SPEEDBOAT CONTEST: APPLYING PHYSICS TO WIN! SPH3U SPH4C

ROBERTA TEVLIN (/USERS/ROBERTA-TEVLIN)

Students work in small groups to design, build, and test a speedboat powered by a hand-made propeller that pushes air. The boats are raced in a 20-foot length of eavestroughing filled with water. A set of guided-inquiry worksheets has the students apply key physics concepts and equations to design their boat before building. Time is provided to test and modify their choices.

Grade Level/Course Code: SPH3U, SPH4C

Strand(s) and Unit(s): SPH3U C: Forces, SPH4C E: Energy Transformations

INQUIRY FOCUS:

- Why do the boats stop accelerating?
- Where does the electrical energy go if the boat's kinetic energy stays constant?
- How can you maximize the forward force (thrust)?
- How can you minimize the backwards forces (drag, friction, surface tension)?
- How do you keep the other forces (gravity, buoyancy) balanced?

TIMELINE:

This contest can be done in a couple of classes but is worth allocating five. The more time that you provide, the more inquiry-based it can be. Students should already be familiar with electrical energy ($E = V I t$), kinetic energy ($E = ½ mv^2$), density ($d = m/V$), and Newton's second law ($F = ma$).

BIG IDEAS:

Engineering a good product starts with a thorough understanding of the physics concepts and equations involved, applying these in the design and construction of the product, and ending with cycles of testing and modification.

OVERALL EXPECTATIONS:

SPH 3U/4C:A1 demonstrate scientific investigation skills (related to both inquiry and research) in the four areas of skills (initiating and planning, performing and recording, analysing and interpreting, and communicating)

SPH 3U: C2 investigate in qualitative and quantitative terms, net force, acceleration, and mass, and solve related problems

SPH 4C: E3 demonstrate an understanding of diverse forms of energy, energy transformations, and efficiency.

SPECIFIC EXPECTATIONS:

SPH 3U and SPH 4C

A1.1 formulate relevant scientific questions about observed relationships, ideas, problems, or issues, make informed predictions, and/or formulate educated hypotheses to focus inquiry or research

A1.5 conduct inquiries controlling relevant variables, adapting or extending procedures as required, and using appropriate materials and equipment safely, accurately, and effectively. To collect observations and data

A1.11 communicate ideas, plans, procedures, results and conclusions orally, in writing, and/or electronic presentations using appropriate language and a variety of formats

SPH 3U

C2.1 use appropriate terminology related to forces, including but not limited to: mass, time, speed, velocity, acceleration, friction, gravity, normal force, and free-body diagrams

C2.3 conduct an inquiry into the relationship between the acceleration of an object and its net force and mass

C2.5 plan and conduct an inquiry to analyse the effect of forces acting on objects in one dimension using vector diagrams, free-body diagrams, and Newton's Laws

SPH 4C

E3.1 describe and compare various types of energy and energy transformations

E3.2 explain the energy transformation in a system

KEY CONCEPTS:

Conservation of energy, net force, terminal velocity

PRIOR SKILL SETS:

- drawing free-body diagrams
- manipulating equations
- controlling variables in an experiment
- grade 9 electricity unit

PRIOR KNOWLEDGE:

- density = mass/volume
- force = mass x acceleration
- electrical energy input = potential difference x current x time
- kinetic energy = ½ mass x speed squared
- energy is conserved
- buoyant force

MATERIALS AND EQUIPMENT:

Each student needs a multiple-choice booklet and each group needs a whiteboard, markers, and erasers for the knowledge-building classes.

Each group needs to be provided with a 15 cm by 40 cm piece of insulating Styrofoam (http://www.homedepot.ca/product/durofoam-eps-rigid-insulation-96inch-x-48inch-x-3-4inch/940437), a selection of small DC hobby motors, ½" lengths of ½ " diameter wooden dowelling, several tongue depressors and Popsicle sticks, two alligator clips, several 9-V batteries, sand paper, and a skill knife.

The groups need access to hair dryers or hot air guns to dry the propellers, boiling water, glue guns, a voltmeter, and a hammer.

