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A Comparison of Succeeding Mission-Critical Mechanical Engineering Design/Fabrication Projects.

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A Comparison of Succeeding *Mission-Critical* Mechanical Engineering Design/Fabrication Projects.

The project, aimed at drawing crowds of local people to our combination Charity event and Engineering Open house late in October, became known as “The Halloween Pumpkin Flinging for Charity at Baker College School of Engineering”.

The first attempt was successful both from a financial standpoint ($350 raised) and perhaps more importantly, showed creditable data indicating that student groups, when faced with a problem beyond or outside their skillsets, naturally (with minimal steering) followed a plan of their own that turned out to be basically indistinguishable from that of Bloom’s Taxonomy.

This paper is a report of the outcomes of the second attempt to allow a student design group to research, plan, design, fabricate, and test a modern version of an ancient device (catapult) while watching for adherence to an ‘internalized’ version of Bloom’s Taxonomy, as was seen in the previous group.

Beginning with the same requirements as defined the first attempt, size, payload, distance, and overall time period, we expected that the group, although smaller in number, would follow roughly the same path as the previous class and arrive at the end of the project after having spent the design/build period developing the same high-order skills.

Results indicate, however, that while the standard tasks of the pyramid did indeed propel the group toward the project end, the addition of an unexpected failure added an additional test of the validity of the ‘internalized pyramid’ theory and its influence on the final outcome. Again, the group succeeded, although not without setbacks, as described in later sections.

“Blackman Twp., MI - How far can you toss a pumpkin? The world record is just under 4,695 feet, says the World Championship Punkin Chunkin Association. Can’t hurl a pumpkin nearly a mile? No worries. The Baker College of Jackson,…will still let you throw at its annual “Pumpkin Fling” from 11 a.m. to 2 p.m. Saturday, October 26…”[1] Initiated just last year, pumpkin flinging for charity quickly became an established event at Baker College in Jackson, MI.

Initially conceived as an exercise to test the skills of engineering students nearing the end of their degree, the ME4850 class has grown to become a yearly community supported event. Last year’s project report discussed the realization that “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.”[2], and related the project milestones to visible (although internalized) progress through the steps of Bloom’s Taxonomy [2], [3] pyramid, described in Figure 1, below.

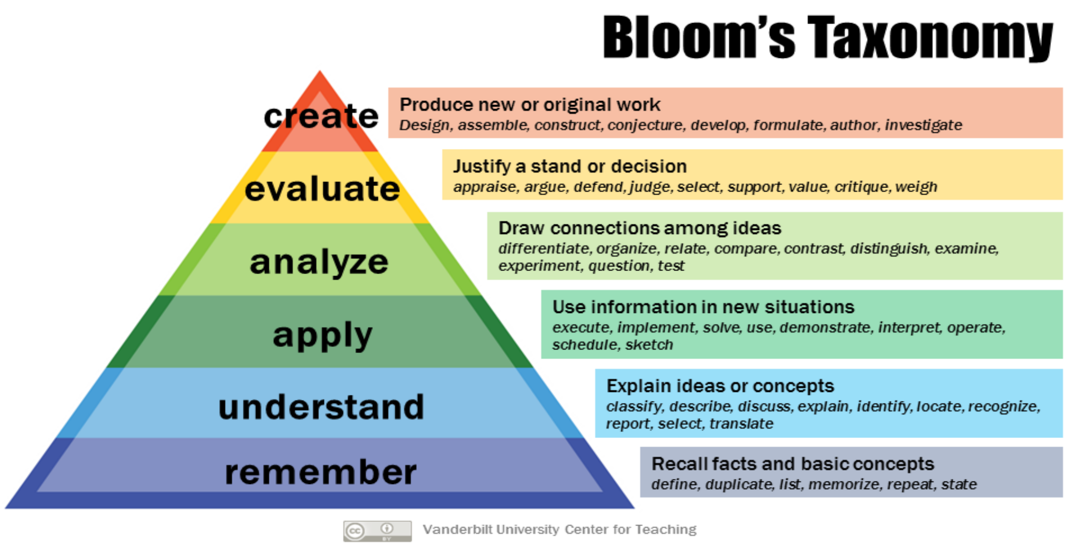
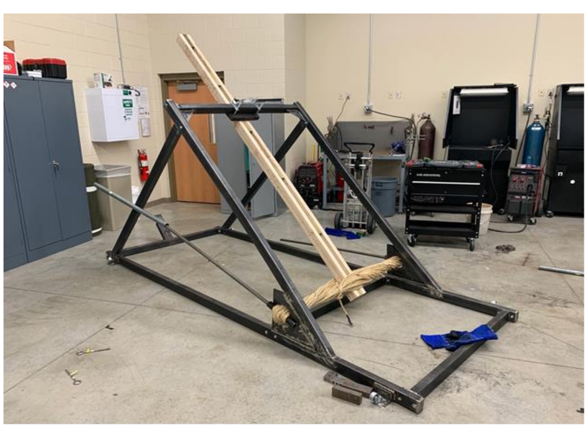


Figure 1. Bloom's Taxonomy Pyramid (revised 2001) framework, education outcomes and levels of thinking.

