State of Iowa Physics Competition
OFFICIAL 2018-19 RULES
FOR REGIONAL (AEA) AND STATE COMPETITIONS

Rules/Advisory Committee

Peggy Christensen, Heartland AEA
Larry Escalada, University of Northern Iowa
Chris Like, Bettendorf CSD
Jeff Morgan, University of Northern Iowa
Meghan Lang, Cedar Falls High School
Marcy Seavey, University of Northern Iowa

Scott Greenhalgh, University of Northern Iowa
Jason Martin-Hiner, Keystone AEA
Tami Plein, Great Prairie AEA
Amanda Sanderman, Central Rivers AEA
Tom Stierman, Loras College

Table of Contents

Overview 2
Contact Information 2
Regional AEA Definitions and Clarifications 2
State Competition Definitions and Clarifications 3

Device Rules - All Competitions 3

Scoring - All Competitions 4

Schedule, Costs, and Information 5

Events 6

CATAPULT 6

MOUSETRAP CAR 7

BRIDGE BUILDING 8

SODA STRAW ARM 9

CHALLENGE PROBLEM 11

CHALLENGE PROBLEM WORKSHEET 13

Work Done Scoring Rubric (Judges use only) Error! Bookmark not defined.

CHALLENGE PROBLEM WORKSHEET - GOOD SAMPLE Error! Bookmark not defined.

CHALLENGE PROBLEM WORKSHEET - POOR SAMPLE Error! Bookmark not defined.

Judge and Event Director Checklists 30

CATAPULT Checklist 30
MOUSETRAP CAR Checklist 31
BRIDGE BUILDING Checklist 32
SODA STRAW ARM Checklist 33

CHALLENGE PROBLEM Checklist 34
Overview
The Physics Competition is a series of 5 competitive physics events for high school (Grades 9-12) students. The competition stresses creativity and ingenuity as well as an understanding of physics related principles and is intended to stimulate interest in Science, Technology, Engineering, and Mathematics (STEM). The competition emphasizes the scientific and engineering practices found in the Next Generation Science Standards (NGSS) and participation in the competition integrated with appropriate instruction can address the Iowa Core.

Each participating school shall form one or more school teams who will organize themselves into event teams and compete at a Regional Area Education Agency (AEA) Physics Competition. Regional AEA Physics Competition winners and runners-up advance to the State of Iowa Physics Competition.

The events include:
1. Catapult
2. Mousetrap Car
3. Bridge Building
4. Soda Straw Arm
5. Challenge Problem

Contact Information
Regional AEA Physics Competition
Contact your AEA representative for information about the competition in your region. Questions related to the UNI/Central Rivers AEA Regional Competition should be directed to Larry Escalada (319-273-2431 or Lawrence.Escalada@uni.edu).

State of Iowa Physics Competition
Questions related to the State of Iowa Physics Competition should be directed to Larry Escalada (319-273-2431 or Lawrence.Escalada@uni.edu).

Regional AEA Definitions and Clarifications
1. An individual school is defined as a building within a school district. If a school district has multiple high schools, each building is considered a separate individual high school.
2. A school team is defined as one consisting of 2 students for each event entered and whose event scores count towards the school team’s total score. The school team does not have to enter all events but a score of 0 will be entered in the team score for events in which 2 students fail to compete. A school team may consist of a maximum of 10 students. Each school team may enter only one device in each event. An individual student may be a member of only one school team.
3. An event team is defined as one consisting of 2 students whose scores do not count towards the school team total score. An event team must consist of two students. Each event team may enter only one device in each event. Students in an event team may compete in only 2 events.
4. An individual school may enter multiple teams. It will be up to the individual AEA competition organizer(s) to determine how many teams from a school may compete at the regional competition. Only one school team from any school may advance to the state competition.
5. All students, competing and observing, must be accompanied by a school representative.
**State Competition Definitions and Clarifications**

1. The definitions of individual school, school team, and event team provided previously apply to state competition.
2. The qualifying school teams finishing first and second at each regional competition advance to the state competition. An individual school invited to send a school team to the state competition may enter a maximum of 10 students for the 5 events.
3. The qualifying event team finishing first and/or second for any event who is NOT part of a school team qualifying for the state competition also advances to the state competition.
4. All students, competing and observing, must be accompanied by a school representative.
5. If there is no regional competition in an AEA region, two schools per AEA region may compete at the State Competition with a maximum of one school team or 5 event teams per school. If there is no regional competition, the AEA consultant should be contacted to let him/her know that a school is interested in participating in the State Competition. The school should also contact a neighboring AEA to determine if it is possible to compete in their regional competition in order to qualify. Teachers, in communication with their AEA consultant, may organize and facilitate a regional competition to determine the teams who will represent their area at the state competition. The AEA consultant should notify Larry Escalada of these plans.

