Recruiting and Retaining Undergraduate Engineering Students

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Recruiting: K-12 Engineering Outreach

- To inspire and propel youngsters
- To increase the pipeline
- Design woven through the pre-engineering curriculum
- All initiatives evaluated for continuous improvement
Our Motivation

• Poor U.S. student science and math performance
• Lagging enrollment at U.S. engineering colleges
• Low numbers of under-represented students (Women, African-American, Hispanic, American Indian)
• Unacceptable engineering retention rates (~50% national average)
Our Approach

K-16 hands-on, design-based, engineering education to...

- Increase retention of college engineering students
- Increase STEM skill development in youngsters
- Increase number and diversity of students in the pipeline
Why K-12 Engineering?

Engineering is about increasing a nation's capacity to perform.
Outreach Mission…

Use engineering as a vehicle to integrate science and math through inquiry-based curricula and hands-on activities that are relevant to the lives of youth.
Integrated Teaching and Learning Laboratory
Integrated Teaching & Learning

- Hands-on learning brings theory to life
- Open-ended problem solving promotes understanding and confidence
- Technological literacy *is* basic literacy
- Team-based learning $\rightarrow$ leadership
Discovery Learning Center
Discovery Learning Initiative
Outreach: Methods

- Outreach Corps -- CU students visit area schools
- Teach for Colorado – CU students spend 1 or 2 semesters in residence at a K-12 school
- Digital Library of Science and Engineering
- Service Learning for CU Students – a “make a wish” resource for K-12 science and math teachers.
- CU Mobile Laboratory for Science and Engineering.
- K-12 Curricula and Materials
- Summer Resident and Non-resident Programs for K-12 Students
- Summer Resident and Non-resident Programs for K-12 Science and Math Teachers
K-12: Why Engineering So Soon?

- Engineering cements math and science concepts
- Demonstrate societal relevance of math & science
- Motivator for continuing math and science
- Integrator for problem-based learning
- Platform for technological literacy
- Sharpens ability to visualize in 3-D
Target K-12 Engineering Population

- All people
- Those who haven't tinkered
- Those without family role models
- Population that is more representative of society
- Create tomorrow’s engineers
Creating Tomorrow’s Engineers

Sample Elementary Curricula:
- Laws of Motion
- Energy
- Electricity & Magnetism
- Environmental Engineering
Creating Tomorrow’s Engineers

Sample Middle School Curricula:
• Ideal Gas Law / Phase Behavior
• Structures
• Environmental Science & Engineering
Sample High School Experiences:
- Lifeboats and Life Preservers
- Dead Christmas Lights
- Your Car Battery
- Everybody Does Math
- Robotics
Students Explore:
• Hands-on engineering
• Data collection and analysis
• Real-life applications of technology
• Design/build processes

9th-12th grade students of color explore the joys and challenges of engineering
On-campus two- to five-day resident workshops
Students return each summer
Parallel one-day parent workshop

In Partnership with:
• Multicultural Engineering Program
• Women in Engineering Program
Children’s Summer Classes

Classes:
- How Do Things Work?
- Kinetics for Kids
- Too Hot to Handle
- The Sounds of Music
- Go with the Flow
- Green by Design

Hands-on
Minds-on
Ears-on
Summer K-12 Teacher Workshops

- Four-day professional development workshops
- Engineering meshes theory with everyday experiences
- Hands-on, standards-based curriculum
- Make and take design/build component

Workshops:
- Kinetics for Kids
- Too Hot to Handle
- Green by Design
- Shock Your Socks Off
- Go with the Flow

Engineering in Everyday Life
Field Trips to the ITL Laboratory

Thousands of K-12 students visit the ITL Laboratory every year.
NSF GK-12 Program

- 11 engineering graduate students
- Hands-on, standards-based K-12 engineering curriculum
- 4 elementary, 2 middle and 1 high school
Sustainability: K-12 Outreach Corps

- Continually serve K-12 students in a broad range of communities and school districts
- K-12 Outreach Corps (~ 50/year)
  - Engineering juniors (elementary)
  - Engineering seniors (middle school)
  - BS/MS students (high school)
- Year-long commitment:
  - 3 c.h. technical elective over AY
  - Meet for a weekly 2-hour studio
  - Support 2 classrooms for weekly engineering lab or provide hands-on engineering for after-school programs: MESA clubs, science clubs, elementary childcare programs, OM, JETTS, etc.

