they relate directly to the experiment.

The student workbook provides step- by-step instructions to conduct the lab experiments and to record the collected data. The experiment is a hands-on experience that motivates students and stimulates curiosity. Working sometimes as individuals and at other times in teams, they investigate, experiment, gather data, organize findings, and interpret and analyze results to reach logical conclusions. Multiple senses are employed to promote greater understanding, enabling students to hear and see and touch physical applications of the concepts that they have previously learned theoretically. Seeing how the VI works physically makes engineering subject matter more appealing and helps keep students engaged. Hands-on experimentation also helps students connect to the real world applications of engineering. Making the ECE 446L labs, students become proficient in the tools currently employed in industry and research while linking mathematical theory to real world experiences.

After each lab session students write a lab report describing the procedure they followed and reporting, analyzing and presenting conclusions on their findings. Each student is required to write an individual report, even on group projects, in order to support full comprehension and support the development of appropriate skills in writing and data analysis.

A second key element of the Innovation-Plaza program is its outreach efforts. By providing opportunities to connect to the cultural capital privileged sectors take for granted, the program seeks to overcome demographic challenges facing including those historically associated with a majority population of underserved students: high dropout rates; limited interaction with higher education institutions, public schools (aren't they IN public school?), industry and government; and a lack of international collaboration. Outreach efforts embedded in the Innovation-Plaza program seek to remedy unengaging undergraduate curricula in STEM fields at both secondary and post-secondary levels. In this way, Innovation-Plaza represents a powerful, practical way to integrate enhanced curricula and educational outreach through an open, globally connected, interdisciplinary program for experiential learning and collaboration.

Innovation-Plaza breaks down the traditional "silos" that isolate students and faculty in high school, trade school, university, research, and professional domains. In the traditional model, students in high school are taught mainly to think about science and engineering in abstract terms. In college, similar work continues, if at a higher level, as students learn engineering concepts. They are trained to apply them, especially at the graduate level, but usually in abstract case-study or virtual applications that often leave them ill-prepared for real-world challenges. In trade schools, students are taught to take on a supporting role in engineering enterprises, but not to innovate or do creative work. Traditionally, it is only in research and professional work that engineers have the opportunity to "do" engineering, expanding the field, practicing innovation and entrepreneurship.

Innovation-Plaza breaks down the walls between these traditional roles and provides a common meeting-ground for students at all levels of education, in all courses of study and with varying professional goals to work collaboratively in active, hands-on learning and to build their skills in applied research, innovation and entrepreneurship. By providing dual-credit courses that are available to secondary students, Innovation-Plaza does not just reach out to provide early experiences in engineering to attract and retain students, but can provide them with one year or more of college credit in engineering and prerequisite courses that will provide them with advanced standing and a savings of, at current rates, nearly twenty thousand dollars in tuition and fees.

University of New Mexico (UNM) and the Albuquerque Public Schools (APS) signed a cooperative agreement in 2011 that enables APS high school students to enroll and take first year ECE courses on the UNM campus. Since that time, increasing numbers of students have participated in Innovation-Plaza and earned high school and college credit in engineering, mathematics, and science.

In addition, Innovation-Plaza is working successfully with students at a Middle School to build Rube Goldberg machines and plans to expand the program to middle schools across the city, enriching and expanding students' access to quality STEM education and providing in-service training and opportunities for innovation and collaboration to their teachers.

Innovation-Plaza high school program offers college courses to high school students. One student that successfully participated in the program graduated in May, 2013 at the age of 17 having completed more than two semesters of college-level work in ECE and prerequisite courses at UNM. He took Calculus I and II; Physics I and II; ECE 101, 131, 231, 238L; and English 101 and 102 in his last year of high school. He was hired to work on a Raytheon-Brazil project during the summer and will attend UNM as an honor student with advanced sophomore standing in the fall.

In addition to work with the APS, Innovation-Plaza is reaching out internationally through collaboration with, among many others, ISTEC-Innovate which works in twenty-eight countries; CAPES, PUCRS, UNISINOS, and UNICAMP in Brazil; UNLP and U. Palermo in Argentina; PUCP and UTEC in Peru, and UTPL in Ecuador and CONACYT in Mexico, and HEC in Pakistan.

Through collaborative relationships with these institutions, Innovation-Plaza sponsors undergraduate and graduate student exchanges, double graduate degree programs, cooperative projects, and sponsorship of entrepreneurial enterprises.

Innovative educational programs for international students include the 4 + 1 Program in which students study in their home institution for four years and then for one year at UNM, earning B.S. and M.S. degrees from both. There is also the 2 + 2 program for Spanish-speaking students which enables them to complete a BS at UNM studying for two years mainly in Spanish or Portuguese under the auspices of UNM's Instituto Cervantes and Fundacion Iberdola while studying English. When they have developed fluency, these students continue to study for the last two years in English, earning the B.S. degree from UNM.

The fundamental elements of Innovation Plaza are interrelated and build one upon another toward mastery. These elements are motivation, creative concepts, mathematics modeling, prediction and simulation, analysis, implementation, measurement and observation, testing and refinement, reporting and presentation, and entrepreneurship.

Utilizing the most effective pedagogical methods; an active program of outreach and support; a real-world, hands-on approach to learning; international collaboration; the breaking down of academic silos; an emphasis on entrepreneurship; and collaboration with industry, government, and educational institutions at every level, Innovation-Plaza will continue to expand its influence within and beyond the University of New Mexico with the intention of improving instruction in the STEM fields, reversing the alarming rate of dropout, and eradicating barriers to ethnic and gender diversity that now afflict higher education in engineering and the sciences.

Conclusion

Innovation-Plaza seeks to bring together students at every grade level nationally and internationally to work cooperatively to challenge stereotypes, improve STEM pedagogy, and meet the challenges of the STEM fields with creativity and an entrepreneurial spirit. Dissemination of the program throughout the university, local school systems, and internationally can be an effective force toward improving the rates of participation, retention, academic success, and graduation of currently-underserved female and minority populations.

Chapter 4

Innovation-Plaza and ABET Accreditation

Introduction

Innovation-Plaza is aligned with and supports the ECE Department's accreditation goals. Through its support of continual improvement in instruction, content, and student recruitment, academic success, retention and graduation, Innovation-Plaza is an active and important contributor to the department's successful efforts to meet and exceed requirements for national accreditation.

Innovation-Plaza and ABET

The Accreditation Board for Engineering and Technology (ABET) has accredited the Electrical and Computer Engineering Department at UNM. The general ABET criteria for accrediting engineering programs for baccalaureate level are:

1. Students

2. Program Educational Objectives

3. Student Outcomes

4. Continuous Improvement

5. Curriculum

6. Faculty

7. Facilities

8. Institutional Support

According to the ABET website, student outcomes “describe what students are expected to know and be able to do by the time of graduation,” and assessment is “one or more processes that identify, collect, and prepare data to evaluate the attainment of student outcomes and program educational objectives”.

The ABET Self-Study Report for the Electrical Engineering Program at The University of New Mexico states that students graduating with a degree in Electrical or Computer Engineering have:

A. an ability to apply knowledge of mathematics, science and engineering;

B. an ability to design and conduct experiments as well as analyze and interpret data;

C. an ability to design a system, component, or process to meet desired needs;

D. an ability to function on multidisciplinary teams;

E. an ability to identify, formulate, and solve engineering problems;

F. understanding of professional and ethical responsibility;

G. an ability to communicate effectively;

H. a broad education necessary to understand impact of engineering solutions in global/societal context;

I. a recognition of need for, and an ability to engage in life-long learning;

J. a knowledge of contemporary issues;

K. an ability to use techniques, skills and modern engineering tools necessary for engineering practice.

The document also explains how the ECE outcomes map to the ECE courses. For the Feedback Control Systems course, the ABET outcomes assessed before the Innovation-Plaza labs were part of it were: “A”, “E”, “I”, “J”, and “K”. The goal of the ECE program is to teach students the fundamental knowledge associated with Electrical Engineering and provide hands-on experience that demonstrates how this knowledge is applied. Innovation-Plaza is committed to fulfill these goals by providing experiential learning using real-world applications and instruments facilitating the learning process of engineering students and increasing creativity and innovation.