**Device Rules - All Competitions**

1. Each team (school or event) will enter ONLY ONE DEVICE in each event.
2. If a device qualifies for a state event and one or both of the students responsible is or are not able to come for any reason, the device may still be entered in competition by alternative student(s) at the discretion of their teacher.
3. All catapults, cars, and bridges must be labeled with the names of the competing student(s) and school.
4. Unless otherwise stated in the event rules, only that event’s team members may manipulate the team’s device during the event.
5. Accommodations will be allowed for participants with disabilities where a 3rd person will be allowed to move the device for that participant under the direction of the participant, if necessary. It is the responsibility of the coach or participant to inform the judges of accommodations ahead of time.
6. Each teacher will sign a compliance form certifying that their students constructed their own devices from scratch for the current year of competition, with only materials as specified in these rules, and without the use of a commercial kit. It is the responsibility of the sponsoring teacher to assure student compliance with all of the applicable rules as well as appropriate moral and ethical behavior.
Scoring - All Competitions

Each event is scored separately with the top three places being declared for each event. **The overall school team score will be the sum of the 5 event scores with the highest scoring school team being declared the Physics Competition Grand Champion.**

**Individual Event Scoring**

1. A single team is awarded a maximum of 10 points for each event.
2. All teams that enter and compete in an event without being disqualified will score a minimum of 1 point.
3. If fewer than 10 competing teams, points will be awarded only for those places. If more than 10 teams compete, those in 10th place and lower each receive 1 point.
4. In the event of a tie, the teams will share points from the 2 places. For example, tie for 2nd place, split 2nd and 3rd place with no 3rd place points awarded.
5. Teams that enter a device in an event but receive a default, will have their place points divided equally between all the defaulting teams for that event.
6. Teams that register for an event but do not enter a device, will receive zero points for that event. Each event is scored separately with a winner and runner-up being declared.
7. The overall school team score will be the sum of the event team scores. The school team with the highest sum of the 5 events scores will be declared the Physics Competition Grand Champion.

<table>
<thead>
<tr>
<th>Placement</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
<th>5th</th>
<th>6th</th>
<th>7th</th>
<th>8th</th>
<th>9th</th>
<th>10th</th>
</tr>
</thead>
<tbody>
<tr>
<td>Points Awarded</td>
<td>10 pts</td>
<td>9 pts</td>
<td>8 pts</td>
<td>7 pts</td>
<td>6 pts</td>
<td>5 pts</td>
<td>4 pts</td>
<td>3 pts</td>
<td>2 pts</td>
<td>1 pt</td>
</tr>
</tbody>
</table>

**Rulings and Appeal**

In the case of any clarification or contention of an event or another team’s entry, within one minute of being informed of the judges’ decision or the completion of the other entry’s trials respectively, a student team member may appeal to the event judges without outside influence or input (i.e. coaches, parents, other students, etc.). Any device ruled by the judges that does not comply with the rules will be given a time interval (determined by the judges) to be modified to comply. The resolution is up to the judges. The event judges may confer with head judges and/or competition director if necessary. **The decision of the judges is final.**

**Awards**

Medals will be provided for the top 3 places in each individual event and trophies will be provided for the Grand Champion School Team, First Runner-Up School Team, and Second Runner Up School Team for the state competition. **Awards will be determined by each regional competition.**
Schedule, Costs, and Information

AEA Regional Competition
Contact your AEA consultant for information about schedule, costs, and information for the competition in your region. The UNI/Central Rivers Regional Competition will be held on Tuesday, March 26, 2019 at the UNI McLeod Center. Information about the UNI/Central Rivers Regional Competition may be found at http://www.physics.uni.edu/outreach/uni-phys-olympics. For questions related to the UNI/Central Rivers Regional Competition, call 319-273-2431 or email Larry Escalada at Lawrence.Escalada@uni.edu.