This year, pumpkins were flung, and the event met the goal of showcasing the design and development of a project while also looking for confirmation of the innate grasp of Bloom’s tenets, as seen last year, that would also contribute to the success of the project.

Sequels are sometimes disappointing and this possibility was, of course, on the mind of the instructor during the setup of the class. Unlike the preceding semester, students registered for the class *expected* a change in the usual class syllabus, and so may have come to the class with preconceived expectations of the task. A discussion of the expected project outcomes was followed by a short ‘brush-up session’ in using the FEA software (previously used in an earlier course) that would be used to analyze the structures developed. This year, several possible versions of historical ‘throwing’ devices were considered. Students were assigned this design problem with the final method of throwing left open, although all of the other constraints (400 ft. range, 5 lb. pumpkin) remained the same as the previous design. No group structure was pre-assigned, allowing each member to find their own role within the team. The instructor acted as a resource and a guardrail, but did not try to ‘steer’ the project. The group spent the initial weeks (Week 1 and Week 2) accumulating information (not all relevant) about members of the family of throwing machines and discussing possible approaches to the project, appearing to work through the first two steps (*remember*, *understand*) of the Bloom’s pyramid. The expected integration of existing engineering knowledge (physics, mechanics, materials) with information found due to research (internet and other sources) was not as visible in this group as in the previous group by this time. By Week 3, however, a time line was set and materials were chosen and by Week 4, seemingly having worked through the remaining steps, (*apply*, *analyze*, *evaluate*) construction had begun. Materials were ordered and cut lists were generated from the initial sketches. Several tape-measure/paper sketches outlining what the group believed the design should be were created and modified ending in a simple, somewhat elegant structure (*create*) that seemed to cover most of the requirements. CAD drawings were begun about this time to check construction angles and hole locations. After some discussion regarding the best method to supply power to the catapult (bands, bungees, springs) the initial selection for motive power for the unit was decided to be torsion springs. After some research into the properties of the springs, a local business was convinced to supply a set of springs for trial. This information (size, clearances) were fed into the design and construction continued. By Week 4, several team roles had been filled and a leader-by-acclimation had been found. This person had the most available time to devote to the project and was both leader and the student who wound up doing most of the fabrication and therefore drove most of the design and construction. Initial design calculations indicated a frame of ample size and of a shape that would give enough 'base' for the catapult (it was now a catapult) to operate according to accepted principles. This group did not spend as much time as the last group on design (*analyze*) calculations. The calculations for torsion springs used in this manner were less than clear and after consultation with another resource (another instructor) the project halted. The torsion springs of this size were rated to hold 300 lbs. in balance (overhead door) but when the force was applied over an arm the available force left for throwing dwindled down to almost nothing. Additional hurried research led to changing direction to the final catapult design approach, the design used a bundle of regular sisal rope, twisted to supply the force, for the 'spring' (torsion siege engine) to move the arm and throw the pumpkin. Construction of the unit continued requiring some redesign and the addition of several parts required by the change from torsion springs to a torsion bundle was finished by Week 6, and the arm fabrication was also completed, as seen in Figure 2.



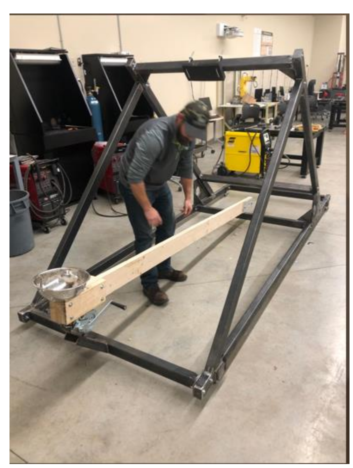


Figure 2. Completed torsion engine design (Version 1).

Complications continued in week 6 and 7, however. Initial testing of the catapult showed a tendency of the rope bundle (spring) to deform the structure of the catapult as the bundle was twisted. Gussets and braces were hurriedly designed and welded in and the modification seemed to be adequate to stop the deformation of the frame. Testing continued and the catapult settled into consistent if uninspiring performance. The catapult was completed during Week 8, in time for the event, and was able to throw test-pumpkins.

During the event, the throwing arm failed. The 'engineered-type' beam that comprised the throwing arm broke, Figure 3, at what would later be seen as an obvious weak spot in the construction. The catapult could not be repaired in place and was returned to the shop.

Figure 3. Showing arm failure at weak point.

Although analysis had gone on at a low level during the design and build stage, it was never a major driver of the design process. This group initially appeared to be following the same smooth progression through the steps of the pyramid when the change from the metal torsion spring to the twisted rope bundle was required. Rearrangement of the order of steps (skipping *analysis* and moving to *create* in order to address problems) seems to have created, or at least aggravated, several opportunities for additional errors and problems to creep in causing the failure of the arm. The aftermath of the failure of the throwing arm was that analysis and repair of the faults in the design became more important and continued to be so for the remainder of the semester.