The Quanser laboratories used in the Innovation-Plaza labs assess the outcomes “A”, “B”, “G” and “K”. These outcomes can be assessed using different assessment tools, however after each practice the students have to write a Pre-Lab and a Lab Report. Both reports have a specific template for each practice. The reports assess outcomes “A”, “B”, “G” and “K”.

Outcome A: ability to apply knowledge of mathematics, science and engineering; in the Pre-Lab report and the Lab Report, students must show strategies to solve problems. They have to perform calculations to find correct answers using precise mathematics language, symbolic notation, graphs and diagrams. Finally they have to explain their results in the contest of the completed calculation drawing clear and logical conclusions.

Outcome B**:** ability to design and conduct experiments as well as analyze and interpret data; students must be able to use the scientific method: identify hypothesis framing a testable question, identify the independent and dependent variables, list all the assumptions made, develop an experimental procedure with step by step details, follow the procedure, document and analyze data, find inconsistencies and explain them, and finally interpret the results with respect to the original hypothesis.

Outcome G: ability to communicate effectively; this outcome refers to the format of the reports. The content should be presented well organized with each section and subsection complete, all the necessary background information (principles, theory) should be given, with a cover page, typed, with the equations, tables, diagrams and figures numbered, without spelling/grammar mistakes and all the reference cited correctly.

Outcome K: ability to use the techniques, skills, and modern engineering tools necessary for engineering practice; students will use software tools for analysis, to present data in useful format (graphs, tables, charts, diagrams) and to simulate physical systems.

Assessing the ABET outcomes is different than assigning a grade. For each section of the Innovation-Plaza labs an Excel document is provided to record "level of achievement" for each outcome. The purpose of this assessment is to measure the level of achievement of these skills by students and enable the instructor to target areas for improvement in instruction.

Students are shown what they are learning by seeing their scores, a meaningful form of feedback. Feedback should be provided to students regularly and while relevant. It should focus on the task and be specific [15]. Students are better able to participate in and understand assessments when expectations and objectives have been clearly stated by the instructor. Richard M. Felder explains that an effective approach to achieving any desired learning outcome is to show students specific course learning objectives that address the desired outcome. The ECE 446 laboratories are designed to demonstrate for students the relationship between course objectives and desired outcomes. Students understand from the first day that they have to write reports, which clearly state and reflect on learning goals [26].

All of the sessions in the Innovation-Plaza laboratory are student-centered. Problem-based and cooperative learning take place, moving the responsibility for learning from the instructor to the students, preparing them for the demands of industry, where there are no instructors, textbooks or classrooms.

ABET outcomes are assessed in the different Quanser units, making the assessment valid and reliable. During each lab session there is a "Background" section that students have to read prior to the class, promoting a sense of individual responsibility for learning. During the experiments the students work in teams, each one being accountable to the others for doing their share of the work. Working in groups helps students practice skills in communication, conflict management and other important aspects of effective teamwork. Innovation-Plaza is preparing students by guiding them, not lecturing them. The instructor is a resource at all times, supporting students in acquiring greater mastery of lifelong learning skills [27].

One of the important educational principles practiced through Innovation-Plaza labs is that assessment drives learning [26]. If students know they will be held individually accountable for course material, most will make a serious attempt to learn it and to do it the best they can. Students are required to work in teams during the experiments, but they know their lab reports are individual and they have to expend personal effort to demonstrate mastery of the material and earn a good grade.

Conclusion

The inclusion of Innovation-Plaza labs and teaching strategies in several key courses in ECE helps to better prepare students for future academic and professional opportunities, makes their learning more meaningful and interesting and supports the ECE department's ABET accreditation goals.

Chapter 5

Disseminating Change Throughout The ECE Program Via Innovation-Plaza

Introduction

The Electrical and Computer Engineering Department is being redesigned using Innovation-Plaza as a primary tool for reform. The department seeks to improve instruction in both the Electrical and Computer Engineering Programs by expanding the use of laboratories and support services throughout the curriculum. This has been achieved via a number of innovations.

Instituting and Disseminating Change

Innovation-Plaza has improved instruction and promoted systemic change in pedagogy throughout the ECE program through a variety of new and innovative programs. For example, a new tutoring program for undergraduate students was developed to help students engage with programming from the very beginning of the program. Graduate students in the various honor societies are paid to work one-on-one with undergraduate students. In this tutoring program undergraduate students can get assistance in learning course content and in successfully completing lab requirements, in some cases supporting them directly during class sessions, or replicating and improving their performance on lab assignments outside the laboratory.

During the past year, Innovation-Plaza labs have involved students in hands-on projects featuring the development of radar devices, helicopters, and IPGA robots, most of which were built from scratch utilizing simple, easily available materials like coffee cans. The popularity of these projects and their success in engaging student interest and improvement in learning has produced many suggestions from students and faculty for additional lab projects. For example, in fall 2013 students will learn fundamentals of android application design, including how to build a simple user interface and a functioning app.

Additional tutoring and hands-on laboratory experiences are provided to students by graduate students enrolled in the required one-semester Seminar for M.S. students and two-semester Seminar for Ph.D. students.   These seminars, through a reform initiated by Innovation Plaza, now requires graduate students to provide tutoring support to undergraduates and to design two original hands-on laboratory projects that they will complete with their tutees. This will not only help support Innovation-Plaza's goals of improving retention and graduation rates at the undergraduate level, but provide graduate students with the opportunity to enhance and apply their knowledge through hands-on applications, and prepare them not only to be better, more securely grounded engineers, developing curriculum, but potentially better teachers and team members in their professional careers.

Chapter 4 explains how ECE 446 better prepares students for future academic and professional opportunities by offering hands-on labs in addition to class instruction. However, it is important to note that several other courses in the ECE Department have also been redesigned through Innovation-Plaza and are enjoying similar success. For example, in ECE 101, Introduction to Electrical and Computer Engineering, students learn through hands-on experiments, videos and using matlab and LabView to learn basic problem-solving skills. In other courses, like ECE 231 Intermediate Programming and Engineering Problem Solving the material is scaffolded to help students organize their thinking. Students learn introduction to elementary data structures, program design and computer-based solution of engineering problems first using matlab and Labview and then C++.

In addition, hands-on labs and other improvements in instruction have been instituted in ECE 131, 231, 238, 314 and 360. It is the intention of the ECE Department and Innovation-Plaza to continue to disseminate these models of improved pedagogy throughout the department.

Conclusion

Innovation-Plaza has sponsored programmatic and systemic change in the ECE Department's approach to curriculum development, instruction, and student outreach and support. Through tutoring programs, practical and engaging hands-on laboratory projects, and improvements in class instruction, Innovation-Plaza is working to sponsor continual improvement in the recruitment, retention and academic success of students in ECE.

Chapter 6

Conclusions, Future Work and Recommendations

Innovation-Plaza represents a significant advance on the path toward improvement in instruction, higher rates of student retention and graduation, and greater success for students traditionally underserved by engineering programs. Through the employment of improved teaching methods in a key ECE course; dual-credit courses for high school students; and outreach to public schools, industry, government and international organizations, Innovation-Plaza has already improved the prospects for academic and professional success for some students in the ECE program at UNM. Expansion and dissemination of the innovations piloted in this program can serve an important role in improving the prospects for students traditionally underserved by engineering and other higher education STEM programs, change that is essential if the United States is to remain competitive with other nations in science and technology.

