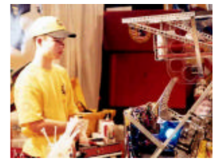
ASME International

Best Practices In
High School
Engineering



Best Practice

Principles of Engineering

Wayne D. Lang - Rapid City Central High School

Course Description:

The Introduction to Engineering course was developed in 1985 as a Technology Education course at Rapid City Central High School. It was designed so that students could blend the creative design process with realistic problem-solving activities, giving them an opportunity to fully realize ideas. The course was created by the teacher who was heavily influenced by the writings of Woody Flowers and George Beakley. During a 1996 curriculum project, the course was renamed Principles of Engineering.

The main intent was to help students discover their place on the engineering team and to determine if their aptitudes and interests were in the realm of the scientist, the engineer, the technician, or the craftsperson. Projects relating to several engineering fields were included so students could experience different roles within the team.

The course content was organized around several themes: the engineering team; the process of design; technical communications; materials science; modeling processes and prototyping, and realistic design projects. In addition, students experienced and applied the engineering process to stimulate career awareness.

Originally the course met one 50-minute period per day over the course of a full year but it easily fit into other scheduling arrangements. This elective course was open to grade 11 and 12 students and had no prerequisites. Ideally, students were either enrolled in or had already completed Algebra, Geometry, Chemistry, or Physics.

Course Objectives:

Upon completion of the course, each student was able to:

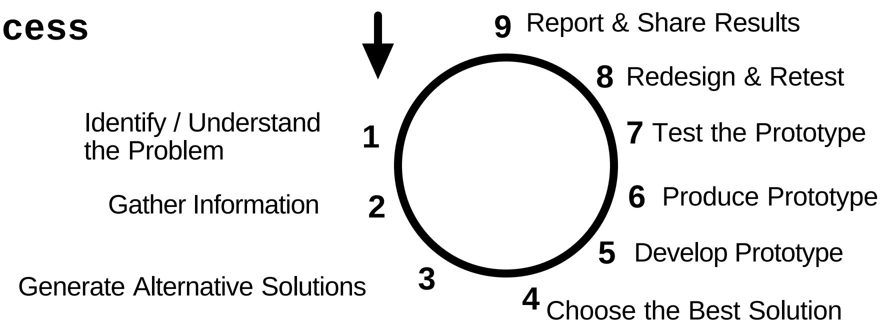
- ✓ Recognize the core concepts of technology and the need for problem-solving
- ✓ Communicate graphically using sketching, drafting, and computer-aided-design
- ✓ Communicate through technical writing and oral presentations
- ✓ Apply the attributes of design through creative thinking and optimization
- ✓ Identify, evaluate, and test engineering materials
- ✓ Make prototypes and mathematical models with workshop tools, modeling components, and computers
- ✓ Participate as a member of an engineering team
- ✓ Apply the design process to mechanical, structural, and other systems
- ✓ Test and assess designs, products, and information

Instructional Philosophy and Expected Results:

Students learned about the work done by engineers and technicians as they prepared designs, produced prototypes, and tested their results. Students actively developed their technological problem-solving skills as they worked with structural, mechanical, electrical, and computer-control activities. During the course, students worked through the Design Process, individually and in teams. To encourage creative thinking, most assigned activities were open-ended in nature. Beginning projects were instructor-planned. As the year progressed, students gradually assumed more and more control of projects. The final project, a major effort based on their personal interests, was an example of problem-finding as much as problem-solving.

Throughout the activity sequence, students were expected to learn and apply new technical information to the design projects. This new material was delivered through reading, lecture and demonstration, Internet research, self-paced modular lessons and computer-aided-instruction. Students were also expected to use business and higher education contacts during the investigation phase of the design process. Design projects were developed so they linked to the students' existing knowledge and skills. Whenever possible, the teacher related the engineering process with mathematical and scientific knowledge. Discussions about class projects were used as opportunities for the teacher to motivate students to seek more educational challenges.

