Assessment of a Multi-Goal Mechanical Engineering Design/Fabrication Project Used as a Mission-Critical Exercise.

The project was born out of a need for a demonstration engineering project that could be completed in 8-9 weeks, used straightforward principles and materials, and most of all was likely to draw crowds of local people to our combination Charity event and Engineering Open house late in October. The secondary, or perhaps tertiary, requirement was to enable junior and senior mechanical engineering students to practice developing a ‘mission critical-product package’ in a short time span.

At one of the discussion sessions the words October, Pumpkin and Trebuchet landed in the same sentence; our project became “Halloween Pumpkin Flinging for Charity (Do’chas) at Baker College Jackson School of Engineering. This paper is a report of the outcomes of this attempt to allow a student design group to research, plan, design, fabricate and test a modern version of an ancient device.

Preliminary compilation of surveyed data indicates that a design team knowing little about the workings (physics, mechanics, materials, construction techniques) of the ‘flinging’ family of ancient offensive weapons were able to assemble and process enough knowledge in all required areas to enable the development of the higher order skills required to design, test, revise and at the end, to create a functioning design (a la Bloom). The students succeeded mostly in their attempt, as described in later sections.

"Jackson, MI -- Pumpkins are in abundance this time of year, and at Baker College of Jackson, dozens were flying through the sky with the help of a trebuchet." [1] Flying pumpkins were the result of an engineering project undertaken by students in the mechanical engineering program at Baker College of Engineering in Jackson, MI. Any engineering program relies on the bringing together of learned skills (during the courses), the ability to find and use information, and ultimately synthesize the whole into a new product, device, or solution to a problem. The process outlined above sounds strikingly like the order of Blooms Taxonomy (BT), a method of describing a creative learning model. Taxonomy of educational objectives, known as Bloom's Taxonomy, developed in the 1950's [2] and revised in 2001 [3], has been one of the guiding references on the subject of cognitive learning. It has been widely used as a basis for the design of curricula in engineering specializations such as Civil, Chemical and Software [4], and Mechanical. Briefly, the revised version of Bloom's Taxonomy applies tasks to six stages of learning (remember, understand, apply, analyze, evaluate, create) and is shown in Figure 1.

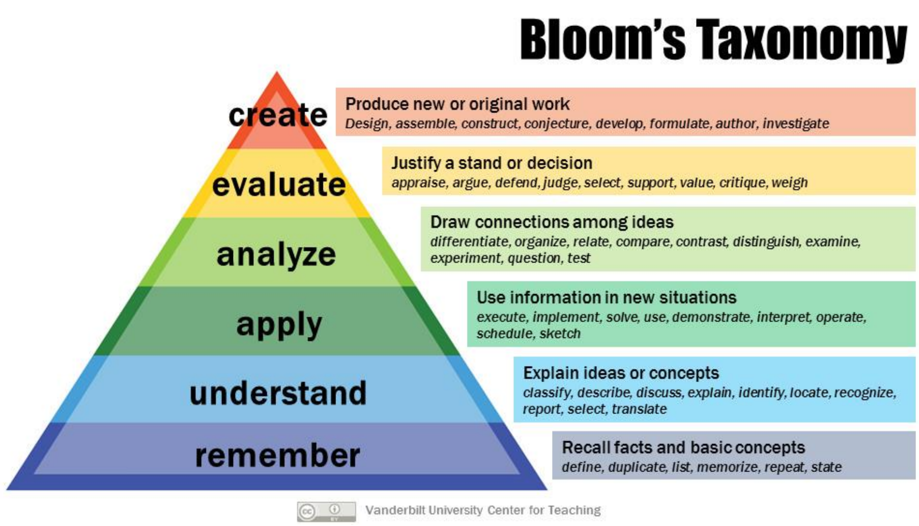

Figure 1. Bloom's Taxonomy Pyramid (revised version 2001) showing the framework, educational outcomes, and levels of thinking.

Before the beginning of the semester, students in the xx class were notified of a change in usual class syllabus and were directed to a new class outline. The new outline required the design of an ancient siege engine to be designed, built, and used in the 8th week of class to throw not heads and flaming pots of Greek fire, but pumpkins for a local charity event. Students were assigned this design problem with very little ready-to-apply knowledge of catapult-type engines, although as juniors they were well versed in the mechanics, dynamics, and physics, and materials properties (general engineering knowledge) that should have enabled them to easily begin the preliminary what-if portion of the design process after very little basic research into the physics of this class of devices. At this stage of the project BT would expect the students to be engaged in serious research (internet-based, with reference to engineering texts) to determine the general scope of the problem in order to move to the next step of the design process. No project leader was assigned at the beginning of the project and no leader-by-acclimation emerged in the first week of work. Even though ample materials consisting of research suggestions, websites and URL's were available (and provided), nothing much was accomplished (Week 1).