- Intellectual component: develop, test and document a complete lesson for the curriculum repository
Sustainability: K-12 Curriculum Repository

- Searchable, online K-12 Engineering curriculum repository
- Resource for other engineering colleges
- Resource for K-12 teachers nationwide
- Contents: see handout
- Link lesson/activity to national standards
- Separate by 4 levels: Primary (K-2); Intermediate (gr 3-5); Middle School; High School
- System design underway
- Content development in progress
- Link to other teacher resources – e.g. Eisenhower Clearinghouse
Summer Pre-Collegiate Programs

- Five-week to six-week *campus-wide* programs for rising high school seniors
- Statewide for students of color (16)
- Nationwide for American Indian students (11)
- Engineering “major” first available summer ‘01
- Design/build focus 8-9 hours weekly
- Goal: recruitment to CU Engineering
- Future: provide engineering credit?
Children’s Summer Classes

Week-long Classes:
- How Do Things Work?
- Kinetics for Kids
- Too Hot to Handle
- The Sounds of Music
- Go with the Flow
- Green by Design
- Kids Invent Toys
- Kids Invent Robots
Separator Slide
Targeting Youngsters

Design as the motivator in weeklong summer classes for kids who are introduced to the engineering process...
Targeting Youngsters

- Upper elementary and middle school students:
  - Naturally open and inquisitive
  - Still time to acquire science and math skills
- Weeklong summer classes:
  - Kids Invent Toys (toy invention)
  - Sweet Machines (robot challenge)
  - How Do Things Work? (electro-mechanical design/build with motors and sensors)
GET Internship

Girls Embrace Technology —

- Six-week summer internship
- Targets “techno-neutral” high school girls
- Interns explore their potential for a career in engineering or technology
- Receive $50/week stipend; teams of four girls

Open-ended design project:

*Develop interactive educational multimedia software that teaches elementary and middle school kids basic scientific principles*
GET Internship

• **Goal:** Overcome social & stereotype hurdles to envision themselves in engineering or technology

• Develop technical skills: *graphic design, user interface development, visual programming, digital communication, multimedia authoring, user testing*

• University women student mentors

32% returnees 47% non white
Partner w/ University Initiatives

- **CU Pre-Collegiate Development Program** —
  - Grooms grades 6-12 first-generation, college-bound students to attend university
  - Five-week summer engineering track offers team-based design/build experiences

- **American Indian Upward Bound** —
  - Six-week, on-campus program for high school seniors from 13 reservations
  - Engineering track focuses on the design/build process
Targeting Teachers

• Summer teacher professional development workshops
• In-classroom graduate Fellows
• K-12 engineering curricula: TeachEngineering.com digital library
  • Standards-based, classroom-tested K-12 engineering curricula
  • Late 2002
Teacher Training

• Two-day professional development workshops
• Hands-on learning activities
• Focus on one curricular unit:
  – Shock Your Socks Off (E & M)
  – Up, Up and Away (laws of motion)
  – Air Pollution Solution (environmental)
Give Them Tools

Integrated Teaching and Learning Laboratory —

• Team study rooms, design studios, extensive data acquisition capability, CAD software, cameras, scanners, etc.
• Electronics Center
• Manufacturing Center

He worked so slowly for the dullness of his tools that he had not time to sharpen them.

— Cormac McCarthy
First-Year Engineering Projects course —

- College-wide initiative
- Required in 3 degree programs; honored by all in college
- ~400 students annually
- Small class size (max = 30)
- Team based
- Outstanding, student-focused teachers
Design as a Motivator

- **Broad appeal to diverse populations**
  Engineering is about creating things for the benefit of society

- **Ideal hands-on learning**
  Engineering design provides real-world context to anchor theory and abstract concepts

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**Scientists** investigate what is; they discover new knowledge by peering into the unknown…

**Engineers** create what has not been; they make things that have never existed before…

— Joseph Bordogna, Deputy Director, NSF
Design as a Motivator

- Open-ended exploration
- Multidisciplinary
- Real-world relevance
- Forces effective teamwork skills
- Joys and challenges of engineering
- Fun and creative
- Inspiring to students of all ages
Course Goals

• Introduction to engineering
• Experience the iterative design and build process
• Produce a multidisciplinary product
• Experimental testing and analysis
• Communication skills (oral and written)
• Project management
• Learn through *doing*
Course Components