The Design Process



Course Assessment:

Student assessment was based on how well the design process was applied to authentic situations. Students were evaluated on how well they synthesized prior knowledge, new knowledge, hands-on skills, and creativity within constraints. Student work was evaluated and graded according to the following components:

Knowledge - 40%:	Written tests, written reports, vocabulary
Application - 40%:	Laboratory activities and design projects were evaluated according to a rubric based on the Design Process
Productivity - 20%:	A rubric was used to evaluate the following items during projects: - Effective use of time - Use of facilities & equipment - Safety - Cooperation with others - Following procedures

Research:

In 1993 the author conducted thesis research to determine the influence of the course on students. Over 80% of former students responded to a follow-up study. The respondents indicated that the greatest positive influences on their work and education resulted from the personal, small-team, and large-team design projects, from idea-generation sessions, and from learning to use Computer Aided Design software. In general, the study concluded that the structure of the course benefited students and that small-team problem-solving activities should be used most often in engineering courses. Details about the study may be found in the thesis document at the Chester Fritz Library, University of North Dakota, Grand Forks. The title of the thesis is *A Study to Ascertain the Influence of a Technological Problem-Solving Course on Student Career and Education Goals*.

Contact Information:

Wayne D. Lang
Rapid City Central High School
433 N. 8th Street
Rapid City, SD 57701
Phone: 605-394-4023
E-mail: wlang@aptustechnologies.com

Plan of Study:

First 9-weeks Period

Opening presentation

Presented what engineering is and the need for problem solving during technological change

- ✓ Introduced the roles of the engineering team: scientist, engineer, technician, craftsperson (1 wk.)

Graphic communications (2 wk.)

- ✓ Sketched real objects to learn about multi-view and pictorial-view drawings
- ✓ Used T-square and triangle drafting skills to learn line types, projections, neatness
- ✓ Used drafting and computer skills to produce personal business cards for a "professional identity"

Written communications (1 wk.)

- ✓ Used a computer to assemble and print a document that explained technical writing

Oral communications

- ✓ Every other Friday, students gave a short report to share "What's Happening in Technology"
- ✓ The purpose of the report was to develop confidence for public speaking. The report had 3 evaluation points: the technology explained, impacts predicted, and source of information given.

Structures (1 wk.)

- ✓ Read and reported from *Structures: Or Why Things Don't Fall Down*
- ✓ Made 3D shapes (prisms) out of cardboard after laying out a 2D pattern development
- ✓ Made towers out of spaghetti so they support a golf ball. Put loaded towers into a humidified box.
- ✓ As the tower collapsed students observed the differences between tension and compression.

Forces and mechanics (1 wk.)

- ✓ A lecture explained and identified forces; compression, tension, torsion, shear; stress vs strain
- ✓ Students used Bow's notation to graphically solve force vectors

Structural design project (approx. 3 weeks)

- ✓ Teacher explained the concept of constraints and design trade-offs
- ✓ Students worked individually on the Crane Boom project; they followed the project design brief

Second 9-weeks Period

A teacher lecture introduced the Design Process, the process of design, and the contents of a design brief

- ✓ The teacher introduced Ideation; students practiced brainstorming and clustering
- ✓ A teacher lecture explained differences between sequential and concurrent engineering methods.
- ✓ Students watched a video about development of the Boeing 777 (21st Century Jet - PBS), they recorded observations and discussed examples of concurrency and examples of engineering team roles
- ✓ Textbooks and handouts introduced simple machines and mechanical advantage calculations (1 wk.)

Engineering materials (2 wk.)

- ✓ Demonstrations and CAI lessons presented properties and identification of materials
- ✓ Students prepared specimens for materials samples that were placed outside for weathering test
- ✓ Materials testing
- ✓ Students designed and made either a concrete beam or a fiber-composite panel
- ✓ Panels were tested and test data were recorded and charted on a computer spreadsheet

- ✓ Students concluded which design is best by comparing testing data
- ✓ Mechanical Systems design project to experience concurrent engineering (approx. 2 weeks)
- ✓ Students formed small teams; each team designed and made a system that contributed at least 3 changes of direction for a Rube Goldberg Device and included at least 3 simple machines.
- ✓ To illustrate concurrency, the teams coordinated their systems to fit on a vertical pegboard panel

Prototyping processes (3 wk.)