Recent reports document the consequences of the growing demand for a highly educated and skilled workforce in the United States and the decreasing proportion of college-educated adults, especially as rising student debt and stagnant job growth undermine the "education gospel" that higher education assures every graduate a good job.

Comparatively, the United States, with nearly five thousand colleges and universities serving a population of three hundred million, is falling behind other countries, including Canada, Japan, Korea, Norway, Ireland, Belgium, Denmark, Spain, and France, in the proportion of 25- to 34-year-olds with college degrees. With only half as many colleges and universities and nearly twice the population of the United States, interest in and competition for places in higher education remains high in Europe, and a much larger proportion of college-age students earn degrees. Latin America, with more than twice the population of the United States and only a quarter the number of universities enjoys similar growth, as do Russia and many countries in Asia.

Clearly the extensive system of public and private higher education in the United States, a tremendous resource that is admired throughout the world, is in danger of collapse if new paradigms for recruiting, educating, retaining and graduating diverse populations of students, including foreign students, are not put in place soon.

In his first address to Congress, President Barack Obama called on all Americans to complete at least one year of postsecondary education to help the United States regain its former status of having the most highly educated populace in the world. Since that time, the number of post-secondary degrees granted has declined. To regain first place by 2025, the nation must award three million postsecondary degrees and certificates every year, nearly twice the number currently awarded.

The NSF report *Characteristics of Scientists and Engineers in the United States: 2008* [44] showed that from a total of 19,244,00 U.S. scientists and engineers employed in 2008, 2,453,000 (12.7%) were working in engineering of whom only 13% were women (319,000) and 5.9% (145,000) were Hispanic [44]. According to projections released by the U.S. Census Bureau more than half of the population of the United States will be members of racial, ethnic and linguistic minorities by 2050 [78].

Steve Jobs once told President Obama that the reason Apple employs 700,000 people outside the United States is because it could not find engineers in the United States. The Journal of International Commerce and Economics estimates that the 700 engineers who created the iPod were accompanied by 14,000 other workers in the United States and 25,000 abroad. With only 4% of college graduates receiving degrees in engineering or science, the U.S. lags far behind other nations since 50 to 85% of job growth in the U.S. is dependent on scientists and engineers [12].

Dowell Myers describes demographic change and the economy as being "on a collision course" that can be avoided "only by elevating the educational level of the newest generation entering the workforce" [59]. That newest generation is predominantly Hispanic and female, populations traditionally underserved in the STEM fields. Hispanic students currently represent one fourth of all students in American schools and will compose more than a third of the student population by 2040 [53].

Women, though approximately half of the nation's population, represent a disappointingly low proportion of college graduates and professionals in engineering and other STEM fields. As Alicia Dowd points out, educational disparities signal the emergence of a dangerously polarized society with a shrinking professional class and a growing population of Latinas/os and women in the unskilled labor force. She further states that recent studies have shown that large numbers of students who are eligible to enroll in college are not doing so, thereby forming a pool of "undeveloped talent" [22].

This undeveloped talent of Latinas/os and women in science, technology, engineering, and mathematics (STEM) has negative implications not only for these populations, but for the nation as a whole. According to the Census Bureau's 2009 American Community Survey (ACS), women comprise 48 percent of the U.S. workforce but just 24 percent of STEM workers. Hispanics represent 24% of the workforce, but only 8% of workers in STEM fields. With more than two million new technology-related jobs projected to open in the United States by 2020, it is clear that there will be a shortage of American workers to fill these jobs if participation of traditionally underserved groups is not increased [34].

By reaching out to students as early as middle school and shepherding them toward success in engineering through their high school years and higher education, Innovation-Plaza is working proactively to improve the prospects of Latinas/os, women and other underserved populations in the STEM fields.

However, there remain numerous challenges for the program that must be addressed if it is to succeed. The following recommendations for further development of Innovation-Plaza, if implemented, will enhance the success and dissemination of the program.

1. The enhanced instruction techniques and hands-on labs employed to enhance learning in ECE 446 must be employed in other engineering and other STEM courses, particularly at the introductory level.
2. The Rube Goldberg project successfully piloted at a Middle School must be disseminated to other APS middle schools and students brought to the UNM campus for seminars and competitions to build early interest in engineering and dual-credit early college courses.
3. The success enjoyed by several students, in early dual-credit secondary outreach efforts, should be replicated in other high schools with a diverse population of students. Additional support services will be required if the program is to effectively serve bright students who possess great potential, but lack appropriate basic mathematics and literacy skills.
4. Agreements are in place with institutions throughout Latin America and other parts of the world. Innovation-Plaza needs to move proactively to exploit the potential inherent in these agreements by working collaboratively with these organizations to sponsor conferences, student exchanges, and dual-degree programs.

Given improvements in these important areas, it can be expected that Innovation-Plaza will continue to experience growth and success in fulfilling its mission to promote academic success and sponsor improved rates of retention and graduation for all students in engineering and other STEM fields.

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Appendices

A Syllabus ECE 446 Design of Feedback Control Systems

B ECE 446L Design of Feedback Control Systems Material

Appendix A

Syllabus: ECE 446 Design of Feedback Control Systems

ECE 446 Design of Feedback Control Systems
Spring 2013

Instructor: Dr. Rafael Fierro
Department of Electrical & Computer Engineering
ECE Bldg. 133-B
Tel. (505) 277-4125 Fax. (505) 277-1439
E-mail: rfierro@ece.unm.edu
http://marhes.ece.unm.edu
Wiki: http://ece446.ece.unm.edu
UNM Learn: http://learn.unm.edu

Section: 001 **Credits**: 3

Course description: (UNM Catalog) ECE 446 Design of Feedback Control Systems (3 credits) Modeling of continuous and sampled-data control systems. State-space representation. Sensitivity, stability, and optimization of control systems. Design of compensators in the frequency and time domains. Phase-plane and describing function design for non-linear systems, and laboratory design project.

Prerequisites: ECE 445 Introduction to Control Systems.

Motivation

Feedback control systems are everywhere. They are found in aircraft, cars, robots, and manufacturing systems to mention a few. These systems are equipped with microcontrollers, sensors, and communication devices and interact with uncertain dynamic environments.

Goals

ECE 446 has ambitious goals!!

1. Design and experimental verification of feedback control systems,
2. Learn how to analyze and design digital control systems,

3. Study state feedback, output feedback (state estimators), and LQR,
4. Give an introduction to nonlinear control systems,
5. Design PID controllers,
6. Apply the concepts learned on real-world nontrivial control problems,
7. Introduce Hybrid and Networked Control Systems.

- **Time and location:** Monday (M) and Wednesday (W) 9:30-10:45am, ECE Bldg. 311.
- **Announcements:**
  1. I will use UNM Learn to post grades, course documents (*e.g.*, homework solutions, lecture notes, slides). Please visit UNM Learn regularly. You are strongly encouraged to use the tools available in UNM Learn.

     `https://learn.unm.edu`
  2. General information is posted on this wiki page: `http://ece446.ece.unm.edu`
  3. We will use Matlab/Simulink/StateFlow and LabVIEW extensively in this class.
  4. The class will meet in room ECE 311 after the first lecture. Also, we might do some lab exercises in ECE L217. We have a number of PC's with Matlab/Simulink, LabVIEW, and five compactRIOs from National Instruments.
- **Instructor Office Hours:** Please make an appointment (email or call).
- **Teaching and Lab Assistant:** Patricio Cruz
  Office Hours: By appointment.
  Office: ECE L216D, Marhes Lab
  Phone: 505-277-0103
  Email: `pcruzec@unm.edu`
- **Textbook Information**

  Norman S. Nise, *Control Systems Engineering*, Wiley, 6th edition, 2010.