State Physics Competition
The State Physics Competition will be held on Tuesday, April 9, 2019 at the UNI McLeod Center. Information about the state competition may be found www.physics.uni.edu/outreach/uni-phys-olympics. For questions related to the State Competition, call 319-273-2431 or email Larry Escalada at Lawrence.Escalada@uni.edu.

Teams that enter 2 events or less with their completed registrations received by Friday, April 5th, 2019 pay $20. Completed registrations received after April 5th up to Tuesday, April 9th, 2019 pay $30. Teams that enter 3 or more events with their completed registrations received by Friday, April 5th pay $40. Completed registrations received after April 5th up to Tuesday, April 9th pay $50.

All payments for the State Physics Competition should be sent directly to the UNI Physics Department. Checks and P.O.’s will be accepted. P.O.’s can be sent to Becky Adams via email at: becky.adams@uni.edu or you can fax (319-273-7136), or mail the P.O. to Becky at: 215 Begeman Hall, Department of Physics, University of Northern Iowa, Cedar Falls, IA 50614-0150. Please use the same address for payment by check. For questions related to payment, contact Becky Adams via phone (319-273-2420) or email provided above.
Events

CATAPULT

1. CATAPULT. Each team will submit one stationary "Catapult," built by both members to launch a ping-pong or table tennis ball from a starting line to 3 given targets. The device shall NOT exceed the following dimensions: **50 cm** in length, **40 cm** in width, and **60 cm** in height. Teams may place their devices in either cocked or uncocked position prior to the judges’ measurements of the device’s dimensions. Cocked position is defined as when the device is in “ready to fire” position. The energy sources shall consist of any elastic storage device (rubber bands, bungee cords, leaf springs, etc.) and/or gravity-powered device. No other mechanical or chemical device may provide energy the propulsion of the ball. The judges will provide the ping-pong balls. Once the catapults are found to be in compliance with the construction parameters, the students may not handle their catapults until they compete. **The students may activate the catapult by releasing a tripping mechanism or releasing the propelling device manually.**

The Competition - The official competition ping-pong ball will be a 40mm table tennis ball. Teams will use ping-pong balls supplied by the judges. Each device will be placed behind a starting line. After being given the ping-pong ball to be placed on their device, teams have 1 minute to launch the ping-pong ball.

1. A target will be marked on the floor **2 meters** from the starting line. The distance measured radially from the center of the target to the point where the ball first contacts the floor, will be the launch distance. Each team gets one trial at this distance.
2. Another target will be marked on the floor **4 meters** from the starting line. The distance measured radially from the center of the target to the point where the ball first contacts the floor, will be the launch distance. Each team gets one trial at this distance.
3. A target will be marked on the floor **8 meters** from the starting line. The distance measured radially from the center of the target to the point where the ball first contacts the floor, will be the launch distance. Each team gets one trial at this distance.

The distances will vary from year-to-year with at least two of the distances changing.

Once the competing student places the catapult behind the starting line, he/she will have a maximum of one minute to launch the ping-pong ball. Exceeding the 1-minute time frame will result in a default score of 2 meters. No student may enter the competition zone once the ping-pong ball has been given to the team. Students who want to line up their device before launching the ball must do so within the 1 minute time limit and before being given the ping-pong ball.

Each device entered will be allowed one trial at each distance (with an exception explained below). Scores will be based on the total of the three trials. The team with the smallest total launch distance will be declared the winner. Each default or failure to launch will be assigned a distance of **2 meters**. Any otherwise legal trial that lands beyond the default distance will be assigned the default distance of **2 meters**.

Each team will be permitted one and only one additional trial. This is intended to permit one “redo”of a trial that fails to launch or lands outside the 2 meter zone. The additional trial must be selected immediately after the poor trial or may be saved until the trial at another distance. If a team completes three successful trials, they may take their extra trial at the last distance with the hope of improving that trial. A team that selects to use their extra trial at the first or the second distance cannot attempt another extra trial at any other distance. Once a default score is recorded for any trial, there is no reason for a team to save their extra trial for a later attempt unless they are confident that they can have greater success at another distance. After the extra trial is attempted, the better of the two trials at that distance will be recorded as the score for that distance.

