Skyscraper

Project Based Learning

1.Overview

1.1.Overall Goal

Allow students to describe, anticipate and plan for some of the realistic factors encountered in a real engineering project through a team activity.

1.2.Societal Context

In the 1920's there was an economic boom that drove up real estate prices in cities in America, particularly in New York City. Inspired by the rising cost of land, the availability of new materials such as stainless steel, and the competition for bragging rights for the tallest building in the world, a number of projects were launched to build successively taller buildings. In this race, as soon as one building was announced at a certain planned height, competitors would begin planning for another building that would be slightly taller.

One of these projects, commissioned by the Chrysler Corporation in 1928, added an innovation to the competition. Planned and announced at 925 ft., the building design included a "secret" tall spike, which at the last minute was assembled in 90 minutes and raised into position, suddenly adding 121 extra feet to the height of the building. At 1046 ft., it became the tallest structure in the world at the time. Combined with its beautiful art deco exterior, the innovation cemented the place of the Chrysler Building in the hearts of Americans as one of the great "skyscrapers" (a term originally used for the highest sail on a clipper ship).

1.3.Program Integration

This project is targeted for first and second year engineering students. With variations, it can be used for third year students as well.

1.4.Description

Groups of 5 to 13 design and fabricate a skyscraper capable of sustaining a load. Materials for the structures are limited to polystyrene foam and pencils. Variable aspects of the project include but are not limited to an allocated budget, capability of the structure to handle an "earthquake," the use of the budget to purchase real estate and intergroup communication.

1.5.Learning Activities and Tasks

- Conceive/Design a skyscraper capable of:
    - Sustaining the weight of a 0.5 liter bottle
    - Remaining stable when on a 10% incline
- Present plans to a building inspector for review

- Implement/Operate through testing and construction
- Test the final structure
- Self-assessment

2.Learning Objectives

2.1.Technical Objectives

- Design and document plans for the skyscraper
- Explain to the building inspector the documents detailing the group's plans
- Build and test the structure while adhering to the plans made
- Explain how a budget and deadline can affect the group's attitude and the finished product

2.2.CDIO Skills

- 2.1.1 Problem Identification and Formulation
  - Identify obstacles from the conditions given
  - Formulate solutions to those obstacles
- 2.3.4 Trade-offs, Judgment and Balance in Resolution
  - Identify tensions and factors to resolve through trade-offs
  - Choose and employ solutions that balance various factors, resolve tensions and optimize the system as a whole
- 2.4.4 Critical Thinking
  - Analyze the statement of the problem
  - Choose logical arguments and solutions
- 2.4.7 Time and Resource Management
  - Discuss task prioritization
  - Explain the importance and/or urgency of tasks
  - Explain efficient execution of tasks
- 3.1.1 Forming Effective Teams
  - Identify team roles and responsibilities
- 3.1.2 Team Operation
  - Choose goals and agenda
  - Practice effective communication
  - Practice the planning, scheduling and execution of a project
  - Formulate solutions to problems
- 4.3.2 Defining Function, Concept and Architecture
  - Identify necessary system functions (and behavioral specifications)
- 4.4.1 The Design Process
  - Choose requirements for each element or component derived from system level goals and requirements
  - Analyze alternatives in design
- 4.4.3 Utilization of Knowledge in Design
  - Utilize technical and scientific knowledge
  - Practice creative and critical thinking, and problem solving

3. Team Organization & Management
   3.1. Group size
      - 5 to 13 students
   3.2. Group organization
      - Determined by each group
   3.3. Group management
      - Determined by each group
   3.4. Number of groups
      - 2 to 6

4. Notes to Students
   4.1. Project handout
      - Appendix 10.4

5. Notes to Instructors
   5.1. Instructor guide
      - Appendix 10.5

6. Assessment
   6.1. Summary of methods and tools used
      - Not Applicable
   6.2. Summary of the way assessment is embedded in the learning activities and tasks. Criteria for student products, processes, or performances
      - Not Applicable
   6.3. Reflection methods
      - Appendix 10.6
   6.4. Written Assessment
      - Appendix 10.6
   6.5. Oral Assessment
      - Not Applicable
   6.6. Peer/Team Assessment
      - Not Applicable