• Social styles workshop
• Team dynamics exercises
• “Mini” design project
• Comprehensive design/build project
  • Assistive technology devices
  • Appropriate technology projects
  • Rube Goldberg contraptions
  • Interactive learning exhibits
  • Autonomous Lego® robots
• Design Expo
Conclusion

- It always works on paper!
  - Hands-on design teaches more than textbooks
  - Experience underscores need for in-depth analysis
  - Limits of mathematical models of real-world phenomena
- Hands-on prototype fabrication
  - Designing within constraints + iteration = creativity and deeper understanding
  - All on team find contribution niche
- Problem-solving
  - Satisfying to all learners
  - Accomplishment promotes self esteem
  - Inspires further inquiry
Example: Studying Engineering
By Building Robots:

• Motivation
• Implementation
• Video
• Lessons Learned
• Final Thoughts
Introduction to Engineering Design

- No prerequisites
- Intended for both majors and non-majors
- Designed to address two problems ...
What's wrong with our current curriculum?

- Time lag before "real" engineering
- Few opportunities for non-majors to experience anything related to the practice of engineering
Few opportunities to do "real" engineering

• Two years of math, chemistry, and physics

• Hard to get the "feel" of engineering early on

=> Possible cause of attrition
This is more of a problem now than 20-30 years ago ...

- Prospective engineers were "tinkers"

- This activity led to an intuitive understanding of electrical and mechanical systems that is increasingly rare today
Tinkering is harder to do these days

Things have gotten really complicated...

- VCR's
- Even toasters have microprocessors
- "No user serviceable parts inside"
- "Breaking seal voids all warranties"

This situation motivated two course goals ...
Primary Goals for Engineering Students in Robotics Course:

• Do some engineering

• Develop intuition about how things work
Few opportunities for non-majors to experience anything related to the practice of engineering

Impediments to teaching engineering to non-majors:

• A daunting pre-requisite structure

• No "Engineering Distribution Courses"
ENGI 201: Studying Engineering By Building Robots:

• Motivation
• Implementation
• Video
• Lessons Learned
• Final Thoughts
Teaching First-Year Engineering...

The challenge in creating a course like ENGI 201 was to make a significant body of technical material accessible, without requiring students to master what have traditionally been considered the "core" engineering prerequisites.

Solution: Make the course hands-on ...
Students learn engineering by practicing engineering.

In the process of designing, constructing, and programming a simple robot assembled from "LEGO" building blocks, surplus motors and sensors, and a printed circuit computer board that the students solder together, the students are exposed to issues that confront every practicing engineer.
Engineering Issues Confronted By ENGI 201 Students:

• working with available technology
• design team interaction
• design tradeoffs in electro-mechanical systems
• iterative design
• the value of prototyping
• scheduling constraints
Educational Approach

• Provide rudiments of a wide variety of technical material

• Show students how and where they can learn more

=> Students are motivated to learn additional material needed to solve particular technical problems.

• Contest at end of semester
Seymour Papert
Director of the Epistemology and Learning Research Project at M.I.T.

Constructionism

• Learning and the acquisition of knowledge are active processes engaged in by the learner.
• Knowledge is thus "constructed" by the learner.
• The learning process is enhanced when the learner is building something real in the world, in addition to building knowledge inside his or her own mind.
Malcolm Knowles

Theory of Self-Directed Learning

• Education is a life-long process; as people grow older, they learn more from experience than from books.
• Students tend to learn more from the necessity of accomplishing a particular task, rather than from an abstract desire to know more.
• Task-centered, instead of subject centered, approach to learning
The Origin of These Ideas

What I hear I forget, what I see I remember, what I do I know.

CONFUCIUS (551 - 479 BC)
ITLL Credo

I hear...I forget.
I see...I remember.
I do...
I understand
How were these ideas applied?

Task-centered, self-directed, and independent students seemed to be just what we wanted.