Analysis conducted during the re-engineering exercise required after the failure showed that the construction of the first throwing arm allowed a dangerous buildup of stress around a guide hole used to secure the center of the rope bundle. Redesign of the parts, shown in Figure 4, guided by analysis showed an increase in the safety factor of the locating feature and surrounding areas with the addition of the aluminum support plates.

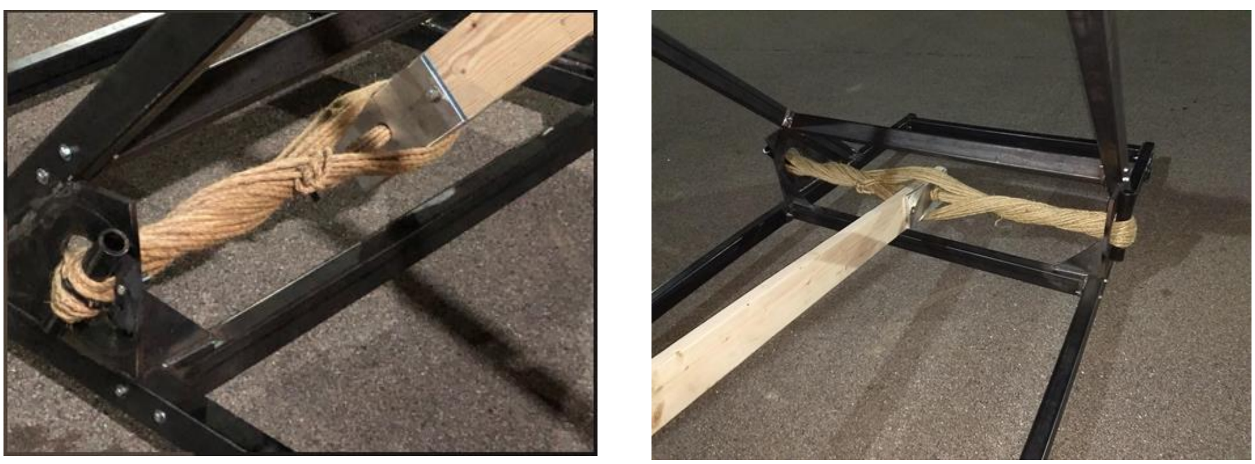


Figure 4. Re-designed catapult arm.

Based on the outstanding results of last year's class, we expected a repeat of the progression through the steps of the design-build process that would again mirror an orderly passage through the steps of Bloom's pyramid, shown by the last team, and that using planning, mechanics, physics, and elements of design would lead to a successful performance by this team. Using the timeline as an indicator group progress (as before) showed a spotty progression through the steps. Week 1 and Week 2 were spent gathering and collating information from several of the group members (*remember*, *understand*) which can be tied to level 1 and 2 of the pyramid. No analysis beyond spring calculations had begun and the team was not yet working together as a group. By Week 4 the group had begun to act as a team (*apply*) and some analysis and preliminary documentation had begun. It appears that the hurried change to the torsion engine model was the turning (breaking) point for the orderly progression through the levels of the pyramid. By Week 5, the design had changed to the torsion engine and some analysis and some amount of re-engineering of structures had begun. The group had moved through all of the levels (*remember*, *understand*, *apply*, *analyze*, *evaluate*, *create*) of the pyramid and were building and solving problems as they arose. At this point, however, the documentation was sketchy, and the analysis that supported it was for the most part, 'experience-based'. Construction continued as more minor design-related problems arose and were solved on an almost ongoing basis. Construction was completed in Week 8 and functional tests were successful.

The catapult catastrophically failed at its debut.

Analysis, though after the fact, showed a concentration of stress in the area around the failure site; a potential problem flag. This weakness discovered in the design was further analyzed and showed that the addition of additional bearing plates would balance and diffuse the stresses in the area and prevent the failure the catapult suffered. Reexamination (*analyze*) of the hurried analysis after the failure showed that the initial design was under-designed in a critical area that likely led to the failure. Redesign led by the new analyses outlined changes that resulted in a catapult that, although it did not reach initial design goals, has performed consistently since the redesign.

The goal of reinforcing the assertion that an upper-level engineering design class is able to design, fabricate, and analyze an ancient throwing device was not supported entirely in this report, indications are that skipping or losing concentration while working through the steps can be indicative of a future bad outcome. While the performance of the device during the event was not acceptable (fail), after returning to the ‘path up the pyramid’ and committing to analysis driven redesign, the final outcome showed that the device did show mixed success and was able to finally perform within most of the prescribed specifications and consistently threw a 5lb. pumpkin 75 ft.

References

[1] S. Dodge, *Mlive.com,* 21 October, 2019

[2] R. L. Rhoton, “Assessment of a Multi-Goal Mechanical Engineering Design/Fabrication Project Used as a Mission-Critical Exercise,” in Proceedings of the 2019 ASEE NCS Conference, Grand Rapids, MI, March 2019.

[3] 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.

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