7. Resources
   7.1. Budget
      7.1.1. Recurring
      7.1.2. Non-recurring

   7.2. Materials
      7.2.1. Materials List
         7.2.1.1. Reusable
            - Pencils
         7.2.1.2. Consumable
            - Polystyrene Foam
            - Batteries for hot wire cutters (if necessary)
      7.2.2. Tooling

- Hot wire cutters

7.3. Staffing (describe particular skills and scope of commitment)

7.3.1. Faculty

- 1 Faculty
- 1 Teaching Assistant for every two groups

7.3.2. Technical Staff

- Not Applicable

7.3.3. Other (some projects might require additional expertise or licensure, such as an amateur radio license or pilot's license)

- Not Applicable

7.4. Spaces (identify the minimum feasible space requirements per student or per student team. Indicate whether space is dedicated or only during student activity.)

7.4.1. Design

- Table space for all students (only during activity)

7.4.2. Build

- Floor space for all students (only during activity)

7.4.3. Storage

- Space may be needed to store the hot wire cutters and possibly the pencils

7.4.4. Operate

- Floor space for all students (only during activity)

7.5. Software Resources (for example, this might include any Java applets, Matlab scripts, or Labview files which other faculty might find helpful.)

- Not Applicable

8. Safety & Risk Mitigation

8.1. Hazardous Materials

- Not Applicable

8.2. Equipment

8.2.1. Electrical

- Hot wire cutters for foam

8.2.2. Mechanical

- Not Applicable

8.2.3. Hand/ Shop tools

- Not Applicable

8.3. Operational Safety (see reference below)

- Use caution while using the hot wire cutters

8.4. Governing Policy/Regulation. (Identify regulations which might constrain the activity, e.g. weight limits on RC airplanes, altitude limits for model rockets, or broadcast limits on transmitters.)

8.4.1. Governmental

- Not Applicable

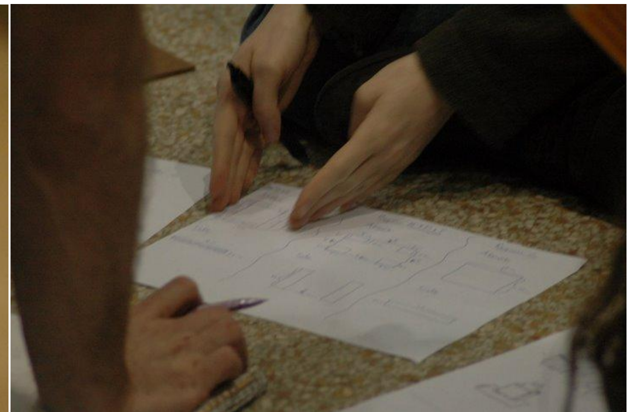
8.4.2. Institutional (These will clearly vary from institution to institution, but faculty might not realize that their campus already regulates an activity, and they need to explore local policy. For example, many institutions have a formal laser safety policy. Where they do, few faculty have likely read it, and fewer students.)

- Not Applicable

9. Variations- many projects have variations on design requirements or project details that permit faculty to adjust to local resources (time/space/money), to increase or decrease the scope, or change the project subtly from year to year.
   - Cutting new elements from the foam can be omitted
   - The purchase of real estate can be omitted.
   - The “earthquake” aspect can be omitted.
   - Whether or not an “earthquake” occurs can be decided by a coin toss.
   - One group can design the building, and pass the drawings to another group, who then implements, forcing far greater clarity in design documentation. This will be a great challenge for students, and force them to understand how much information is actually required to allow someone else to implement a design. It will also force students to implement the predetermined design, causing them to realize how much they tend to work in prototype of spiral mode, modifying the design “on the fly” during implementation.
   - The leader of the group or a leadership structure can be designated, or no recommendation on leadership structure can be made.
   - The customer requirements, regulations, or resources available can be changed after the first 15 minutes, simulating the realistic uncertainty and likelihood of change in these factors.
   - A two price scheme can be set up for materials, which prices higher for sustainable materials, but then giving the teams credit for having built a more “sustainable building”
   - A “patent office” can be set up, which allows teams to register innovations, blocking others from using them. As in the real world this will take some time for a team member to file an application, and a fee will have to be paid to the “patent office.” There will also have to be a final step in the “competition” in which patent holders are allowed to challenge other designs for infringement.