- ✓ Lecture and demonstrations introduced shop safety practices
- ✓ Teacher demonstrated lathe, drill press, milling machine, brakes, welding operations
- ✓ Self-paced lessons introduced precision measurement tools: scales, micrometers, vernier caliper
- ✓ Students worked through laboratory activities:
  - Calculations of RPM using cutting a speed equation; discussed effects of tolerances
  - Precision measurements of objects to 0.001" and 0.01mm accuracy
  - Lathe turning to produce a tool steel heat-treatment specimen
  - Milling a precisely sized and located step on an aluminum block
  - Cutting/forming steel strips and then brazing them to form the student's name

Third 9-weeks Period

Teacher presented a review of technical writing and introduced project planning with Gantt charts (1 wk.)

Students used computer to write instructional steps for a process (2 wk.)

Students began planning a personal design project; found a problem to solve and wrote design brief (1 wk.)

Supporting Topics - students spent 4 periods on each of the following mini-lessons (4 wk.)

- ✓ CADD; learning to use the CADD system basic drawing, visualization, and dimensioning
- ✓ Materials research; entering engineering material information into a class database
- ✓ Controls & Modeling; assembling Fischertechnik components; programming and running a robot
- ✓ Digital electronics; using modular curriculum kit from E & L's Exploring Electronics Technology
- ✓ Ergonomics; measuring students to collect ergonomic data; researching ergonomic tables
- ✓ Careers; take a career assessment using Bridge's CHOICES software and/or Gale's book

Fourth 9-weeks Period

Students worked on their personal design projects

- ✓ They conducted library research, Internet research, interviews (1 wk.)
- ✓ They did developmental sketches, drawings, and optimized designs (2 wk.)
- ✓ They built prototypes (3 wk.)
- ✓ They tested and redesigned prototypes (1 wk.)

Student seminars; each student reported results of their personal project (1 wk.)

Note: In future years, the independent and large-group design projects will be re-structured so students will participate in the FIRST Robotics Competition. FIRST, and other similar activities, are logical components for this course.

Laboratory Equipment and Supplies:

Computing Equipment:

Wintel, Macintosh, and Apple II computers were utilized. Internet access was available and computers were networked to both inkjet and laser printers.

Prototyping Equipment:
Students had access to a metal lathe, a vertical milling machine, a drill press, oxy-acetylene and arc welding equipment, bandsaws, hot-wire foam cutters, strip-heaters, sheet metal forming brakes, a foundry setup for aluminum casting, and typical hand tools. The teacher built a materials testing unit for measuring tensile and compression forces. A Rockwell hardness tester was borrowed from another school. Students used triple-beam balances from the Science department. A standard home vaporizer was ducted into a large, plastic box. For testing, spaghetti structures were placed in the box and moistened until they collapsed.

Print resources used by students:

- ✓ *A Kick in the Seat of the Pants* by von Oech (ISBN 0-0609-6024-8)
- ✓ *A Whack on the Side of the Head* by von Oech (ISBN 0-4463-8000-8)
- ✓ *Design & Problem Solving in Technology* by Hutchinson & Karsnitz (ISBN 0-8273-5244-1)
- ✓ *Design Yourself* by Hanks, Belliston,Edwards (ISBN 1-5605-2046-1)
- ✓ *Discover Your High-Tech Talents* by Gale (ISBN 0-6715-0740-0)
- ✓ *Human Dimension & Interior Space* by Panero & Zelnick (ISBN 0-8230-7271-1)
- ✓ *Materials Technology* by Oliver & Boyd, UK (ISBN 0-0500-3395-6)
- ✓ *Problem Solving* by Oliver & Boyd, UK (ISBN 0-0500-3392-1)
- ✓ *Structures* by Oliver & Boyd, UK (ISBN 0-05003389-1)
- ✓ *Structures: Or Why Things Don't Fall Down* by Gordon (ISBN 0-3068-0151-5)

Print resources that influenced the author/teacher:

- ✓ Beakley, G.C. & Leach, H. W. (1972). *Engineering: An introduction to a creative profession* (2nd ed.). New York: MacMillan
- ✓ Maley, D. (1986). *Research and experimentation in technology education*. Reston, VA: International Technology Education Association.
- ✓ Waetjen, W.B. (1989). *Technological problem solving: A proposal*. Reston, VA. International Technology Education Association.
- ✓ West, H., Flowers, W., & Gilmore, D. (1990). Hands-on design in engineering education: Learning by doing what? *Engineering Education*, 80 (5), 560-564.