**The target distance and/or other parameters may change each year.**
MOUSETRAP CAR

2. MOUSETRAP CAR. Each team will enter one mousetrap-powered car, built by both team members. The car shall not include any parts from a commercial mouse trap car kit.

Design Requirements:

a. Dimensions: **25 cm in length x 15 cm in width x 15 cm in height.** Teams may place their devices in either cocked or uncocked position prior to the judges’ measurements of device dimensions. Cocked position is defined as when the device is in “ready to fire” position. Teams must clearly mark their designated front edge of the car and inform the judges of their front edge before any measurements are made by the judges. Once identified with a permanent marker, this point may not be changed.

b. The car shall have a minimum of two (2) wheels in contact with the testing surface at all times. **If any portion of the device (other than a string) makes contact with testing surface during the trial, the device scored as a default of 600 cm.** String may touch the surface at any given time without disqualification.

c. **Surfaces at different competition sites and at the location where you design and test your device may be different. It is recommended that your device be adaptable to the type of surface used.**

d. The sole power source of the car shall be a mousetrap (about 2” x 4”) as a part of the car. Rat traps may NOT be used.

e. No string, wire, materials, or system may be used to link the device to another object during the trials.

f. In the cocked position the only part of the car that may touch the trap is the frame and the string.

g. Cars must be self-starting - no pushing for starts.

Competition Field

a. The car must travel within a **200 cm wide lane.** The lane will also extend 50 cm before the start line to form a start zone. The front edge of the car must start within the designated start zone defined by the interior edge of the line.

   i. Please note: The surface of the lane may vary from year-to-year. It is recommended that the cars be adaptable to the type of surface used.

b. The target line will be **600 cm** from the launch line. **The students will clearly mark the front edge of their car that will act as the point from which the measurement(s) will be taken.** The car may pass over the 600 cm target line with their designated front edge to be measured from this line.

c. Any attempt in which the car breaks the plane of either side boundary width line will be declared a fault and will be assigned the default distance of **600 cm.**

The Competition -

a. The car will be allowed **two trials** to determine the best distance.

b. The car may be launched from any point within the start zone.

c. Once the competitor steps behind the line, **there will be a maximum of two minutes to launch.** Exceeding the 2-minute time frame will result in a default for that trial and will be scored as a default of **600 cm.**

d. No false starts will be allowed. Cars must be self-starting - no pushing for starts.

e. The distance travelled will be measured perpendicularly from the target line to the point on the front edge of the car that was designated by students prior to measurements being made.

f. The shortest perpendicular distance from the front edge as determined by the students to the target line determines the car with the best score.

g. A car stopping point can be on either side of the target line.

h. In the case of a tie, the results of the other trial score will break the tie. Next best scores will determine runners-up.

The target distance and/or other parameters will change each year.
3. BRIDGE BUILDING. Each team will submit one toothpick bridge for testing, built by both team members.

Design Requirements
a. The bridge will be constructed from Diamond or Forster flat, round, or square wooden toothpicks approximately 6.5 cm in length from a box labeled accordingly: Flat, Round, or Square Toothpicks; and Elmer's™ white glue may be used. **NO other glue may be used. Any off-white color for dried glue found on the bridge will result in a disqualification.**

b. The bridge resting on a table should be constructed in such a way to provide clearance on its underside for a 5 cm x 5 cm x 30 cm board to pass under the bridge between its two supports as the board moves along table top with its 30 cm length parallel to the length of the bridge. See the illustration on the right to visualize the clearance that must be provided. The illustration, however, does NOT show a roadway that is within the required specifications for this event.

c. The roadway of the bridge between the two supports, which is the location of the bridge on which the load will be tested (may or may not be the top of the bridge), shall be a minimum of 4 cm wide along the maximum length of the bridge and at a height from the tabletop of not more than 10 cm.

d. The roadway (see definition in part c) shall consist of at least a rail along each side, which is continuous along the maximum length of the bridge. It need not have a travelable surface.