10. Appendices

10.1. Multi-media. (For example, photos of student designs, video of build or operate… anything which a recipient faculty member might find helpful in recreating the project experience)



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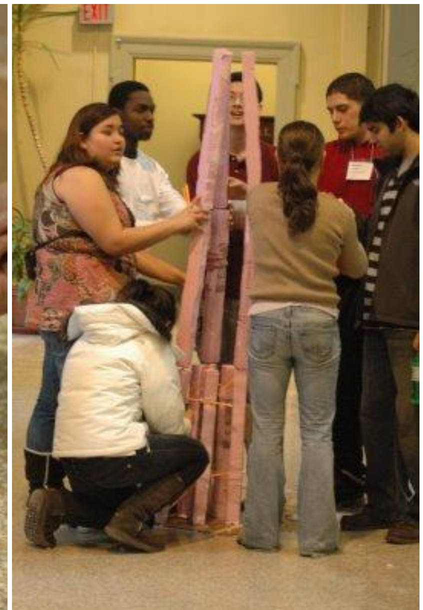
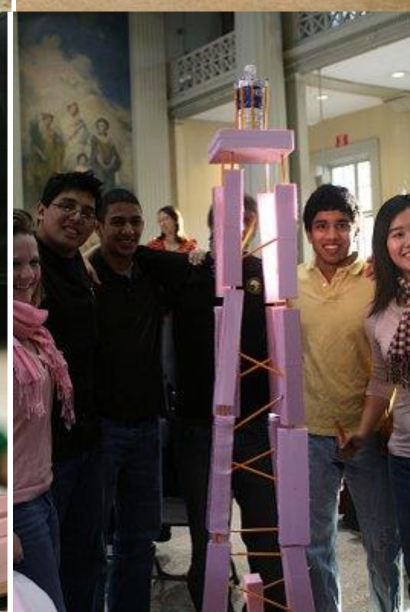


MIT



10.2. Other resources
- 10.2.1. Presentation materials
- 10.2.2. Links
- 10.2.3. Papers
- 10.2.4. Bibliography

10.3. Sample Student Products (each contributing institution must locally resolve implications of student IP)

10.4.

Skyscraper

Project Based Learning Experience

Information for Students
Version 3.0

Background

In the 1920's there was an economic boom that drove up real estate prices in cities in America, particularly in New York City. Inspired by the rising cost of land, the availability of new materials such as stainless steel, and the competition for bragging rights for the tallest building in the world, a number of projects were launched to build successively taller buildings. In this race, as soon as one building was announced at a certain planned height, competitors would begin planning for another building that would be slightly taller.

One of these projects, commissioned by the Chrysler Corporation in 1928, added an innovation to the competition. Planned and announced at 925 ft., the building design included a "secret" tall spike, which at the last minute was assembled in 90 minutes and raised into position, suddenly adding 121 extra feet to the height of the building. At 1046 ft., it became the tallest structure in the world at the time. Combined with its beautiful art deco exterior, the innovation cemented the place of the Chrysler Building in the hearts of Americans as one of the great "skyscrapers" (a term originally used for the highest sail on a clipper ship).

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

This project will emulate the task of the engineers and builders of the Chrysler Building. You must build the tallest building possible within budget and schedule, with the ability, at the last minute, to add a tall element to the top. It is desirable that, like the Chrysler Building, the designs have an aesthetic appeal, and a sense of quality construction.

Inspired by this case, we have outlined below the customer requirements, pertinent regulations, and project engineering considerations with which you must work.

Customer Requirements

Your team must build the tallest building possible, within budget and schedule (see below), with the materials and tools provided, and satisfying regulations (see below). At "the last minute" (as the final step in implementation), you must place a full 0.5 liter water bottle on top of the "building." In order to be in competition for the tallest building, your building must remain standing under the conditions specified in Regulations (see below). In the case of buildings of similar height, the one with the greater aesthetic appeal, and appearance of quality construction will be the winner.