⇒ Provide the means to solutions, rather than the solutions themselves, when students encounter technical obstacles.
Course Format

• 3 hours lecture per week

• 4 hours scheduled lab per week

• 8 hours optional lab per week

• 24-7 lab access (students have keys)

=> Can't be creative on demand
Lecture Topics

- What is Engineering?
- RoboBoard Structure
- Circuits
- IC Programming
- Digital Logic
- Sensors
- Structures
- Mechanics & Machines
- Robot Control
- State Machine Design
- Lego Design
- Robotics
- Robust Control
- Engineering Ethics
- Electro-mechanics
- Lab Skills
- Basic Semiconductors
- Intellectual Property
- Game Strategies
- Dealing with Failure
Credit and Grading Guidelines

• Class Attendance

• Individual Written Reports
  • Actual construction work, programming, or other tangible results that student has achieved
  • Ideas that student has contributed to the design of their robot (whether they have been implemented or not)
  • Plans for the next week of work

• Team Video Reports
  • Focus on issues that the team has worked on together
  • Current state of the robot
  • Robot strategy
  • How the team arrived at consensus (or not!) on open issues

• Peer evaluations by students and Lab Assistants
Deliverables

• Robot Functional Specifications
• “How to Build Your Robot”
• Completed Robot
• Program Listing
• Peer Evaluations
Milestones

• RoboBoard Assembly Complete - (Sept. 24)

• Mobile Robot - (Oct. 1)

• Meaningful Encounter With a Wall - (Oct. 8)

• Follow a Line - (Oct. 15)

• Track a Light Source – (Oct. 22)

• Avoid Another Robot – (Oct. 29)

• “Beat the Brick” - (Nov. 5)

• Score More Than One Point – (Nov. 12)

• Programming Complete – (Nov. 19)
Sample Game Board

Foam Blocks (black)  Foam Blocks (white)

2" square blocks  Holding Area  6" high wall

4" high walls

Starting Area

2" high walls

Flag

Starting Area

indicates 1/2" wide black stripe on white side, white stripe on black side
Week 1: Soldering

“In lab we soldered our circuit board together. I didn’t burn myself and I don’t think anyone else did.”
Week 2: Finish the RoboBoard

“Today we completed the basic assembly of the RoboBoard. We also experimented with gear trains and the basic structure of our robot.”
“We have a problem with the robot leaning too far forward on the front wheels – it’s not a big deal now, but it’s going to have to be ironed out if we ever want to turn.”

“The burns on my fingers (from soldering two weeks ago) have healed quite nicely.”
Block Grabber
Block Storage
Sensor Details

fig. 6
Week 4: Mobile Robots

• “It moved! Yes, we finally got our robot to move.”

• “Today was the best day yet in lab! The robot is able to follow a line well and can adjust to switching sides of the board. Scott was writing the program. It made me happy when I was able to show him how to download the program, unload the program, and even point out reasons why the programming was not compiling.”
Week 5: Robot Control

• “We did some trial and error work with our robot. Mostly it was error, but that’s life.”

• “WE FOLLOWED A LINE!!! I think it was the first day in lab that we didn’t break anything.”
Week 6: Redesign

• “The belt grips the blocks too well; it presses up against the back gate and threatens to warp the entire structure – I like to think that I’m too good of a mechanical engineer.”

• “We asked our robot to follow a line today, but it was a little testy and ran away from us. Unfortunately, we can’t punish it (mainly because we don’t even know how).”
Week 7: Schedule Concern

"In lab today, we modified our followline program once again, and now it works! Except… when the camera turned on, it didn’t work. AGAIN."

• Oh my gosh! It’s November! Maybe we should name our robot Yikes…"
Week 8: Controlled Movement

• “We finished assembling our device that we’re going to use to gather the blocks. It consists of a short tunnel-like apparatus with four gears, two at each end linked with a chain which will move the block up and then deposit it into a basket. The problem is now finding a good gear ratio so that the two sides move together and in the same direction.”

• “Ivy has programmed our robot to make these incredibly accurate 90 degree turns with shaft encoders, so that’s also very encouraging.”
Week 9: More Redesign

• “Our block-sucker sometimes requires too much force, and occasionally throws off a gear from the motor.”

• “Naturally the robot didn’t work on the first, second, third, or tenth try, as it turns out our reflective sensors are too far back, so we crash into the wall before we notice the line in front of the wall.”

• “The biggest problem was that the robot could not make turns. But, if I just put my hand under the back of the robot to support it, it turned well. So, the robot is just too heavy. Next week, I will try to come up with a way to redistribute the weight.”
Week 10: Final Designs

“Goals for this week – GET AROUND THE BOARD AND PICK UP BLOCKS!”
Week 11: Coping

• “The past 24 hours have been the most productive for our group so far.”