e. As a measure of how level or how flat the roadway is, a 1.9 cm (tall) x 3.5 cm (wide) x 50 cm (long) board is laid along the roadway. There cannot be more than a 1.0-cm vertical gap between the board and roadway on either end.

f. The bridge shall allow for a test rod - a wooden block with the dimensions of 2 cm (tall) x 4 cm (wide) x 15 cm (long) to be placed perpendicularly across the bridge on the roadway and within 3 cm of the center of the 30 cm span roadway. During the competition, student teams can easily remove toothpicks from their bridge for this to be done, they may do so at the discretion of the judges. Teams may or may not be allowed to remove significant sections of their bridge and re-glue any of their components depending on the discretion of the judges.

g. The maximum bridge height shall be 20 cm from the lowest to the highest points of the bridge.

h. The bridge must be "free standing".

The Competition - The bridges will be tested as follows:

a. The bridge shall be placed on a testing stand, by the student(s), which will consist of two flat level surfaces level with respect to each other and separated by approximately 25 cm.

b. The testing apparatus will be placed over the bridge, by the student(s), with the test rod placed on the roadway as specified above. (Maximum bridge height is 20 cm.)

c. The students will indicate at what point to “zero” or pre-load the scale. **Students will make this call, NOT the judges.** No deflection or force prior to this point will be counted towards the final measurement.

d. Force will continue to be applied slowly by the student via the lever to the test rod (by twisting the turnbuckle) while one scorer continuously calls the scale reading until the tester detects a deflection of 0.5 cm. The scale reading last called is the measured force applied or bridge strength.

e. The team with the **largest ratio of measured force applied divided by the mass of the bridge** will be declared the winner.

The testing apparatus pictured to the right shows what will be used at the state competitions. Other devices, including the use of bathroom scales instead of force plates, may be used.
SODA STRAW ARM

4. SODA STRAW ARM - each team will be given 12 jumbo plastic, clear straws, and 10 straight pins. The straws used in the competition will be 7¾” or 10” straws. **Straws will be provided for the actual competition only. No straws will be provided for event preparation.**

The purpose of the competition is, with only the above materials, to construct the longest arm, from their own team design, that will support a 50-gram mass hanging from a 30cm string and attached to a #1 smooth paper clip bent into an “S” shape. The mass must be hung by the paperclip (i.e. - it cannot be tied by the string directly to the arm) and the students cannot bend the paperclip to “wind” it around the straw. It may not be used in any way to strengthen or help construct the arm. Construction time will be **15 minutes** with testing by the team allowed during the construction.

a. **Prior to the competition, students are required to bring and show the judges a sketch of their design which shall guide their construction.** No physical models will be allowed at the competition. If no sketch is provided, this will result in a disqualification.

b. Straws, pins and the mass will be provided at the competition. The mass will be attached to a string (approximately 30-cm from the paperclip to the top of the mass). Scissors, pliers, chemical splash goggles, protective (not rubber/plastic) gloves, and wire cutters will be allowed as tools but they will NOT be provided. These tools and the sketch are the only items the team may bring to the table.

c. **If students wish to cut pins, they must bring and wear chemical splash goggles and gloves and move to the “pin cutting station” to complete this process. Goggles, protective gloves (not rubber or plastic), and wire cutters will NOT be provided.** Students will not be allowed to cut pins without wearing goggles and protective gloves.

d. All construction must be done during one **15-minute** time period at the competition site. If pins bend or break during construction, they will not be replaced. At the end of the **15-minute** period all work on the arms must end. Competitors will be asked to leave their arm on their table and step away from the tables. The team members will pick up the arm only when they are called to compete. **No modifications are allowed after the 15-minute construction period.** This prohibition includes replacing straws or pins, which have pulled loose from the arm.

e. The arm apparatus must be in contact with (not secured to) the top surface only of the table.

f. The arm must support the mass **above the floor** for 10 seconds without any straws "crimping". Crimping is a fold line across the straw and will be allowed in the original construction before testing. Crimping will be treated the same as a weight hitting the floor and the team will receive a default score.

g. A team member is responsible for holding the straw arm and sliding it out from the edge of the table to the desired position. This person may not touch any part of the apparatus that extends beyond the table once timing has begun. Once the straw arm is in the selected position and tension has been supplied by the 50-gram mass, the 10-second period begins, and all manipulation of the arm by the holder must stop.

h. The distance will be measured along a horizontal line perpendicular to the table edge from the point directly above the point of attachment of the weight. The distance to be recorded will be the distance at the end of the 10-second time period.

i. If the arm design is such that the arm end is higher than the tabletop, the 30 cm string must extend below the top of the table so the judge can accurately measure the length using a meter stick at table-top height.