Regulations

1. The building inspector must review drawings and sketches that explain the design and implementation sequence of your building in sufficient clarity and detail that the inspector is able to understand the design and assembly sequence, and agree that they comply with these regulations. You cannot start implementing the actual building until the inspectors approves the drawings, and you must build exactly what is shown in the drawings, and according to the proposed implementation sequence. You can check with the inspector during the conceive/design period to understand how much detail must be provided. If you submit a set of drawings, and they are not of sufficient detail, they will be returned to you, and you must modify them and obtain final approval prior to beginning implementation.
2. The description of the proposed design must be supported by some sort of structural analysis, and/or by experimental evidence based on research and development done by your team during the conceive/design period.
3. There is pending a new regulation for earthquake safety. By the conclusion of implementation, the regulatory board may make a rule that requires all new buildings to meet a test that demonstrates they are resilient to moderate earthquakes, equivalent to building the building on up to a 10% (that is 1 in 10) slope. However at this time, it is not certain if the board will make this rule, and what the final form of the rule will be. If it is enacted, the building inspector will require that after the building is completely erected (but before the water bottle is added) the building “real estate” will be sloped in an arbitrary direction by 10%.
4. To ensure safety of the team during construction, the building must be built from the floor, and all members of the team must have their feet on the floor at all times.

Project Engineering Considerations

Schedule:
The team will have approximately one hour and fifteen minutes (1:15) to execute all phases of the project. It is highly recommended that the team set an internal deadline of completing the conceive/design phase (and submitting drawings to the building inspector) within the first 45 minutes.

Budget:
The team has 1000 Gordon dollars (also called Bernie bucks) to expend on the project. These can be used to purchase real estate, building materials, and manufacturing services, as shown in the attached price list. The team can spend as much of this budget as they choose during the conceive/design period (prior to submission of the design drawings) to perform research and development, build prototypes, innovate, and collect design data. However, no materials used during the research and development phase can be reused in the construction of the building.

Organization:
It is highly recommended that the team designate three leaders, an overall project engineer, a design leader, and an implementation leader. The overall project engineer will be responsible for coordination and project success. The design leader will be responsible for research, development, design and design drawings. The implementation leader will lead the fabrication and construction of the building, and the verification (if needed) of its earthquake regulation compliance.

Cost of materials for the Building

All prices shown in Gordon dollars.

Real Estate: 2$/in^2, available in the following sizes (in inches):
16x16
14x14
12x12
10x10
8x8

Building materials (2 inch thick structural foam): 1$/in^2, available in the following sizes (in inches), while supplies last!
24x9
12x12
8x8
6x6
4x4

Fasteners: 2$ per fastener (fasteners cannot be cut or broken)

Hot wire for cutting foam: 2$ per linear foot of cutting (rounded up, that is the minimum cost for a cut is 2$).

Analysis to support design

You must provide to your building inspector data or analysis to support the argument that you building will stand. You can support your argument with either data taken during the conceive/design period, or with analysis. You might consider the following questions in preparation of your documentation:

- Will the building stand or topple over when the simulation of the earthquake (a 10% slope) is introduced?
- Will the building be strong enough? Will it be able to carry the loads applied by the bottle at the top and its own weight with out breaking or crushing?
- With the building be stiff enough (versus a wet noodle with a big mass at the top)? Will it have enough stiffness to not simply bend over or "buckle" under the load applied by the bottle at the top and its own weight?

10.5.

Skyscraper

Project Based Learning Experience

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Version 3.0

Information for Instructors

Target Students Audience

The project based learning experience is targeted for first and second year engineering students. With elaborations described below, it could be used for third year students. The target audience is largely independent of discipline, as the outcomes are more focused on the real world factors likely to be present in any engineering project. For students that study structures (aerospace/mechanical/civil) there is a bit more disciplinary relevance, but this is not the primary focus of the learning experience.

Learning Objectives:

The principal learning outcome of the project is to allow **a student to describe, anticipate and plan for some of the realistic factors encountered in a real engineering project**.