  Additional References

  Karl J. Åström and Richard M. Murray. *Feedback Systems: An Introduction for Scientists and Engineers*, Princeton University Press, 2008.

  `http://www.cds.caltech.edu/~murray/amwiki/Main_Page`

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Charles L. Phillips, and John M. Parr, *Feedback Control Systems*, 5th ed., Prentice Hall, 2011.

Additional handouts/slides and technical papers will be provided as we go along.

- **Required software**

  Matlab & Simulink Release 2012b, The Mathworks.

  LabVIEW, NI

  `http://www.ni.com/labview/`

- **Grading and Examination Policy**

  Class participation - 5 pts

  Homework/Lab Reports/Quizzes - 35 pts total

  Midterm Exam - 30 pts

  Final Exam - 30 pts

  All exams and quizzes are closed-book/closed-notes, homework is not allowed. You may use your own calculator. Sharing calculators or any other material during exams is not allowed.

  For **exams**, you may use one letter-size sheet both sides with notes *in your own handwriting.*

  No makeup exams or quizzes will be given. Students will be expected to attend class, prepare assignments, and **complete** all lab exercises. Habitual failure to do so will result in a reduced grade.

  Final grade (tentative):

$\geq$ 90%	**A**
80% – 89%	**B**
70% – 79%	**C**
60% – 69 %	**D**
below 60%	**F**

- **Assignments and Homework**
  - Homework and reading assignments will be announced on a weekly basis,
  - Problem sets will be assigned at least one week before they are due,
  - **Paperless Hwk:** All homework must be submitted electronically via UNM Learn as a PDF document. No other format or hardcopy will be accepted. Please make sure that the scanned document is readable.

- **Late homework will not be accepted.** without special permission from the instructor.

- **Attendance** is expected. If you skip classes you will find homework and exams more difficult. You are responsible for all material covered in class regardless of absences. *No make-up quizzes will be given.*

- **Academic Integrity:** Each student is expected to maintain the highest standards of honesty and integrity in academic and professional manners. The University reserves the right to take disciplinary action, up to and including dismissal, against any student who is found guilty of academic dishonesty or otherwise fails to meet these standards.

- **Access to Education:** Qualified students with disabilities needing appropriate academic adjustments should contact the instructor as soon as possible to ensure your needs are met in a timely manner. For information on assistive technology available for student use and additional information on services available through Student Accessibility Services, see `http://www.unm.edu/~sss/`.

- **Audit:** A student may register for a course as an auditor, providing permission of the instructor is obtained. A student has the first four weeks of the semester to change a course to audit status. No changes in audit status will be processed after the fourth week of class. Students are charged the normal tuition rate for auditing a course.

- **Use of Technology:** You can use your laptops to take notes during the lectures. However, surfing the net, working on homework problems and anything not related to the lecture is distracting and not allowed. I understand that emergency situations come up (for example, a sick family member) and you may need to make a call or answer one, in that case, please leave the room to do so. Talking on the phone or texting during the lecture will distract me and your classmates and is not acceptable.

- **Collaboration:** Students are encouraged to collaborate with each other using the UNM Learn discussion area tools. The discussion area is one place to share ideas with others in the class.

- **Copyright:** All materials in this course fall under copyright laws and should not be downloaded, distributed, or used by students for any purposes outside of this course.

- **Contacting the Instructor:** You may call me at (505) 277-4125, during normal Monday-Friday, 9-5 hours or send me an email. You can expect to receive an initial reply within 24 hours. Where appropriate, students are encouraged to post their questions to the discussion areas in UNM Learn so that other students can benefit, and/or another student may be able to answer your question.

- **Incompletes, Withdrawals, and Drops:** I give out incompletes only under extreme circumstances. If you are running into problems with the course, please contact me as early as possible so you do not fall behind.

This course falls under all UNM policies for last day to drop courses, etc. Please see `http://www.unm.edu/studentinfo.html` or the UNM Course Catalog for information on UNM services and policies. Please see the UNM academic calendar for course dates, the last day to drop courses without penalty, and for Financial Disenrollment dates.

- **Tentative Course Outline:**

  1. **Design of control systems in the time domain:** Design specifications in the time domain: design of P, PI, PD, and PID controllers; design of lead, lag, and lead-lag compensators.
  2. **Design of control systems in the frequency domain:** Design specifications in the frequency domain: design of P, PI, PD, and PID controllers; design of lead, lag, and lead-lag compensators.
  3. **Design via state space:** Controllability; observability; controller design; observer design.
  4. **Digital control systems:** Z-Transform; stability; design of digital control systems.
  5. **Nonlinear system analysis:** Linearization; equilibrium and Lyapunov stability; describing function analysis.
  6. **Advanced techniques:** Hybrid control; distributed systems; and networked control systems.

- **Course Evaluations.** You will be asked to complete anonymous course and instructor evaluations. These evaluations will provide useful information to improve this course. If you have any questions or concerns, please ask the instructor.

- **Some philosophy:** "*Knowledge cannot be given, but comes only with great personal sacrifice. It is your job to put forth the effort required to make knowledge a part of yourself and so your personal possession*". Frank Lewis

Appendix B

ECE 446L: Design of Feedback Control Systems Material

ECE-446L Design of Feedback Control Systems

Instructor: Patricio Cruz
Room: ECE L216D, MARHES Lab
Email: pcruzec@unm.edu
Office hours: TR 9:00am-10:30am or by appointment

Objectives

- Familiarize with LabVIEW Environment (Graphical Programming).
- Develop different applications (VIs) using the LabVIEW Control Design and SimulationToolkit.
- Understand the basics about the CompactRIO Module.
- Design and implement a controller using LabVIEW.

Tentative Lab Sessions

Week	Date	Lab Topic	Room
1	M 01/14	Lecture 1 (No lab Session)	ECE310
	W 01/16	Lecture 2 (No lab Session)	ECE311
2	M 01/21	HOLIDAY – MLK DAY	
	W 01/23	Lecture 3 (No lab Session)	ECE311
3	M 01/28	**Introduction to LabVIEW I**	ECE311
	W 01/30	**Introduction to LabVIEW II**	ECE311
4	M 02/04	Lecture 4 (No lab Session)	ECE311
	W 02/06	**LabVIEW Control Design Module**	ECE311
5	M 02/11	Lecture 5 (No lab Session)	ECE311
	W 02/13	**LabVIEW Simulation Module**	ECE311
6	M 02/18	Lecture 6 (No lab Session)	ECE311
	W 02/30	**Cyber Exploration Lab Experiment I**	ECE311
7	M 02/25	Lecture 7 (No lab Session)	ECE311
	W 02/27	**Cyber Exploration Lab Experiment II**	ECE311
8	M 03/04	Lecture 8 (No lab Session)	ECE311
	W 03/06	**Cyber Exploration Lab Experiment III**	ECE311
9	M 03/11	SPRING BREAK	
	M 03/13		

Notes

- The lab schedule may change during the semester. Changes will be announced on UNM Learn in advance.
- The lab groups will consist of two or three students who will work together in the same lab station.
- The lab experiments will contain three parts: a prelab work, a lab work and a postlab work, except for the first lab session. The guidelines for each session will be uploaded to https://learn.unm.edu .
- Each group will submit a report showing its work for the prelab, lab and postlab sections of each lab experiment.
- The report for the prelab will be handed in at the beginning of the corresponding lab; meanwhile, the lab and postlab will be submitted in the next lab session.