Beginning with the second week (Week 2 and Week 3), research and information became the primary product of the team as information collected, trial simulations and preliminary analysis results began to drive the design process. During the first three week period team members spent time working thru the first four levels of Bloom's pyramid (Figure 1) that is, (remember, understand, apply, analyze) gathering information from many sources, collating and discussing the possible approaches to solve the initial problems (size, arm length, basic structure, and the counterweight sizing formula).

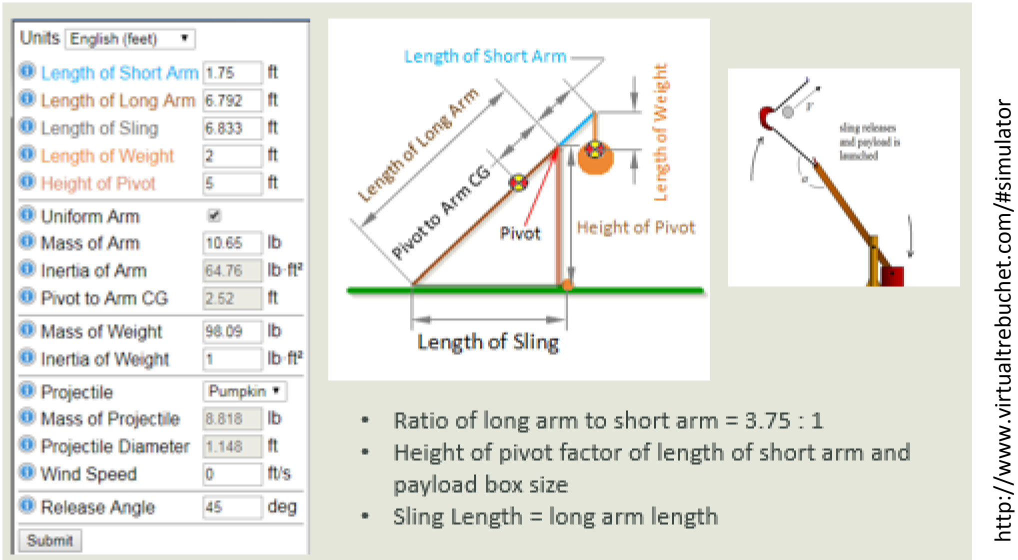

Figure 2. Showing use of simulations to check initial calculations for Mass, Inertia, and Ratios of arm to pivot placement.

Beginning with Week 3, meetings were better organized as defined roles began to emerge with a leader emerging for one session to give direction to the group and then fading back into the overall group work. Research into strength of materials drove the design toward large upright beams to carry the pivot and arm, and smaller wood parts including plywood for gussets/skins. Preliminary design and part/materials selection was complete by the fourth week (Week 4).

Design vs. Build considerations led to the outsourcing of several parts as well as specification of materials for reinforcing plates and other high-strength parts. Preliminary materials orders were complete by the fifth week and fabrication and assembly began at that time as well (Week 5).

Midway through the allotted time period, the group began to build the framework and arm structure after using simulation tools to guide the design process (Bloom 3 & 4). The group began during this time to apply the last two steps (evaluating and creating), to respond to both the final stages of design as well as the final fabrication and assembly of the device.

As the students are all enrolled in a mechanical engineering program, a large component of the curriculum is devoted to statics, mechanics and physical analysis. Initial design ideas shaped by experience and information gathered in earlier parts of the class gave way to design trade-offs supported by stress and strength analyses, (Fig 3).

$$F_{tension} = \frac{mv^2}{L} + mg\cos\theta$$

$$W = mg \rightarrow m = \frac{W}{g} = \frac{585}{32.2} = 18.2\ \frac{lb * s^2}{ft}$$

$$v = \sqrt{2gh} = \sqrt{(2)(32.2)(5.3)} = 18.5\frac{ft}{s}$$

$$L = 3\ ft$$

$$\theta = 0°$$

$$F_{tension} = \frac{(18.2)(18.5)^2}{3} + 585\cos 0° = 2{,}077 + 585 = \boxed{2{,}662\ lbs.}$$

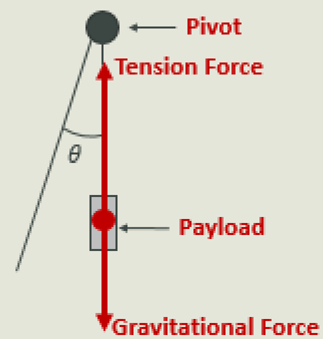

Figure 3. Showing calculated tension on the main pivot.