The **Competition** - One of the team members will hold the arm in the desired test position against the tabletop with no part of the team member's body extending beyond the test edge of the table and with both palms touching the tabletop (hands flat against the table top). No other part of the body may touch the arm or be attached to it. No part of the straw arm may be pinched between two parts of the hand (i.e. the role of this person is to hold the straw arm **down onto the**
table, not strengthen the structure of the straw arm). The other team member will attach the mass by placing the loop of the string attached to the 50-gram mass over the hook end of the paper clip. As soon as the team member hooks the string and immediately removes his/her hand from the string, the 10-second period will begin. This team member may not touch the arm, string, or mass during the 10 second time period. During this time the holding team member may not manipulate the arm. At the end of the 10-second time period, the judge will measure the length (from table edge to string). Each team whose arm successfully holds the 50-gram mass for ten seconds will be immediately given a second trial. No changes may be made to the arm except for desired repositioning on the tabletop. The winner is the team with the arm having the longest recorded distance, which held the mass successfully for 10 seconds.
5. CHALLENGE PROBLEM

Directions for students
1. Students should come to the event with their understanding of physics. Each team should consist of two students.
2. Each team will have a separate set-up on a bench to work with. Benches may or may not be separated with partitions, but should be sufficiently separated so that teams cannot easily follow each other’s work.
3. There will be a minimum of one judge for every two participating teams.
4. Each station will consist of physics laboratory equipment. (Some equipment may not be available at each bench, but rather be communally available from the judges table.) The following items will always be included:
   a. A set of calibrated masses with a minimum 100 g resolution (hanger or slotted style). Each team may bring their own masses for the regional competition, but receive approval of the judge(s) before using them. For the state competition, only provided masses may be used.
   b. A notepad, graph paper, and several pencils.
   c. A non-programmable pocket calculator. (Because many calculators contain clocks and/or stopwatches, only calculators provided by the judges may be used for the competition.)
   d. A formula sheet that includes common physical constants.
   e. An unknown mass (test object), like a sphere, cylinder, or cube with a hook possibly attached to it. (The unknown masses need not be the same for all teams, but should be similar to one another.)
5. The provided equipment may or may not include the following items (the list is neither inclusive or exclusive and may change from one year to the next):
   a. Wooden rulers, graded in millimeters.
   b. Metal hangers with clamps and hooks.
   c. A metal or plastic prism about 5-7 cm on the side.
   d. A graduated beaker with spout that can contain 0.5 l of liquid.
   e. A graduated beaker with spout that can contain 0.25 l of liquid.
   f. A roll of string.
   g. A hollow metal or plastic tube.
   h. A vessel containing clean water (at least 1 liter).
   i. A protractor of 1-degree accuracy.
   j. A small, light pulley.
   k. A flexible metal ruler.
   l. Metal or plastic spring(s).
   m. A stopwatch.
   n. A pair of scissors.
   o. A roll of kitchen paper towels.
6. During the competition, each team should devise and deploy at least one technique to measure the unknown mass, and carry out the necessary experiment(s) to do so.
7. All work done by the team, including formulas used, measurements, calculations, sketches of the apparatus, graphs, and results should be kept and entered in the appropriate section on the challenge problem worksheet. Teams may choose to use the notepad or graph paper for preliminary work, but all work (with the exception of graphs, if used to determine a measured value) must be entered on the official worksheet. Graphs that represent part of a proposed solution may be appended on separate paper and submitted for judging.
8. Teams may not damage, alter, or mark the equipment in any way except for cutting strings and paper.
9. Teams will be given 30 minutes to complete their work.
10. Each team shall present the judges with the following (at the end of the 30 minute period or earlier):
   a. one Challenge Problem worksheet, containing the following:
      i. Team members’ names and school;
      ii. Best estimate of the unknown mass in grams (to an accuracy of 0.1 g);
      iii. Two values, representing the highest and lowest estimate of the mass due to measurement uncertainty;
      iv. The absolute value of the difference between the highest and lowest estimates, divided by 2. This will be quoted as the uncertainty (error) in the measurement;
      v. Written explanation of the experimental approach and/or physical ideas behind any measurements;
      vi. Written record of any data collected in the process of determining the unknown mass;
      vii. Any relevant calculations;
      viii. Written explanation of the technique(s) used to determine uncertainty in any measurements or calculations.
   b. any graph paper (if used). The team’s name should be written on any graph paper submitted by the team.