General References

- LabView

  http://zone.ni.com/devzone/cda/tut/p/id/7466 (Getting Started with NI LabVIEW Student Training) (This link has a tutorial and also some videos)

  http://www.ni.com/pdf/manuals/320998a.pdf (This is a LabView Tutorial Manual)

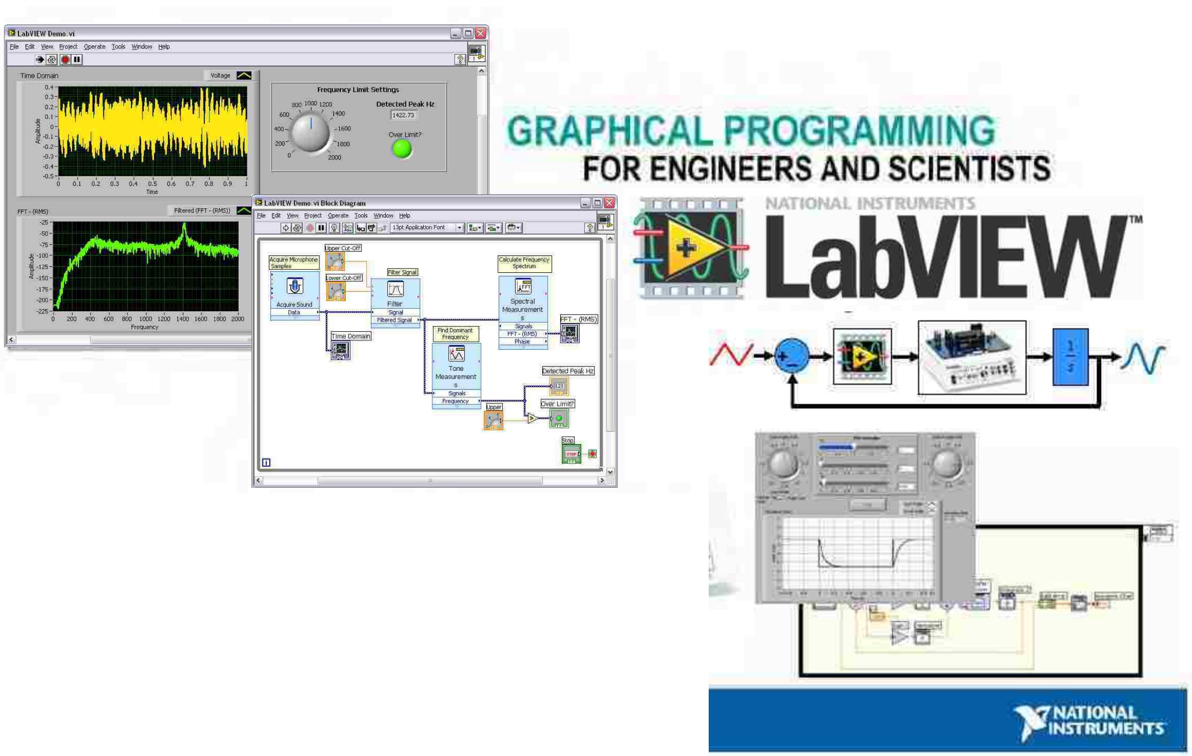
- Control Design Toolkit
  http://zone.ni.com/devzone/cda/tut/p/id/5855 (Introduction to LabVIEW in 3 Hours for Control Design and Simulation)

  http://www.che.utexas.edu/course/che360/documents/labview_tutorial.pdf (Introduction to LabVIEW for Control Design & Simulation)

- CompactRio
  http://sine.ni.com/np/app/main/p/ap/global/lang/en/pg/1/sn/n24:cRIO/fmid/104

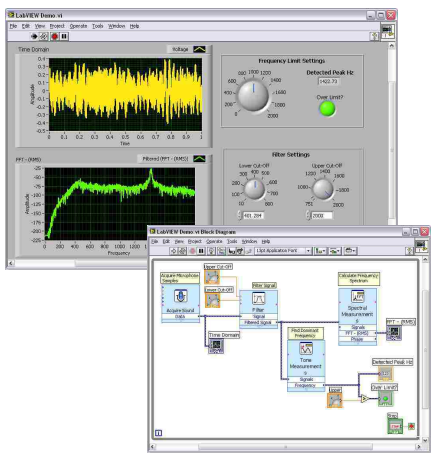
  http://www.ni.com/gettingstarted/beginapplication.htm

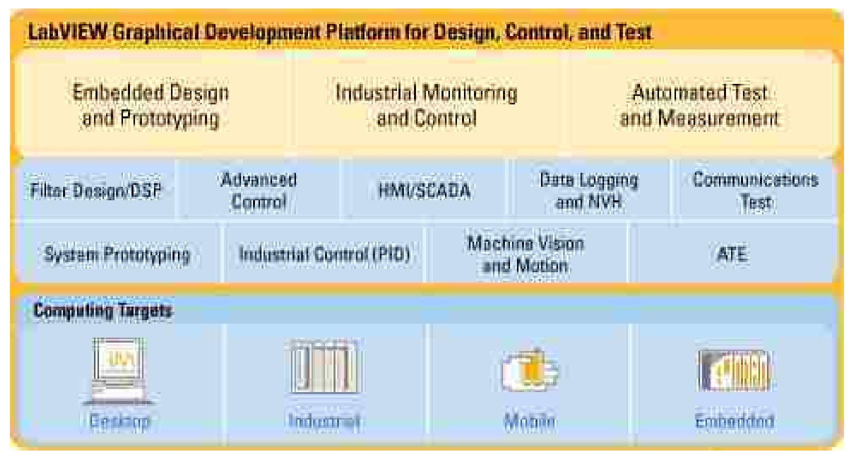
Introduction to LabView



LabVIEW Graphical Development System

- Graphical programming environment
- Compiles code for multiple OS and devices
- Useful in a broad range of applications





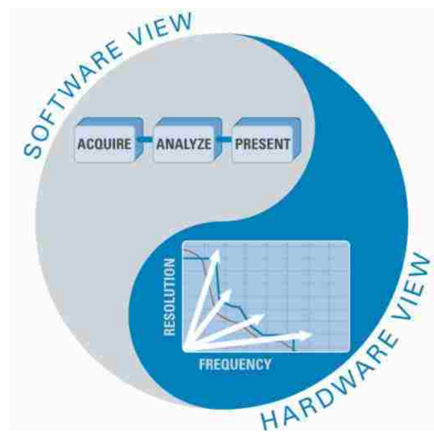
Virtual Instrumentation Applications

- **Design**
  - Signal and image processing
  - Embedded system programming
    - (PC, DSP, FPGA, microcontroller)
  - Simulation and prototyping
  - And more …
- **Control**
  - Automatic controls and dynamic systems
  - Mechatronics and robotics
  - And more …
- **Measurements**
  - Circuits and electronics
  - Measurements and instrumentation
  - And more …

LabVIEW

A single graphical development platform

Design → Prototype → Deploy



Open and Run LabVIEW

Start»All Programs»National Instruments LabVIEW 2009

Startup Screen:

Start from a blank VI:
New»Blank VI

or

Start from an example:
Examples»Find Examples…

LabVIEW Programs Are Called Virtual Instruments (VIs)