Sources for specialty modeling supplies, equipment, and software:

- ✓ Exploring Electronics Technology curriculum - E & L Instruments, Inc.
- ✓ Fischertechnik modeling components - Modern School Supply, Inc.
- ✓ Composite fibers, resins, and layup supplies - IASCO (Industrial Arts Supply Inc..
- ✓ Assorted gears, motors, modeling components - Kelvin, Inc.
- ✓ ProDesktop, 3D modeling software - Parametric Technology Corp.
- ✓ Cadkey, CADD software - Cadkey, Inc.
- ✓ CHOICES career software - http://www.bridges.com

Supplies used during laboratory activities:

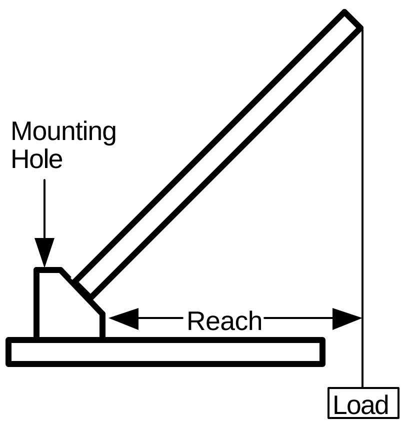
Crane boom activity:
For students: Sketching paper, heavy drafting paper (300mm x 450mm), 8mm x 205mm drinking straws, small paper clips, string, round toothpicks, white PVC glue, a 2" x 2" x 3.5" wood block for each student
For testing: 3/4" x 3.5" x 16" wood for test jig, 100g weight with a hook attached, testing weights

Machining activities: Aluminum stock; 1" diameter for lathe turning, 1.5" square for milling
Water hardening tool steel; 1" diameter for lathe turning heat treating specimens
Welding activity: Steel sheet, 16 ga; steel strip, 16 ga x 1/2" wide; brazing rod
Composites activity: Cement, gravel, sand, water, scrap wood for making molds, wire, string
Polyester resin w/ activator, mixing cups, aprons, rubber gloves, fiberglass matte, fiberglass cloth, chopped fiberglass, carbon fiber tape, Kevlar cloth, cotton cloth, string, wire mesh
Prototyping activities: Sheets of acrylic, polycarbonate, corrugated cardboard, plywood, particle board, steel, aluminum

Crane Boom Design Project Design Brief

Problem Statement:
Design, analyze, produce, and test a crane boom structure which can support a minimum load, stay within a cost limit, and have a maximum "reach distance."

Limitations:
- ✓ The Overview of the Crane Boom Design Project document must be followed exactly.
- ✓ Each person will receive a base block; a 2"x2"x3.5" wooden block with one edge cut at a 45 degree angle.
- ✓ The bottom of the base block must be attached to the testing fixture with a single 3" screw.
- ✓ No part of the crane boom may be attached to any thing other than the base block.
- ✓ The end of your crane boom must permit the attachment of a testing hook.
- ✓ The crane boom must support a minimum load of 100 grams.
- ✓ The cost of materials for your crane boom cannot exceed $25,000.
- ✓ Materials are purchased only once from the teacher; there may be no replacements of materials.



Bill of Materials:

Heavy Paper	300mm x 450mm	$10,000 p/sheet
Drink Straw	8mm x 205mm	$ 5,000 each
Toothpick	2mm x 65mm	$ 1,000 each
Paper Clip	small size	$ 2,000 each
String	2mm dia. x 300mm	$ 2,000 each

PVC white adhesive in assembly quantities only

Project Time Line:

Preliminary designs	2 days
Working drawings & force analysis	2 days
Prototype production	3 days
Preliminary technical report	1 day
Prototype testing	1 day
Redesigning & retesting prototypes	2 days

Technical reports are due 3 days after testing ends.

Overview of the Crane Boom Design Project

Purpose: This project will introduce you to structural design. Typically people think of bridges when structural engineering is mentioned. We will focus on a crane boom because it has clear trade-offs.

Trade-offs: Engineers always must deal with trade-offs when designing. In this project the trade-offs relate to the fact that a successful design can result either from a short boom that has a short reach but can support very heavy loads or a design that has a longer boom with a long reach but supports lighter loads.