11. Prior to the competition, the judges will determine the mass of the test object(s) using an accurate laboratory scale. This result will be recorded as the REAL VALUE of the mass.

12. The judges will track the total time each team takes to complete their work, which should not exceed 30 minutes. Teams who have not submitted written work at the end of 30 minutes will be disqualified.

**Evaluation**

The evaluation of each team’s work will consist of 2 parts: (A) a score of the measurement and (B) a score of the work done. Both scores will be produced by the judges. The final score will be the SUM of the measurement and the work scores.

1. The score of the measurement must be a measure of the closeness to the actual value as well as the precision of the measurement. The following formula will be used to evaluate this score:

   \[
   \text{measurement score} = 100 - \text{fractional absolute error} - \text{fractional uncertainty} - \text{statistical success}
   \]

   where

   \[
   \text{fractional absolute error} = \frac{|\text{real value} - \text{best estimate}|}{\text{real value}} \times 100
   \]

   and

   \[
   \text{fractional uncertainty} = \frac{\text{measurement uncertainty}}{\text{best estimate}} \times 100
   \]

   and

   \[
   \text{statistical success} = |\text{high estimate} - \text{real value}| + |\text{real value} - \text{low estimate}| - (\text{high estimate} - \text{low estimate})
   \]

   The bigger the uncertainty the more likely it is that the measurement will include the actual value of the time. On the other hand the bigger the uncertainty the less valuable the measurement is.

   Using this formula a team that produces an estimate that is closer to the actual value AND has smaller uncertainty in their measurements will get a higher score, provided that the real value lies within the reported uncertainty of the reported estimate. The highest possible score of the measurement is 100.
2. The score of the work done will be given based on the following criteria:
   a. Does the team use a valid experimental approach, and are they able to describe it? (30 points maximum)
   b. Has the team taken all necessary measurements and performed any required calculation(s)? (40 points maximum)
   c. Does the team account for reasonable experimental uncertainty, given their chosen approach? (30 points maximum)

Specific criteria examined by the judges are provided within the judging section of the challenge problem worksheet, included in this document.

The evaluation of the work done certainly includes some subjectivity. If possible, in order to minimize this subjectivity and ensure that all teams are treated equally, this part of the evaluation can be done by the entire team of judges.

In the case of a tie the team who finishes in the shortest time will be ranked higher.

NOTE: No measurement will be accepted without a measurement error estimate. If a team reports a measurement without an error estimate they will be disqualified.
Challenge Problem Worksheet and Scoring Rubric

Team Members’ Names:___________________________________________________________

School:_________________________________________________________________________

Table or Station:__________________________

**Reported Values** - be sure to include appropriate units!

Best Estimate of the Mass:_________

High Estimate of the Mass (accounting for experimental uncertainty):_________

Low Estimate of the Mass (accounting for experimental uncertainty):_________

Experimental Uncertainty ([high estimate – low estimate] ÷ 2):_________

**Experimental Approach**

Briefly describe, in paragraph form, the physics theory you used to determine your reported value for the mass:

<table>
<thead>
<tr>
<th>Experimental Approach (Theory) Score - Judges Use Only</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Could the method described be used to measure or calculate mass?</td>
<td>☐ Yes (5 pts) ☐ No (0 pts)</td>
</tr>
<tr>
<td>Does the description of the method incorporate and correctly use physics terminology?</td>
<td>☐ Yes (5 pts) ☐ No (0 pts)</td>
</tr>
<tr>
<td>Is the description of the method written in paragraph form, employing good grammar?</td>
<td>☐ Yes (5 pts) ☐ No (0 pts)</td>
</tr>
</tbody>
</table>