The competition requires a water-filled race track made of two 10-foot lengths of eavestroughing (http://http://www.homedepot.ca/product/vinyl-gutter-white/975700) joined together and sealed at the ends.

SAFETY:

The tips of the glue guns get very hot and should never be touched.

The skill knives should have their blades retracted when not in use. When cutting with the skill knives, the object should be held on a firm surface and the blade should never be directed toward any body parts.

INSTRUCTIONAL PLANNING AND DELIVERY:

This contest should come after completing the units on kinematics and dynamics, and probably after the units on electricity and energy. It could make an exciting culminating project before reviewing for the final exam.

This activity has three knowledge-building lessons, two days of open inquiry, and an optional sixth day for consolidation.

- The first lesson looks at the electrical energy input, and kinetic and other energy outputs. Students consider the effects of different battery and motor choices on their boat's speed.
- The second lesson looks at why the boat does not keep accelerating and examines how the force of drag can be reduced. Students use these ideas to calculate some critical dimensions of their boat.
- The third lesson has students look at propellers, balance, and then has them design their hull using everything that they have learnt.
- After these three classes, the students have a couple of open inquiry classes to build, test, and modify their designs.
- Finally, a sixth class has students do review questions and a self-evaluation sheet to consolidate what was learnt in the five classes.

The students need to be divided into groups of two to four students. One way to form groups is to ask the students to write the names of five students that they think would be good leaders. Point out that good leaders are not necessarily the students with the highest marks or the most friends. They are people who work well with others. They encourage the quiet students and are able to gently restrain the outspoken ones. Collect names; the students with the most votes will be the leaders. Send the leaders out of the class to divide up the rest of the students. While they are doing this, you can go over the contest rules. The students who are in class have the responsibility to pass this information on to the leaders. (See student resource 0.)

The first three classes are knowledge-building lessons but they still have an inquiry approach. Each class is structured around a separate guided-inquiry worksheet. (See student resources 1, 2, and 3.) The worksheets provide a framework of questions to get students thinking about the physics of the contest. The worksheet is scaffolded to prompt students to remember what they already know, have them learn some new concepts, and then apply their knowledge to the contest. The worksheets require the students to deepen their understanding by comparing alternatives, manipulating objects, explaining their ideas to each other, and communicating their understanding using diagrams, equations, and words.

The teams work on the questions together but each individual student is responsible for the completion of their own worksheet. The teacher's job is to circulate and observe the groups' progress and, at appropriate times, help groups that are struggling, and bring the class together to consolidate the key ideas. The teacher should provide enough guidance that all of the boats will be able to work, but student input will result in some boats working much better than others. A 12C or an 11U class will probably need more direction than a 12U class and the worksheets could be modified to provide more direct instruction. The answers in the submitted worksheets should fulfil the four C's of good communication. They should be correct, complete, concise, and clear. The answers should include words, diagrams, and equations as are appropriate.

The three knowledge-building classes are followed by two open-inquiry classes. The construction of the boats should be completed during the first open-inquiry class so that testing and modification can take place during the second. The competition results are determined during this second class, by keeping track of the best three times for each group. Every group should be able to finish the race in less than fifteen seconds and the winning boats may take less than four.

For the sixth class, students should sit in small groups that do not contain members of their speedboat team. They will reflect individually on their team work. (See student resource 4.) They will work in their new groups on the review questions. (See student resource 5.)

Student Support Resources

0. Speedboat Rules
1. Speedboat Energy
2. Speedboat Forces
3. Speedboat Design
4. Speedboat Self-Assessment
5. Speedboat Review
6. Multiple Choice Letters

Note: Each of these resources comes with a student version ready for photocopying and a teacher version with embedded answers and extra tips.

RELATED BACKGROUND RESOURCES AND/OR LINKS:

This lesson was inspired by an excellent article in the Physics Teacher. You might want to read the article and visit the author's website to see how else the project can be run. The contest rules have been modified quite a bit. They have been made more restrictive, so that the most successful boats will be a result of careful experimenting and skilful application of physics, and not due to purchasing better materials or being lucky. Furthermore, the students must do the work in class and not at home. This ensures that the competition does not favour students with extra help and equipment at home.