The project has learning more detailed learning outcomes. As a result of the learning exercise, students should be able to:

- Recognize when previously obtained disciplinary knowledge can be applied to a design.
- Describe what additional disciplinary knowledge would be useful to actually design and analyze such as structure.
- Explain how creativity, problems solving and experimentation played a part in their team process
- Describe the importance of dividing the job into tasks to be performed by members of the team with strengths for that task (leadership, analysis, design, manufacturing, etc.)
- Explain the benefit of designating a leader to coordinate the effort, and the dividing of the tasks and their assignment to team members best qualified to execute them.
- Describe the need for good documentation of designs and implementation processes.
- Explain the challenge of, and trade-offs necessary to meet the requirements and regulations within the fixed budget
- Describe the benefit of doing some exploratory (R&D) testing, and moving to the implementation phase in time to have access to materials and manufacturing.

Commentary on the learning outcomes follows.

Primary learning outcome:
In contrast to their exposure in disciplinary courses typical of the early years of engineering education, there is a wide variety of process knowledge, instinct and judgment, and focused leadership effort necessary to successfully deliver a competitive engineering solution on time and budget. This exercise, and the reflection at the end, have been designed to develop some of this understanding, including: understanding customer requirements; following regulations and anticipated regulation; innovating based on technical need; developing a competitive concept; applying disciplinary knowledge in design while also using design intuition; producing design documentation; planning the project within budget and schedule; making make-buy decisions; planning and executing efficient and timely manufacturing; planning for operations: and expecting resources and/or requirements to change.

Disciplinary knowledge:

Reinforcement of previously obtained disciplinary knowledge. The exercise builds on knowledge of statics and mechanics that many students will have learned in their first year engineering or physics courses. The requirement to produce analysis of the design to show the “building inspector” makes students consider how to apply previously obtained knowledge to the design. The option of doing testing is more costly but also viable.

Establishing the framework for future knowledge acquisition. As described, the principle outcomes are focused on design process and intuition. For mechanical/ aerospace/civil engineering students, the exposure to the need to model statically determinant and indeterminant structures, columns and buckling will be valuable in subsequent structures subjects.

Personal skills and modes of thought:

Modes of thought: The exercise emphasizes creativity, both in the overall design, and in the design innovation needed to win, and engineering reasoning and problem solving. In order to produce data on strength needed to satisfy the building inspector, some experimentation will probably be required.

Metacognition: There are no significant metacognitive learning outcomes, but the reflection does ask students to reflect on what they learned, and how it can be applied to other engineering projects.

Interpersonal skills:

Teamwork: The groups will have to make a series of decisions under pressure. They will need build on the strengths of the group, efficiently employing students to work on tasks they are better able to do, such as to design, draw, and do rudimentary structural calculations, and perform project engineering skills such as time and budget management.

Leadership skills: Assuming the group designates one or several leaders for overall leadership, design and construction leadership, there will be an excellent opportunity to reflect on their effectiveness. If the students choose to be “leaderless”, observations about their performance or emergence of situational leaders are appropriate.

Communications: The students must prepare graphical communications of the planned building, and its assembly sequence, which must be approved by the "inspector." For many early engineering students, this will be among the first time they have been required to produce engineering renderings, and will realize how difficult this is. Requiring the students to build what they drew will further emphasize the importance of clarity in documentation.

Conceiving, Designing, Implementing, Operating:

Enterprise and Societal Context: The issue of pending regulation should promote a discussion of what is the responsibility of an engineer to not only the safety factors that are currently included in regulations, but also those under consideration.

Conceiving, Designing: The constraints of materials, tools and budget will force a careful design decision. It is possible to build various frame-truss structures that are higher than the simple staking of blocks, but it takes efficient design and utilization of materials. The possibility of cutting foam to various shapes introduces a possibility of innovation, and a make-buy decision. Students are required to commit to a design before assembly is begun, and produce construction documents, unlike many design-implement projects that allow spiral development on a prototype up to the last minute of delivery and operations.