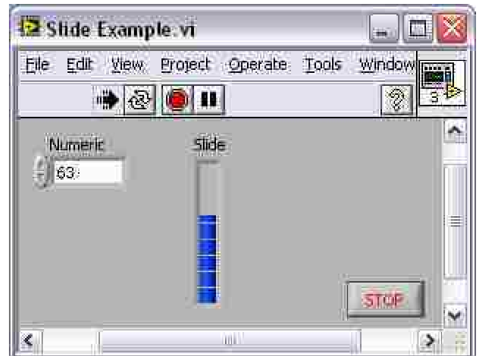
Each VI has 2 windows

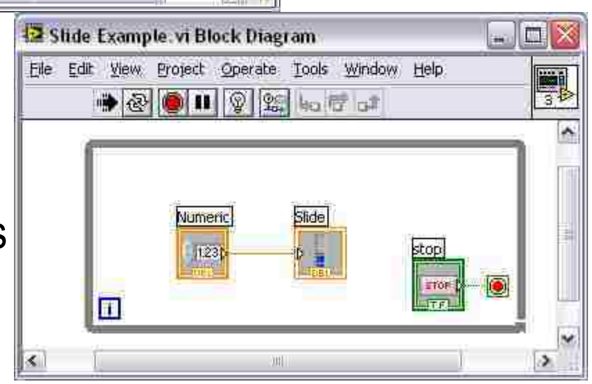
Front Panel

- User interface (UI)
  - Controls = inputs
  - Indicators = outputs

Block Diagram

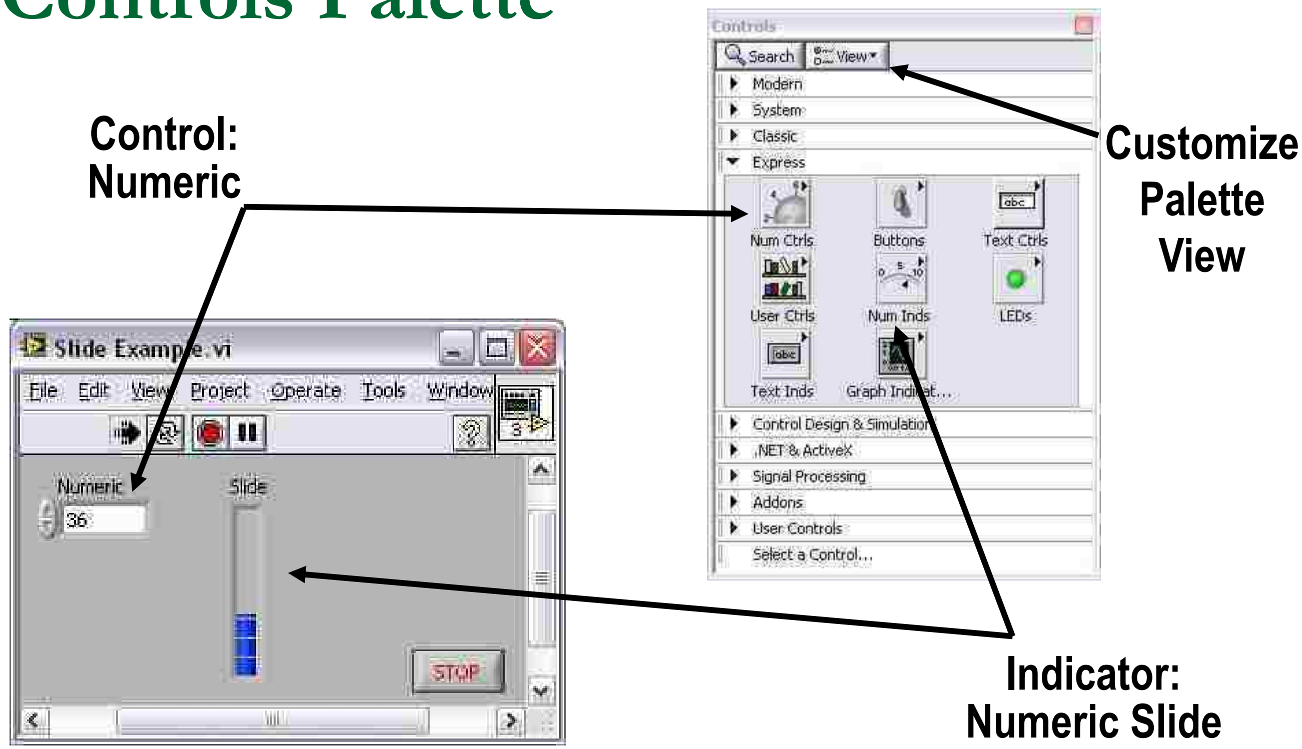
- Graphical code
  - Data travels on wires from controls through functions to indicators
  - Blocks execute by data flow





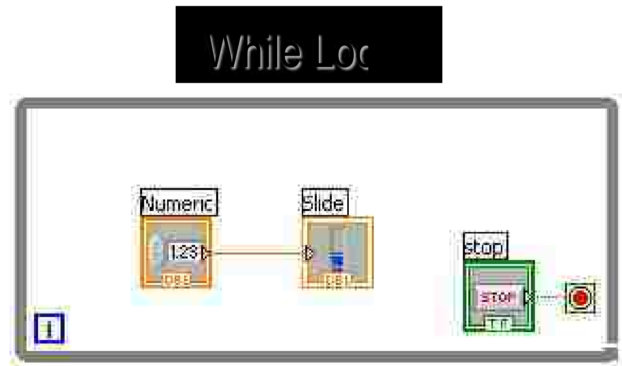
Controls Palette

(Place items on the front panel window)

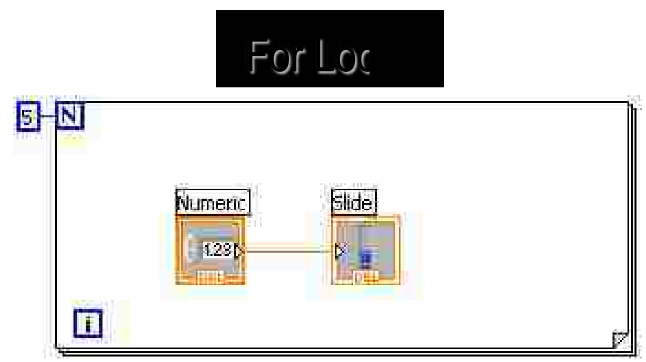


Loops

- While Loop
  -  Terminal counts iterations
  - Always runs at least once
  -  Runs until stop condition is met



- For Loop
  -  Terminal counts iterations
  -  Runs according to input **N** of count terminal



Introduction to LabVIEW Control Design Toolkit

- **OBJECTIVES**

  - Get familiar with the LabVIEW Control Design Toolkit

  - Construct transfer functions

  - Build and interconnect systems

  - Convert between model representations

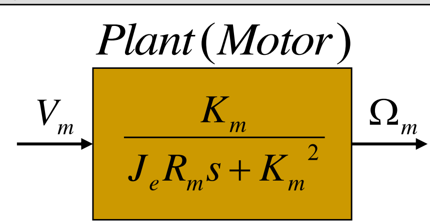
  - Obtain the Time and Frequency Response

The Design Process

1. **Modeling** – Identify a mathematical representation of the plant
2. **Control Design** – Choose a control method and design a controller
3. **Simulation** – Employ a point-by-point approach to simulate the system timing with a solver
4. **Tuning and Verification** – Introduce real-world nonlinearities, tune, and verify the control algorithm
5. **Deployment** – Implement the finalized control system

Motor Specifications Sheet

Symbol	Description	Value	Unit
Motor:			
R_m	Motor armature resistance.	3.30	ohms
K_t	Motor torque constant.	0.0280	N.m
K_m	Motor back-emf constant	0.0280	V/(rad/s)
J_m	Moment of inertia of motor rotor	9.64e-6	$kg.m^2$
M_l	Inertial load disc mass	0.033	kg
r_l	Inertial load disc radius	0.0242	m
Pulse-Width Modulated Amplifier:			
V_{max}	PWM amplifier maximum output voltage	24	V
	PWM amplifier maximum output current	5	A
	PWM amplifier gain	2.3	V/V



V_m – Input Voltage

Ω_m – Angular Velocity

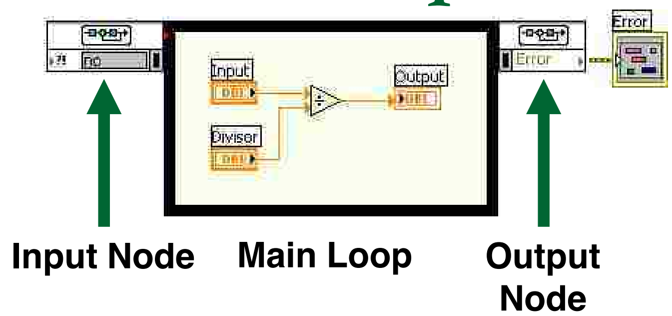
The Design Process

1. **Modeling** – Identify a mathematical representation of the plant
2. **Control Design** – Choose a control method and design a controller

Simulation – Employ a point-by-point approach to simulate the system timing with a solver

Test the motor and controller with real-world timing and a continuous time solver.