• “So Wednesday night is the big night. I’m staying here until it’s done. DONE! And then we’ll win, and then my GPA will go up, and then I’ll graduate magna cum laude! Woohoo!”
Week 12: Final Push

• “I think our biggest problem is that we made changes in our robot, but didn’t test them.”

• “I feel like I’m in an experiment to test the limits of human endurance. I’ve spent more time in lab this week than I have the entire semester. The days are all a blur, but we accomplish many things. We continued to program and program some more to perfect our robot.”
Week 13: The Contest

“I returned to lab at 6 am to relieve my partners in crime and our still non-qualifying robot. I was left with the task to make it work. This time was probably my most enjoyable time in Lego lab. I just loved it! I think that it was because for the first time I felt as if I was really adding something to the group. For the next 10 hours I worked until the moment when it all came together and our robot beat a brick in a moment of triumph!!!! I was so happy. I told my parents that not every robot got claps when it qualified but gosh darn it you could hear the roar of the crowd when mine finally crossed over to the black side of the board with a foam block in its shovel.”
Fred: The Finished Robot
“Jaundice 5”
“Scooby Doo”

Claire Salomon
Keith Layne
Adam Cohen
“Psycha...”
“Five Things You Learned”

- teamwork
- programming techniques
- limitations of electromechanical structures
- how to build reliable structures and gear trains
- control systems
- multitasking and robust programming
- the value of doing it right the first time
- how sensors work
- how to write a functional specification
- the best designs are often the simplest
- electronic components and circuit boards
On Sleep (and other matters)

- I learned start simple and stay simple. I learned that hot glue is just short of deity status... until it lands on your fingers. I learned all about the adrenaline rush that results from sleeping a total of 18.5 hours over the course of a week. I learned: if at first you don't succeed, don't sleep until you do."

- "I learned the nutritive value of Skittles in keeping one awake in the wee hours of the morning."

- "I have learned that I am even more undecided about my major now than I was before (and before I was pretty darn well undecided)."
In Closing

“I have learned why so many of my engineering friends put themselves through hell to become engineers - it’s because of the awesome sense of achievement you feel when you build something with your own two hands and intellect and make it work really well.”
The Course has succeeded because it satisfied three important needs in our curriculum:

Two of these needs have been mentioned:

- the need for prospective engineers to be exposed to engineering earlier in their careers, and
- the need to expose liberal arts majors to the practice of engineering

The third need was a surprise ...
The presence of non-majors is enriching to the engineering education process

• They bring a fresh perspective.

• They are completely unfettered by conventional wisdom.

• They are unaware of what they are not supposed to be able to do.
Effect of First Year Projects Course on Retention

AY 1994 – 1998
[5 years of data]

Updated January 2003
Study Demographics

- **AY 1994-1998** [5 years of data]
- **N = 2,581 students**
- **Course demographics**
  - 40% Takers (1,035); 60% Non-Takers (1,546)
  - Only included students who took course as first-year students (no transfer students)
- **Gender**
  - 80% males (2,057); 20% females (524)
- **Ethnicity**
  - 80% Caucasians (2,063), 7% Asian (190), 6% Latino (160), 1% African-American (35)
Overall Retention

n = 2,581 students over 5 years
Retention by Gender

[5 years of data]

Female Takers: +27%
Male Takers: +15%

Reference:
All Takers: +19% gain

7th Semester
7th Semester Retention Gain

- All students = +19%* retention gain
- Women = +27%* retention gain
- Men = +15% * retention gain
- Caucasian = +19% * retention gain
- Asian = +3%
- Latino = +54% * retention gain
- African-American = +36% (n too small for analysis)

* Significant retention increase at p < .05
Overall Retention Gains

• **Study**: 2,581 students over 5 years
• **All students**: +19%*
  - Women: +27%*
  - Men: +15%*
  - Caucasian: +19%*
  - Latino: +54%*
  - African-American: +36% (n too small for analysis)
  - Asian: +3% (no significant difference)

* Significant retention increase at p < .05
TeachEngineering.com
→ a searchable, web-enabled digital library collection
(online in late 2004)

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http://itll.colorado.edu
Resources

CU CEAS:
ITLL: http://itll.colorado.edu
DLC
JKB: www.cs.colorado.edu

K-12 Digital Library: www.TeachEngineering.com
(a searchable, digital library collection; online in late 2004)