Implementing, Operating: Teams that design faster will have access to the more of their preferred size pieces, while teams that design slower will have to buy what is on the market and modify them – therefore there is a subtle scarcity of resources and schedule pressure that will not be apparent until the teams begin work. The availability of hotwire cutting should be scaled so that there is a scarcity of manufacturing resource, introducing the need to plan for manufacturing schedules, and manage suppliers. The possible earthquake requirement leads to exposure to consideration of robust design.

Contextual Elements

Context is surrounding or environment that improves understanding. Students benefit from setting such learning activities in a realistic context. The context of the Chrysler Building, described in the "Information to Student", was chosen to connect to a widely known engineering accomplishment, and to motivate the elements of competition, aesthetics, budget and schedule constraints, and the unusual requirement to add the top element at the last moment.

Learning Activities

Preparation: The building materials should be prepared and readily at hand. A sales person and banker should be ready to sell. A manufacturing person should be ready to perform the hot wire cuts. A person should be designated as the building inspector. All of this could be done by as few as two people, or as many as six, depending on how many groups are involved.

Timing: The learning activities are outlined in the student description. A typical timeline for the experience is:

15 min	introduction by instructor
45 min	conceive/design phase

30 min implement/operate phase
30 min reflection on the exercise, and summary of learning

Other information: Other points for instructor (do not give hints to students about these things, but if they ask, here are suggested responses):

- There is no formal competition, the tallest building standing with a water bottle on top (subject to earthquake testing) is simply recognized as such. In the event that several are of similar height, the instructor can comment on the relative aesthetic aspects
- The winning building will likely have some modest innovation, but the budget is set so that a very clever concept is needed to beat a simple tower of blocks.
- The instructor should not give advice to the students other than the following:
  - If, within 15 minutes, they have not worked out any team responsibilities, suggest once that they do
  - If, within 30 minutes they have not considered any R&D investment, ask how they will provide the data for the building permit
  - If, within 45 minutes, they have not begun any building, point out the guidance that they team get to building by 45 minutes into the exercise
  - When they present their drawings, you can suggest changes or improvement until they are satisfactory
- Students will be allowed to buy and sell from other teams
- No mergers of teams will be allowed
- Students can buy services (for example, structural consulting, preferential treatment from the manufacturing facility) for reasonable costs
- Fasteners and materials used in the R&D phase are considered spent and cannot be reused in the actual building. However materials purchased and not used in R&D can be used in the final building
- The building inspector should confirm that at a minimum, the following analysis of the design has been done:
  - A static analysis that with a 10% slope at the base, the center of gravity of the building (approximated as the center of the bottle) is still within the footprint of the base of the building (i.e. the building will not topple).
  - A strength analysis that the structure will hold up to loads and not crush or break (probably done with a simple R&D demo)
- The building inspector can, if asked, approve “engineering change orders”, that is modifications to the submitted design made after the approval of the designs and after construction has begun. But students should be held to building with they actually represented in the drawings (plus approved changes) to emphasize the importance of complete designs.

Discussion and reflection questions with the students

The following are questions you can use to guide student reflection, and notes for instructor-led discussion:

