2008
Winning Lesson Plan from Watertown, Massachusetts

Yo!

by Charles Duggan
Watertown High School

Subject: Rotational Inertia and Rotational Dynamics

Grade Level: 9th Grade Honors Physics, 11-12th Grade Conceptual and Advanced Placement Physics

Duration: The project is given to the students approximately two months in advance with the hope that they will start to build and experiment with a variety of designs.
For the current school year (2007-2008), the project was discussed on November 27, 2007 with completion expected on January 18, 2008.

Overview and Purpose

All too often students are asked to critically analyze experiments with known outcomes in hope that accepted theories are realized and reconfirmed. The Yo! project requires students understand a uniform set of guidelines and apply known physical principles to generate a unique invention that best gives them the chance to compete against peers across a variety learning curves. Students traditionally have problems understanding rotational dynamics and moments of inertia. Past practice has generated minimal interest and understanding of these concepts with most students emerging more confused than before first discussing the subject matter. Yo! effectively attempts to generate interest and lasting comprehension by engaging the students in a competitive effort to “cheat” gravity and make the slowest yo-yo. The basic assumption made by novice students is that mass distribution is independent of angular speed. The usual demonstration of rolling a disk and a hoop of same radii and mass that yields the disk the winner results in exclamations of “there is a trick to the demo”. The slow evolution of the project yields yo-yos that have their mass distributed, many times inadvertently, as far from the rotational axis as the guidelines allow. It is only through visual inspection that many students become aware of what they have created, mimicking accepted theories of rotational inertia. Their natural intuitions coupled with fortitude and continued experimentation yield inventions that ultimately conclude with the “aha” moment typically linked to epiphanic moments of understanding.

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Innovation

The innovation of the project lies in the fact that students have an inherent understanding of how the distribution of mass about an axis of rotation can modify the rate of rotation (angular speed), probably gained from experiences involving spinning objects where mass location can be varied (i.e., kids on merry-go-rounds or ice skaters performing axles), but these same students cannot communicate or justify the scientific basis behind these concepts. Furthermore, students have fundamental misunderstandings concerning the most basic angular quantities or calculations probably due to the limited exposure students receive in their math and science classes.

The Yo! project, along with other projects in the course, builds on student's intuitions and past experiences coupled with accepted scientific theories to fill in the gaps that are historically hard to fill. Students who feel successful and do reasonably well in the school competition many times have the ability to perform their invention in front of a larger audience. Quarterly projects are many times linked to the local science league events understanding that students will have the option to showcase their invention in a larger competition that makes students grapple with issues of performance anxiety as well as the ability of their invention to compete against a larger and stronger group of peers. What ultimately results is that the students realize they are generating ideas that are equal to or better than many of their peers thus reducing their fears and increasing their confidence.

A second and equally important piece to these projects is that they continue over an interval of time which induces an expectation to update and modify the inventions. I believe it is this piece where students really learn what is going on. The students get past the initial construction and experimentation of the project and instead of stopping there, they go back and rethink what is going on mechanically, reflect off of what should be theoretically, and begin to modify with increased awareness and understanding, thus adding another layer of the subject matter to their tool box. After several rounds of this process, students have increased the breadth and depth of understanding a substantial amount.

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Description of Larger Context

Two chapters concerning rotational motion are thoroughly discussed, students work out and practice problems, and guided laboratories are used to illuminate the subject matter. These chapters include the topics:

- angular measures,
- angular speeds in different units,
- relationship between angular speed and tangential velocity,
- centripetal force and acceleration,
- Newton's Universal Law of Gravitation,
- torque,
- angular momentum, and
- moment of inertia.

In the midst of this unit, the Yo! project is given to the students including details concerning constraints and objectives along with scoring rubrics. The students have approximately two months to generate, test, modify, and retest their inventions until they have optimized their project to its maximum potential. Once a project has been discussed, a strict set of guidelines is developed that helps the students understand the limitations concerning size, mass (amount and distribution), calibration, and features their projects are to demonstrate.

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Guidelines: (From Handout to Students)

1. Teams may only consist of one or two people.
2. Yo-yos must be made from scratch. You cannot modify an existing yo-yo.
3. Total mass of the yo-yo must be more than 1.5 kilograms.
4. The yo-yo has a 0.5m x 0.5m x 0.5m size limitation before the yo-yo starts its descent. It may change size when it is in motion. The yo-yo must remain intact at all times.
5. The yo-yo must be made in the image of two masses fixed to an axis that rotates around the axis. Gears or pulleys are not allowed. Balloons are not allowed.
6. Teams must display their name on the yo-yo.
7. The string attached to the descending body must be of minimal length to traverse the length of the course (approx. 6m). Strings cannot be impeded by the use of glues or gels or excessive friction between the string and the yo-yo. String guides are acceptable as long as they induce minimal friction between the string and the guide.
8. Sliding friction between two solid surfaces cannot be used to slow the yo-yo down. Air friction is acceptable.
9. Yo-yos must remain in motion at all times and must either be ascending or descending the string continually.
10. Teams that make their yo-yo whistle in an audible pitch (20 Hz-20 kHz) that is loud enough to be heard by the judges and have a light that emits photons with enough intensity in the visible spectrum (400-700nm) to be seen by the judges will earn extra credit. These can only be artifacts of the rotation of the yo-yo. If the judges do not see or hear your yo-yo perform these tasks, they will be considered not to have happened. Older judges may have reduced sensitivity to pitches on the ends of the audible spectrum and may not hear high and low frequencies very well…if at all. Whistles and lights cannot be "turned on" before the start of the yo-yo.
11. No battery driven motors or other motors accessing stored energy may be used (DQ).
12. Yo-yos must be physically sound to traverse the course and must not cause damage to the school or physical injury to observers.