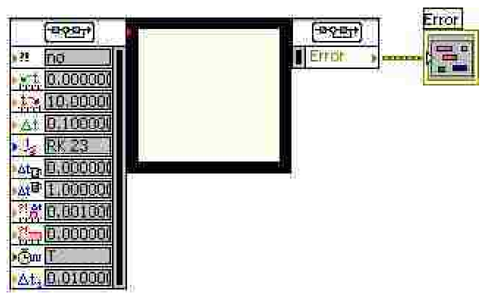
The Simulation Loop



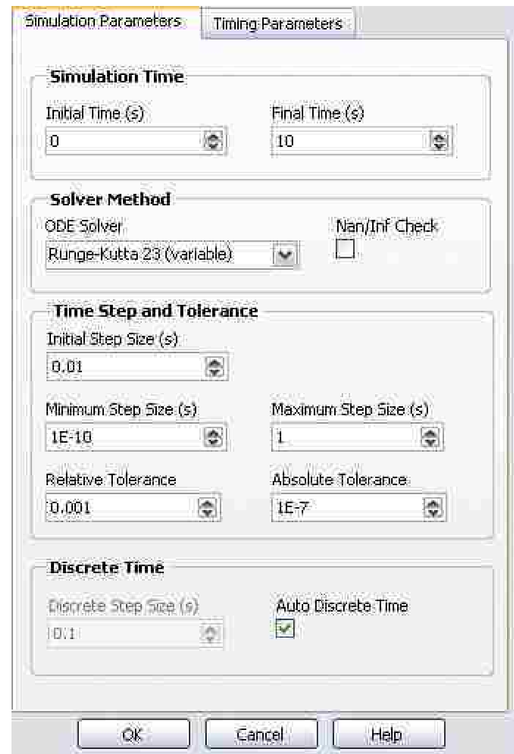
- Built in Differential Equation Solver allows continuous-time system.
- Similar to a While Loop with a predefined time period
- Installed with Simulation Module.
- Double-click Input Node to configure simulation parameters.

Simulation Loop Parameters

- Drag left node to show current parameters and provide inputs for run-time simulation configuration



- Double-click Input Node to configure simulation parameters



The Design Process

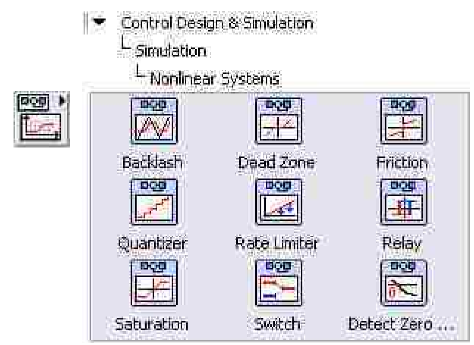
1. **Modeling** – Identify a mathematical representation of the plant
2. **Control Design** – Choose a control method and design a controller
3. **Simulation** – Employ a point-by-point approach to simulate the system timing with a solver

Tuning and Verification – Introduce real-world nonlinearities, tune, and verify the control algorithm

Introduce real-world voltage limits and tune control parameters for performance.

Introducing Nonlinearities

- Sources of Nonlinearities
  - Saturation
  - Dead Zone
  - Friction

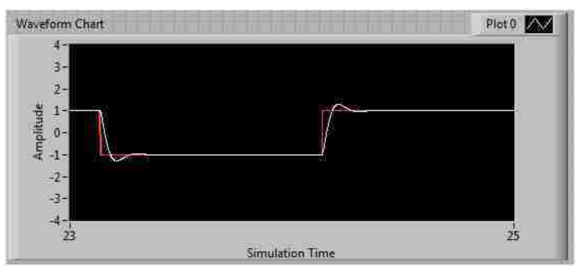


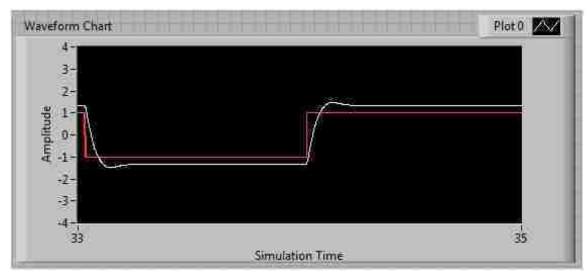
- Nonlinearities cause ideal models and controllers to behave differently in the real world.

Nonlinearity Example

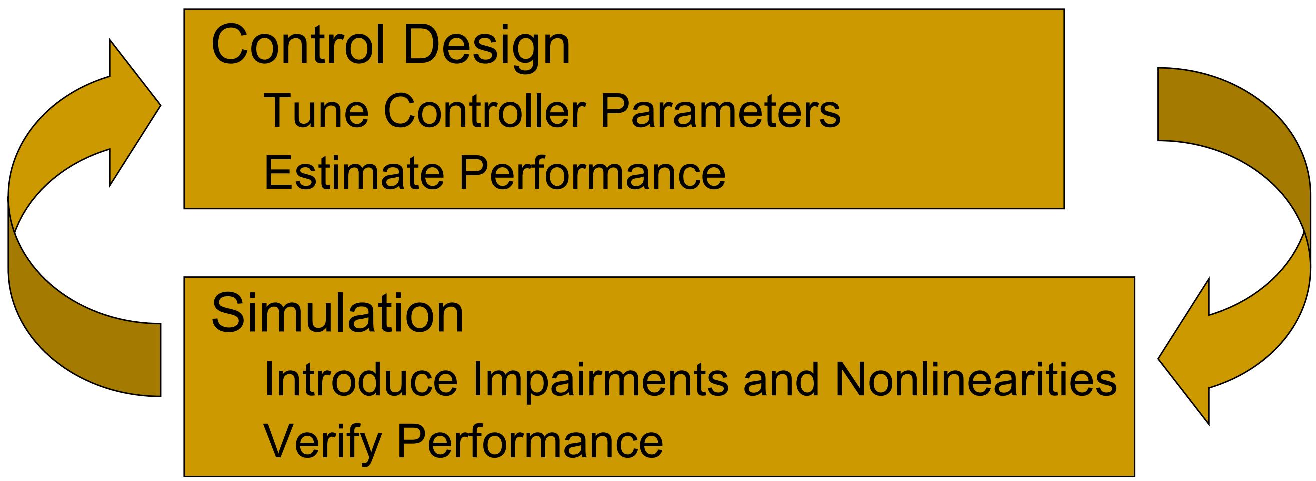
Introducing a dead-zone nonlinearity with the Simulation Module can change the behavior of a model dramatically.