- What was your interpretation of the requirements? How would you have resolved misunderstanding in them?
    - In real engineering practice, customer needs and project requirements are never clear, complete or consistent. There is always ambiguity that must be resolved. If there is a single customer, this can be done by discussion and negotiation. If there are a group of customers, focus groups and interviews are commonly used. It is always a good idea to seek confirmation of requirements by giving the potential customer drawings or prototypes.
- What innovation did you introduce? What was the inspiration? How do you know when to innovate, and when to build "standard work?"
    - Much of engineering is "standard work," that is the application of existing technology to solve a new problem. Often, however, successful new products and systems have an element of new technology, invented by the system developers to meet a new need. Learning to balance reuse of existing designs and technology in contrast to inventing is one of the important skills that engineers develop.
- What R&D did you do, was it worth it? How did you decide how much of your budget to spend on R&D?
    - Almost all successful product systems have some sort of R&D, prototyping or spiral development in which engineers learn about the system by building part of it, or a preliminary version of all of it. Real learning about the system often comes by trying things out. It is not unreasonable in a venture such as this one to spend 5 to 10% of the budget on this R&D phase, which generally saves at least as much money in the design and build phases by avoiding miss-starts and errors.
- How did you apply your existing knowledge of statics to analysis the design? What new knowledge did the exercise make you realized you needed?
    - Good engineers make a connection between their disciplinary knowledge and the design they are developing. Good designs are analyzable. One motto of design is: "design what you can analyze!" This exercise was designed to make a link to your knowledge to statics, but also make you realized that there is other knowledge you need to acquire in order to be successful in engineering projects in general, and more knowledge of structure (analysis of determinant and non-determinant structures, elastic stability) that you will need if you are to be an engineer of this type.
- What design intuition did you use? Was it as important as the analysis? More?
    - While design does not emerge from analysis, intuition developed in analysis can guide design. Other types of "right brain" knowledge are important in design, including "hunches" and "gut feel". Many successful designers say that good designs come first from intuition, and then are substantiated by testing or analysis.
- Did you understand the need to produce good documentation? Why is this important? Did you build what you actually rendered in the drawings?
    - The ultimate product of designers is the design, captured in design documentation – drawings, sketches, CAD renderings, software diagrams and pseudo code, etc. Engineers must be able and willing to produce these important documents to communicate their efforts. If the need for change occurs (sometimes called engineering change orders), they must update the documentation so that it tracks

what is actually being build (reducing the gap between “as designed” and “as built”).

- How did you decide on how to invest budget and time resources? Did you make a plan? Did you follow it?
    - Project engineering is the control of effort on tasks based on ever-present constraints of limited time and budget. Good engineering projects develop budgeting and scheduling processes, and try to stick to them.
- How did you account for the pending regulation? Did you do a design that is robust to this potential change? What is the responsibility of engineers to anticipate changes in requirements and regulations?
    - Nearly all engineering endeavors are subject to regulatory control, from toys to airplanes to pharmaceuticals. Engineers must comply with regulations, but also anticipate expected changes in regulations. One way to do this, and solve other design problems, is to design robustly, that is so that the design will not need to be changed due to minor to moderate changes in customer needs or regulations.
- Did you learn about the need to implement with quality? Did you learn that it important to practice operations?
    - Building an engineering project – implementation – is often as challenging if not more so than designing. In implementation, for software code, molecules or cars, there has to be constant attention to quality – making sure the artifact is well made and meets specifications.
- Did you use the suggested project engineering leadership structure? If so, did it work well? If not, what alternative did you use?
    - There is simply too much to do in this project (scheduling, budgeting, R&D, drawings, analysis, implementation process, etc.) for all members of the team to simultaneously work on all tasks, without some sort of division of responsibility. Teams do better with some responsibility assigned and delivered, and some sort of leadership coordinates the efforts.
- What did you learn, and how could you generalize this to other engineering projects?
    - Hopefully the intended learning outcomes listed above will be mentioned by the students!

<u>Group structure:</u>

Students should be assigned to groups of between 5 and 13. Assignment should be random, or based on balancing student skills in leadership, communications, and statics.

<u>Assessment of student performance:</u>

There is no formal student learning assessment proposed. As in all design-implement project based learning, there should be a balance between the credit given for successful accomplishment and quality of the project, and learning done by the students.

Early in their career, it is recommended that more emphasis should be place on learning. In this exercise, the instructor could:

- Lead the reflective discussion with the students

- Have the students in groups reflect on their group work
- Have each individual student fill out a worksheet based on the reflection questions, asking them to comment on their performance and learning in the exercise (see attached).

Later in their career, it is important for students to learn that actually delivering a successful system or product, on schedule and budget, is the central activity of engineering In later years, increasing emphasis should be place on project outcome, and not process.