Analysis allowed several concerns to be studied. One of the major concerns of the team was the possibility of bending of the main pivot when the device was loaded with the balance weight and the forces generated by the throwing action. Analysis, shown in Figure 4, addressed this concern; analyses, including Von Mieses and stress distribution within the cross-sectional area of the pivot bar, as well as deformation studies of the bar yielded a safety factor of 1.5 for the main pivot bar.

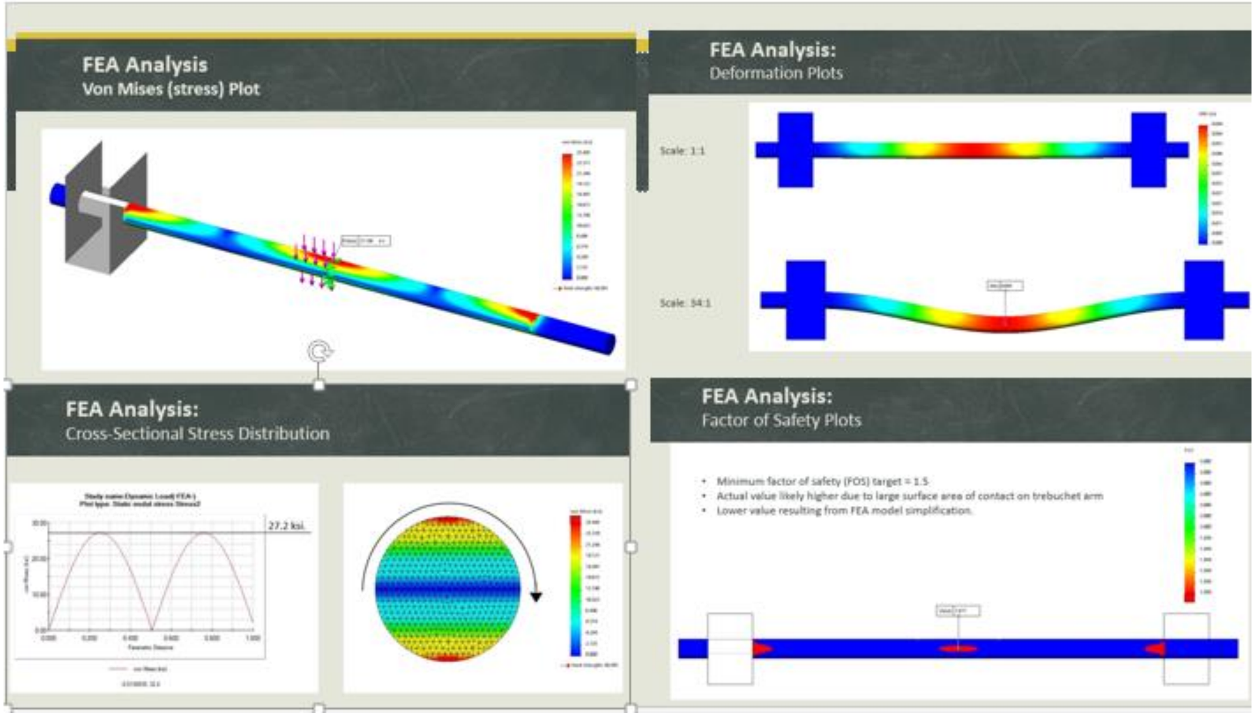

Figure 4. Showing analysis performed to address several design concerns: Stress Concentration, Maximum Deformation, Factor of Safety, and Stress distribution in the cross section. (Clockwise from top left)

The longest period, shown as 16 days by the project timeline was spent in the construction of individual detail parts and their assembly and integration into the structures required for the project now officially known as 'The trebuchet'. Several structural parts were redesigned during this period as the design matured.

By Weeks 6.5 and 7, the design was mostly frozen and most time spent on the project was directed at completion of final parts, reinforcement to weak areas (in lieu of redesign) as the project completion date approached.