- Ideal response with linear model in Control Design
- Same controller with dead-zone added in Simulation



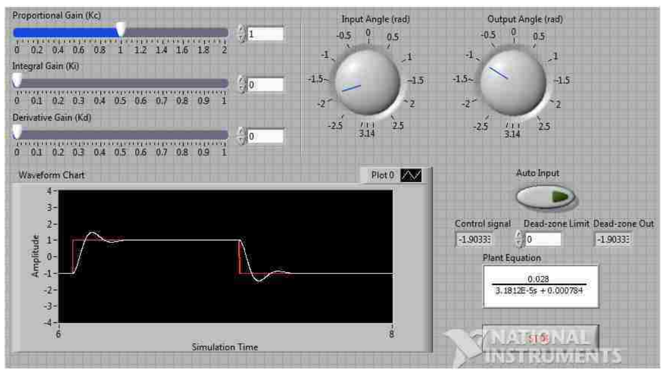


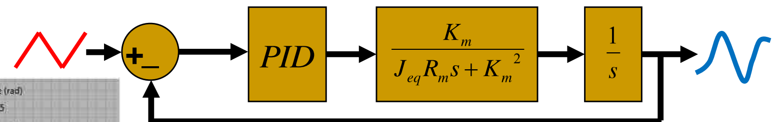
Controller Optimization



Controller optimization is an iterative process

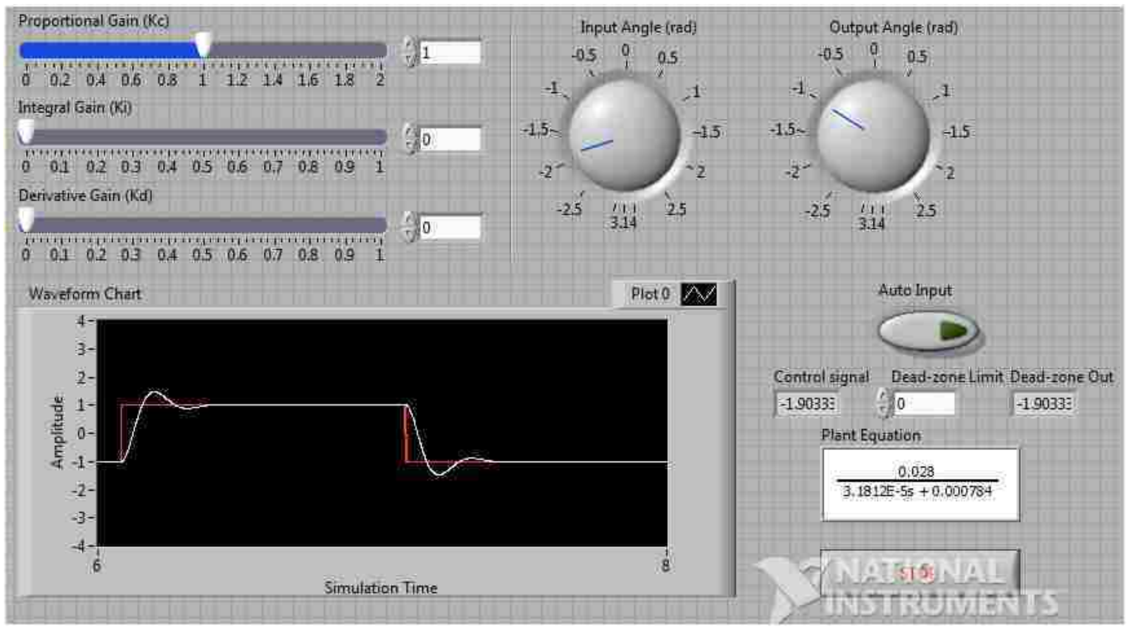
Exercise 3:
Tune the Controller



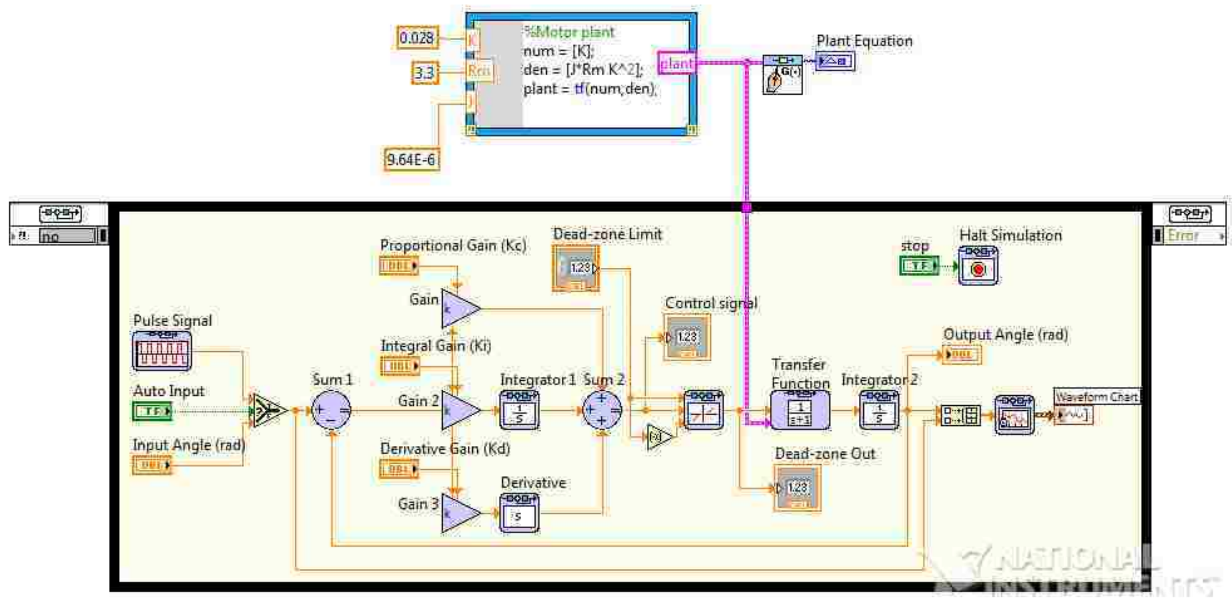


- Change Simulation loop to a continuous model
- Incorporate nonlinearities into state model.
- Tune PID parameters with a continuous input.

Exercise 3:
Tune the Controller



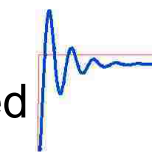
Exercise 3:
Tune the Controller



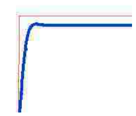
Tuning your PID Controller

Tune PID controller design using the step response

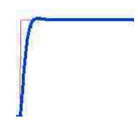
- Begin with Gains set at: $K_c = 1$, $K_i = 0$, and $K_d = 0$
- Increase Proportional Gain (K_c) to get desired rise time



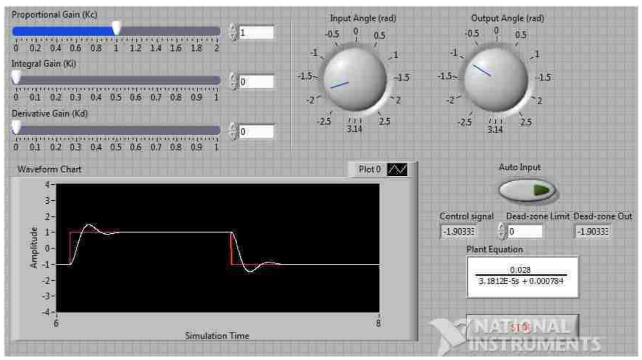
- Increase Derivative Gain (K_d) to reduce overshoot and settling time

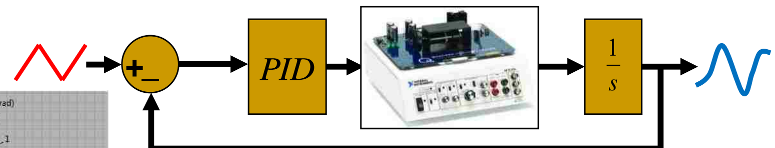


- Increase Integral Gain (K_i) to reduce steady-state error if necessary



Use the Controller in a Real Life System





- Replace the plant model with the real life motor.
- Test the behavior of the motor, and compare to the original plant model.

Using the LabView Simulation Module

- **REFERENCES**

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http://www.che.utexas.edu/course/che360/documents/labview_tutorial.pdf (Introduction to LabVIEW for Control Design & Simulation)

http://techteach.no/labview/lv85/control_design_toolkit/index.htm (Introduction to LabVIEW for Control Design Toolkit)