What you will do during this project:

1. Learn about structural forces and discuss trade-offs
2. Research structures and make preliminary sketches of alternative designs that address the trade-offs
3. Optimize the design by recording reasons why you selected your favorite design
4. Use drafting techniques to make a half-scale working drawing of your proposed design
5. Do a force analysis on your drawing. Label all the forces at work within the members of your design
6. Begin your project technical report
   - ✓ Include your design brief, sketches of at least 3 potential designs, and your working drawing
   - ✓ List the reasons why you selected your final design
   - ✓ On the working drawing, label the point where you predict structural failure will occur
7. Use your working drawing to make a full-scale prototype of your crane boom
8. Test the prototype to its minimum load
9. Apply weights to load the prototype until it begins to fail. Record where it is failing and then record the final reach distance (in mm) and the load (in grams) that caused the structure to fail
10. Redesign and rebuild the failed prototype. Re test the structure. Record the re-test data.
11. Finish your technical report; add the following to what you already have:
    - ✓ Record ALL testing data and record any problems you had making your prototype
    - ✓ Compare your predicted failure point with the actual failure point
    - ✓ Discuss the changes you made during the redesign process and their effects

Evaluation Form for the Crane Boom Project:

Design Phase:	Use of time _____ (0-4)	Alt. designs _____ (0-4)	Wkg. Drwg. _____ (0-4)	Force Analysis _____ (0-4)
Prototype Phase:	Use of time _____ (0-4)	Quality _____ (0-4)	Followed Wkg Drwg _____ (0-4)	Met Cost Limit _____ (0-4)

Technical Report: (0-2) for each

Design Brief ____ Alternative Solutions ____ Optimization Reasons ____

Predicted Failure ____ Compare Predicted and Actual Failure Point ____ Discuss Problems ____

Report Test Results ____ Report Retest Results ____ Report is Typed ____

Spelling & Mechanics ____

Testing Results:

Original Reach _______ mm + Original Load _______ grams = Total _________

Redesigned Reach _______ mm + Original Load _______ grams = Total _________

Design Phase Total: _____ Prototype Phase Total:_____

Testing Phase Total: Holds the minimum load (0-20) ______

Total Project Points: _______

Technical Reporting Phase Total: _____

Learning Objectives and Student Activities and Their Alignment with National Content Standards

ITEA - International Technology Education Association; Technology for All Americans

AAAS - American Association for the Advancement of Science; A-Technology & Science, B-Design & Systems, C-Issues in Technology

NCTM - National Council for the Teaching of Mathematics; Measurement, Algebra, Geometry

Standards	ITEA Std.																				AAAS Std			NCTM Std.		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	A	B	C	Mea.	Alg.	Geo.
Class Activities																										
Relate engr. team to duties & education	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Research technical info. & databases	x	x	x								x	x	x	x	x	x	x	x	x	x	x					
Propose design alternatives re: tradeoffs	x	x	x							x	x							x	x	x		x	x			
Optimize alternative solutions		x							x		x					x		x	x	x	x	x				
Sketch existing and proposed objects											x	x				x		x	x	x		x				x
Prepare working drawings for designs											x	x				x		x	x	x		x		x		x
Interpret info. from working drawings										x		x				x		x	x	x		x		x		x
Use modeling components make prototype											x	x				x		x	x	x		x				x
Use tools & machines to make a prototype											x	x				x		x	x	x		x		x	x	x
Prepare & present technical reports	x	x	x									x				x		x	x	x	x	x	x			
Use computers/sensors to collect data										x		x	x			x		x			x				x	
Collect & analyze testing data			x							x		x	x			x		x		x	x			x	x	
Interpret testing data & make conclusion										x		x	x			x		x		x	x		x			
Analyze structural forces										x		x	x					x		x	x			x		x
Analyze & predict a structural failure										x		x	x					x		x		x		x		x
Design & make a structural system											x	x				x				x		x		x	x	x
Analyze simple machines within a system		x								x	x	x				x			x			x		x	x	x
Design & produce a mechanical system											x	x				x			x			x		x	x	x
Evaluate products & designs of products	x	x	x	x	x					x	x		x	x		x	x	x	x	x			x	x		x
Assess and respond to an ethical dilemma			x	x	x	x	x						x	x			x			x			x			
Individually solve a design problem								x			x	x								x		x		x	x	x
Work in a design team to solve problems								x	x		x	x				x		x	x			x		x	x	x
Individually find a design opportunity	x		x					x	x		x	x	x	x	x	x	x	x	x	x		x		x	x	x