The worksheets that were provided in the original resource were unsatisfactory for two reasons. Firstly, they were too prescriptive. The new worksheets have the students construct their understanding by answering a series of questions rather than following instructions. Secondly, the provided worksheets were focussed on F = ma, which is strange because the boats only accelerate for a fraction of a second and then they travel at constant velocity. The new worksheets look at energy exchanges and modifying the forces acting on the boat, aspects that are more relevant to designing a fast boat.

Barry, Reno (2008). Electric motorboat Drag Racing: A hands-on physics project that motivates students from start to finish. *The Physics Teacher, 46, 267-268* http://electricboatproject.com/TPT_Electric_Motorboat_Drag_Racing_May_2008.pdf (http://electricboatproject.com/TPT_Electric_Motorboat_Drag_Racing_May_2008.pdf) http://electricboatproject.com/ (http://electricboatproject.com/)

If you are interested in incorporating more contests in your classes or would like to introduce an interdisciplinary course that is entirely made up of contests like this, you should visit http://www.tevlin.ca/roberta/Engineering%20Contests/Engineering%20Contests.htm (http://www.tevlin.ca/roberta/Engineering%20Contests/Engineering%20Contests.htm) and/or contact Roberta.Tevlin@tdsb.on.ca (mailto:Roberta.Tevlin@tdsb.on.ca) .

ASSESSMENT OPPORTUNITIES:

The guided-discovery worksheets used in the three knowledge-building lessons use two key tools for assessment as learning and for learning: multiple-choice booklets and whiteboards.

The **multiple-choice questions** are designed to stimulate focussed discussions. To be most effective, you should first give the individual student a chance to read and answer the question on their own. Then have them show you their answers using small booklets with a large letter on each page. (See student resource 6.) Their responses determine what happens next. If very few students have the right answer, you should provide some clarification or guiding prompt and then have them reconsider their answers and vote again. If almost everyone has the right answer, then little time should be spent on this question. You might select a student or two to explain why the right answer is correct. These questions are most useful when a half to two-thirds of the class have the right answer. At this point, you can ask them to show their letters to their neighbours and discuss the question with someone who has a different answer. Emphasize that they need to be able to say why an option is wrong, or right but irrelevant, or right but incomplete or the best correct answer. After the discussion, provide time for students to write their explanations on the worksheet.

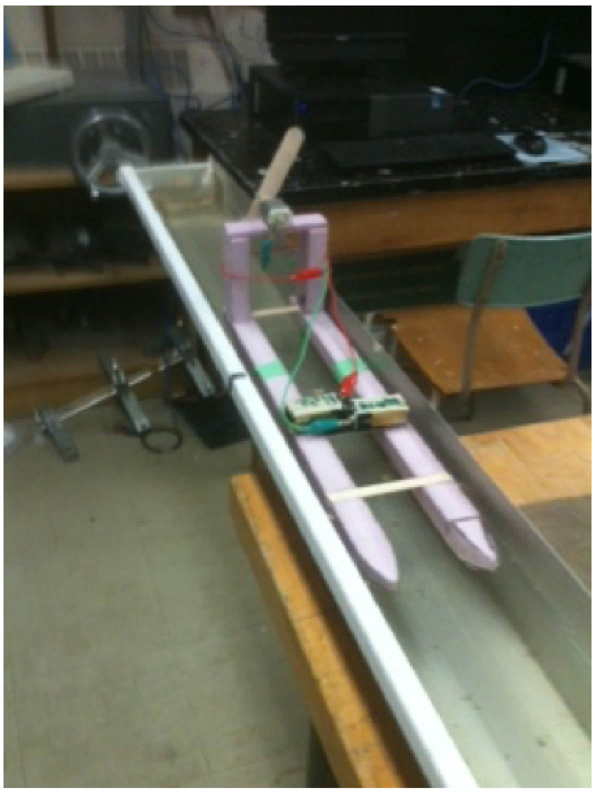
Other questions make use of **whiteboards**. The work on the whiteboard shows that the students are on task, it shows what they think, and how well they can communicate their understanding. During this time, the teacher should circulate and prompt groups for clearer diagrams, more details in the answers, etc. They should not get drawn into lengthy discussions.