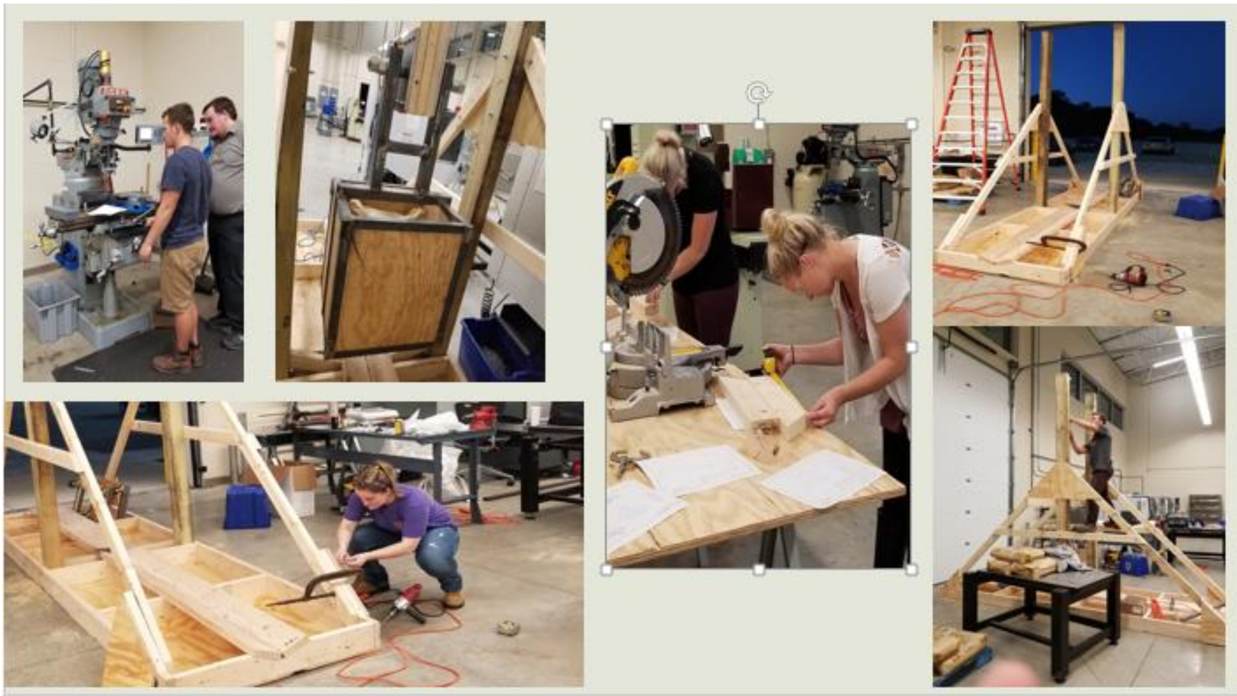

Figure 5. Various stages of the construction and assembly process.

The most exciting part of the design and redesign process was the modification of an existing mechanism (the linkage that controls the release sequencing of the sling) to better suit the requirements of the project. The design changed and grew more concrete as all of the different pieces of information were processed through the pyramid requiring some re design in places as the group discovered that analysis and reality sometimes share only a passing relationship.

Testing was limited to the week of the Trebuchet event and produced several problems (sling modifications, release mechanism) that appeared to be serious but were resolved easily when the combined expertise of the group were turned on them.

We were pleased to see that the students in this design class were able to not only 'rise to the challenge' of designing and fabricating a large model with several moving parts, while using good engineering practice and remembering that physics laws tend to interact. As we examined the progression through the design-build process it became apparent that the steps in the design process could be likened to those outlined in Bloom's original Taxonomy pyramid and followed even more closely the revised pyramid as outlined at the Vanderbilt Center for Teaching, as shown in Figure 1. The timeline was a clear indicator of group progress through the steps as Week 1 was spent preparing to engage in level 1 and 2 of the pyramid (remember, understand) in order to gather and process the information supplied as well as incorporating the information gathered by the group. By Week 2 and 3, the group had begun to pull together (apply) and started to analyze their acquired data a. By week 4, about halfway, analysis was ongoing, first design documents were beginning to appear and most materials were on order or in process. So by Week 4 and 5, students had worked through all of the levels of the pyramid (remember, understand, apply, analyze, evaluate, create) and were creating new parts and approaches either as design objects themselves or as 'fixes' in response to discovered challenges in the design task. Students in a junior level design class were able to conceive, design, and construct a version of an ancient trebuchet, within a short timeframe and meet or surpass the initial design specifications. During the project, the group reinforced the use of Bloom's Taxonomy steps as a valid predictor of outcomes in a design course.

Results showed that the device could throw a 5 lb. pumpkin a consistent 350-400 feet over the entire afternoon of the event. Event attendees paid a small fee to have 'their' pumpkin thrown downrange. $350 was raised for a local charity, Do'chas, which provides free crisis intervention to youth and their families in the Jackson, MI area.

References

[1] N. Frazier, *MLive.com,* 27 October 2018.

[2] B. S. Bloom, M. D. Engelhart, E. J. Furst, W. H. Hill and D. R. Krathwohl, axonomy of educational objectives: The classification of educational goals. Handbook I: Cognitive domain., New York: David McKay Company, 1956.

[3] L. W. Anderson and L. A. Sosniak, Bloom's taxonomy, vol. 36, Univ. Chicago Press, 1994, p. 76.

[4] M. Azuma, F. Coallier and J. Garbajosa, "How to apply the Bloom taxonomy to software engineering," in *Software Technology and Engineering Practice, 2003. Eleventh Annual International Workshop on,* 2003.