Materials needed for the exercise:

1. 2 inch thick extruded polystyrene foam, cut to the sizes listed in table below. If you obtain 2 ft. x 8 ft. sheets, the "2 groups" set will come from one sheet.
2. 3/8 inch thick hardboard, cut to 16x16 inches, one for each team. The smaller sizes for real estate can be created by just marking off a smaller area with masking tape, so that only one size of board is needed.
3. Hot wire cutters, made up of a yoke, nickel chromium wire, and a battery (plus optional switch). One wire is probably enough for up to 3 teams.
4. Sharpened wooden pencils for fasteners, in the number listed in the table below.
5. 1000$ of "currency" for each team (100's, 20's, 5's, 1's are enough, make 2000$ for each team so there is enough for change in the bank)

Foam	2 groups	5 groups
24x9	2	4
12x12	4	8
8x8	9	18
6x6	12	24
4x4	18	36
Fasteners	120	240

Note that in order to have a variety of supply, there are more items listed than two teams can actually buy (by a factor of about 1.5). Therefore the number of items needed for 5 groups is only about twice that needed for two groups, as the variety of design will spread the needs. Note also that the foam material for 2 groups can be cut from one 2 by 8 foot standard size piece of foam. The foam blocks can be cut by scoring with a utility knife and "snapping." The table of materials is set up so that it is possible for one type of material to run out (as it does in the real world), forcing students to fabricate larger members from smaller, or obtain smaller ones by cutting larger ones.

Cutting of foam with a hotwire is not inherently dangerous, but should be done by those familiar with the procedure, and in an area with adequate ventilation.

The hardboard, hot wire, pencils and currency are completely reusable. The unused foam can be reused, and even the uncut pieces of foam with pencil holes can be recycled. Cut foam should be replaced before the next use.

Alternatives to the exercise:

Many alternatives to the described exercise are possible.

Nearly any element except those that would lead to stacking of simple squares of foam can be omitted. For example, the option to cut new elements from foam with a hot wire (which forces make/buy decisions) can be omitted, as can the real estate purchase (which forces a budgetary and technical trade-offs) and the "earthquake requirement (which forces robust design considerations).

The following elements can be added:

- The earthquake regulation can be decided by a random choice after design is started, requiring consideration of design for statistically determined events or criteria.
- One group can design the building, and pass the drawings to another group, who then implements, forcing far greater clarity in design documentation. This will be a great challenge for students, and force them to understand how much information is actually required to allow someone else to implement a design. It will also force students to implement the predetermined design, causing them to realize how much they tend to work in prototype of spiral mode, modifying the design "on the fly" during implementation.
- The leader of the group or a leadership structure can be designated, or no recommendation on leadership structure can be made.
- The customer requirements, regulations, or resources available can be changed after the first 15 minutes, simulating the realistic uncertainty and likelihood of change in these factors.
- A two price scheme can be set up for materials, which prices higher for sustainable materials, but then giving the teams credit for having built a more "sustainable building"
- A "patent office" can be set up, which allows teams to register innovations, blocking others from using them. As in the real world this will take some time for a team member to file an application, and a fee will have to be paid to the "patent office." There will also have to be a final step in the "competition" in which patent holders are allowed to challenge other designs for infringement.

Supplemental readings and resources

Crawley, et al. "Rethinking Engineering Education, the CDIO Approach", Springer, 2007
Power point charts for introduction and student reflection

10.6.

Skyscraper

Project Based Learning Experience

Student Self Evaluation

Reflect on your performance in the learning exercise, and that of your group, and answer the following questions:

- What was your interpretation of the requirements? How would you have resolved misunderstanding in them?
- What innovation did you introduce? What was the inspiration? How do you know when to innovate, and when to build "standard work?"
- What R&D did you do, was it worth it? How did you decide how much of your budget to spend on R&D?
- How did you apply your existing knowledge of statics to analysis the design? What new knowledge did the exercise make you realized you needed?
- What design intuition did you use? Was it as important as the analysis? More?
- Did you understand the need to produce good documentation? Why is this important? Did you build what you actually rendered in the drawings?
- How did you decide on how to invest budget and time resources? Did you make a plan? Did you follow it?
- How did you account for the pending regulation? Did you do a design that is robust to this potential change? What is the responsibility of engineers to anticipate changes in requirements and regulations?
- Did you learn about the need to implement with quality? Did you learn that it important to practice operations?
- Did you use the suggested project engineering leadership structure? If so, did it work well? If not, what alternative did you use?
- What did you learn, and how could you generalize this to other engineering projects?