Assessment of learning during the three knowledge-building classes comes from the three worksheets. These should be collected after each class and marked and returned for the next class. Any significant misunderstanding of key decisions - among individuals or groups - can be addressed during the following class. These sheets are marked for completeness and the quality of the communication. Students need not make all the 'right' decisions, but they should make reasonable choices and justify them.

Assessment of learning during the two open-inquiry classes comes from the self and peer assessment sheets combined with the teacher's observations. A contest mark is shared by the group based on how well they do in the contest. The winners get 11/10 and every boat that is able to move gets at least 6/10. Further optional individual assessment can come from the review sheets or a test that follows the review sheets.

FUTURE OPPORTUNITIES / EXTENSIONS:

The competition is really fun to watch and can be showcased at lunch, during grade 8 tours, or during a Science Fair night. It also can form the basis of a one-day science challenge for visiting grade 7 students. I have run a girls-only version of this that has increased the proportion of girls in our special Math Science and Technology (MaST) program from 18% to 50%.



Above is an example of a very good boat, but not necessarily the best. It could cover the distance in four seconds. It was four times faster than the slowest boat.

- It has two narrow hulls that are widely separated. This provides good side-to-side balance but minimal Styrofoam mass.
- The motor support and the material holding the two hulls together have been kept very light.
- It has a very long hull which reduces drag, mostly by minimizing the cross-sectional area.
- The batteries are placed to balance side to side and front to back.
- The motor is placed just high enough that it can be balanced, but not hit the water or the sides of the trough.
- The propeller is a single tongue depressor with a large twist.
- It uses two 9-V batteries which is usually better than one and may be better than carrying the extra mass of three.

- The hulls are symmetric and smooth.
- The wires are taped down so they don’t rub on the trough walls.

WATCH THE VIDEO

00:39 min

(//www.youtube.com/embed/1y9XR0wZyRw?width=800&height=450&iframe=true)

RESOURCES

- Electric motorboat Drag Racing (http://electricboatproject.com/TPT_Electric_Motorboat_Drag_Racing_May_2008.pdf)
- 0 speedboat rules teacher final edit.docx (https://connex.stao.ca/sites/default/files/0_speedboat_rules_teacher_final_edit.docx)
- 1 speedboat energy student final edit.docx (https://connex.stao.ca/sites/default/files/1_speedboat_energy_student_final_edit.docx)
- 1 speedboat energyteacher final edit.docx (https://connex.stao.ca/sites/default/files/1_speedboat_energyteacher_final_edit.docx)
- 2 speedboat forces teacher final edit.docx (https://connex.stao.ca/sites/default/files/2_speedboat_forces_teacher_final_edit.docx)
- 2 speedboat forces student final edit.docx (https://connex.stao.ca/sites/default/files/2_speedboat_forces_student_final_edit.docx)
- 3 speedboat design student final edit.docx (https://connex.stao.ca/sites/default/files/3_speedboat_design_student_final_edit.docx)
- 3 speedboat design teacher final edit.docx (https://connex.stao.ca/sites/default/files/3_speedboat_design_teacher_final_edit.docx)
- 4 speedboat self assessment student final edit.docx (https://connex.stao.ca/sites/default/files/4_speedboat_self-assessment_student_final_edit.docx)
- 4 speedboat self assessment teacher final edit.docx (https://connex.stao.ca/sites/default/files/4_speedboat_self-assessment_teacher_final_edit.docx)
- 5 speedboat review student final edit.docx (https://connex.stao.ca/sites/default/files/5_speedboat_review_student_final_edit.docx)
- 5 speedboat review teacher final edit.docx (https://connex.stao.ca/sites/default/files/5_speedboat_review_teacher_final_edit.docx)
- 6 mc letters rv2 3.doc (https://connex.stao.ca/sites/default/files/6_mc_letters_rv2_3.doc)
- speedboat contest stao irdp final version.docx (https://connex.stao.ca/sites/default/files/speedboat_contest_stao_irdp_final_version.docx)

ELEMENT

- Inquiry (/expert-elements/inquiry)

(/classroom-catalysts) RETURN TO CATALYSTS (/classroom-catalysts)

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INSTAGRAM (https://instagram.com/staoapso/)