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Description of Larger Context (Cont'd)

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A discussion between the students and the instructor ensues with a debate concerning possible anomalies and other idiosyncrasies that may develop during the duration of the project leading to modifications made to the guidelines if warranted. A scoring rubric with possible completion time-lines help the students understand the expected outcomes and time constraints of the endeavor. Projects are given out one to two months in advance with continued reminders as deadlines approach. Students are given a day here and there to bring their projects into the class and ask for insight from both students and instructors with tweaking and test runs taking place. Cross-curriculum applications encourage instructors in other departments to play a major part in the development of students projects with the industrial technology teachers supplying input regarding materials, structure, and the application of tools in the generation of the project along with computer animated design (CAD) instructors helping with the projects design; a nice relief to the traditional bird houses and chairs made in these courses. Students are given as many chances as possible to test their projects with their best run serving as their score against the rubric. Repetition of trials gives students insight into areas that need improvement while increasing their awareness of the nature of the physics we are studying.

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Educational Standards Addressed

Massachusetts's standards set forth by the Massachusetts Curriculum Frameworks for Science and Technology/Engineering does not address the topic of rotational dynamics in great detail. The Introductory Physics learning standards for a full first-year course (p. 74), Section 1.7 identifies Newton's Law of Universal Gravitation as a main concept, and Section 1.8 identifies a "conceptual description" of forces involved in circular motion, both of which are included in the rotational dynamics unit in Watertown High School. From the perspective of the science department of this school, it is considered the school's responsibility to teach what is considered an important subject whether or not it is deemed a "content standard" by the Massachusetts Department of Education. It is believed that this may be the only time that students are introduced to the idea of rotational motion unless the students enroll in advanced placement physics that typically is less than 10% of a graduating class.

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The main objective of the project is to build a yo-yo that descends a set distance (approx. 6m) in the most time possible. Objectives embedded in the project include understanding the analysis, both qualitative and quantitative, concerning the dynamics of the yo-yo and hopefully the lasting impression of the project and what it entails. As can be seen from the yo-yo write up, students are expected work within set guidelines to build their yo-yo. This encompasses understanding in strength and integrity of materials, use of power tools, and the ability to turn a schematic design into a real product. Qualitative analysis comes from the one page synopsis that expects students to be reflective of what they have achieved, understand modifications made and their affects on the yo-yo's performance, and how their design used concepts of rotational dynamics to slow the yo-yo's descent.

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Scoring

1. Scores will be awarded from longest times to shortest times in each class. Extra credit will be awarded for whistles (10 pts) and lights (10 pts). The top project will earn 100 points with 3-point deductions for each place. Minimum scores will receive 70 points for visible effort.
2. A one page, 1.5 spaced, 12 point typed synopsis must be submitted by the last day of the project. The synopsis must discuss the basic philosophy of your design, modifications (pro or con) made to improve the yo-yo, and the application of rotational inertia principles to the project. (50 pts)
3. A second page (in same format as #2 above) will include data from all complete runs (in table form; individual times, average time for all runs, range of run times (in the format $t \pm \Delta t$), and a set of calculations for average translational speed (m/s), average angular speed (in rads/s, revs/s, and degrees/s), total number of revolutions made by the yo-yo, average tangential speed (m/s), average centripetal acceleration (m/s^2), and average centripetal force (N). (50pts)

Qualitative analysis derives from calculating actual values for angular speed, tangential velocities, centripetal accelerations and forces, and number of revolutions made by their yo-yo. It is expected that the time invested into the building and performance of the yo-yo will make the analysis more meaningful thus adding to the lasting impression made by the project.

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Materials

There are fixed materials for the project. Students are expected to rummage for parts and build a device that is both economical and productive. Examples from previous years are shown and demonstrated to give students a visual representation of what they are trying to achieve.

Procedures

Students will generate their yo-yo outside the class with a first run several weeks before the final week of runs. During the final week, students will get time before and after school and during class to run their yo-yos. Stipulations regarding good sportsmanship and shared use of launchers are made hoping that students will be patient and understanding of other student's ability to run their yo-yo. Students will set their yo-yo on the launcher and will release when the judges are ready to time the run. Students should note time of runs and problems seen during the run.

Outside Activities

The Yo! project is primarily an outside-the-class activity that includes the building of the yo-yo, modifications, quantitative and qualitative analysis's, and, hopefully, parent-student interaction. The projects basic premise is to supplement work done in the class with a project outside the class that reinforces concepts on a personal level.