Briefly describe any measurements you will make, any calculations you anticipate performing, and any equations or formulas you plan to use:
### Experimental Approach (Measurements) Score - Judges Use Only

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes (5 pts)</th>
<th>No (0 pts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does the description include discussion of how data will be or was collected?</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Does the description connect physics theory to the experimental measurements (to be) performed?</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Does the description mention all measurements that will need to be performed, and all constants that will be used to determine mass?</td>
<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>

**Experimental Approach Subtotal:** /30

### Measurements & Calculations

Record all measured data used in your determination of the unknown mass, including appropriate units:

### Measurements & Calculations (Data) Score - Judges Use Only

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes (5 pts)</th>
<th>No (0 pts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are all measurements used to determine the reported mass value recorded?</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Are all measurements reported with appropriate units?</td>
<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>

Show all calculations used to determine your reported best estimate for mass. Include appropriate equations and units for any measured or calculated values.
Did you prepare any graphs used to determine your solution? □ yes □ no (If yes, please append.)

<table>
<thead>
<tr>
<th>Measurements &amp; Calculations (Calculations) Score - Judges Use Only</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do all calculations and/or conversions utilize the correct physics or mathematical formula(s)?</td>
<td>□ Yes (5 pts) □ No (0 pts)</td>
</tr>
<tr>
<td>Are the measurements and calculations consistent with the previously described experimental method?</td>
<td>□ Yes (5 pts) □ No (0 pts)</td>
</tr>
<tr>
<td>Are the calculations free from error?</td>
<td>□ Yes (5 pts) □ No (0 pts)</td>
</tr>
<tr>
<td>Are all calculations presented in a clear, step-by-step manner that is easy for the reader to follow?</td>
<td>□ Yes (5 pts) □ No (0 pts)</td>
</tr>
<tr>
<td>Is the final value for the best estimate of the mass clearly indicated, with appropriate units, showing how it was derived from the measurement(s)?</td>
<td>□ Yes (5 pts) □ No (0 pts)</td>
</tr>
<tr>
<td>Does the reported value of best estimate of the mass match the results of calculation(s)?</td>
<td>□ Yes (5 pts) □ No (0 pts)</td>
</tr>
</tbody>
</table>

Measurements & Calculations Subtotal: /40

Uncertainty
All measured data (or calculated values based on measured data) have some uncertainty associated with them. Briefly describe, in paragraph form, how you determined or estimated the high and low time values you reported on this worksheet.

<table>
<thead>
<tr>
<th>Uncertainty Score - Judges Use Only</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does the report include a description of how uncertainty was determined?</td>
<td>☐ Yes (5 pts) ☐ No (0 pts)</td>
</tr>
<tr>
<td>Is the description of uncertainty written in paragraph form, employing good grammar?</td>
<td>☐ Yes (5 pts) ☐ No (0 pts)</td>
</tr>
<tr>
<td>Has uncertainty been determined either by (i) analyzing several independent measurements of the system (multiple trials), or (ii) analysis of the measurement limitations of the device(s) used for collecting data?</td>
<td>☐ Yes (5 pts) ☐ No (0 pts)</td>
</tr>
<tr>
<td>Do the calculations or other determination of uncertainty presented agree with the reported values?</td>
<td>☐ Yes (5 pts) ☐ No (0 pts)</td>
</tr>
<tr>
<td>Is the reported uncertainty reasonable relative to the data?</td>
<td>☐ Yes (5 pts) ☐ No (0 pts)</td>
</tr>
<tr>
<td>Is the uncertainty reported with appropriate units?</td>
<td>☐ Yes (5 pts) ☐ No (0 pts)</td>
</tr>
</tbody>
</table>

Uncertainty Subtotal: /30

Work Done Total: /100
Challenge Problem Example

Suppose that on the bench you find, among other items, a set of masses, a metal spring, a ruler, and a hanger with a horizontal bar from which the spring can be suspended. The first idea that may come to mind is use Hooke’s law for springs to measure the unknown mass.

Recall that if a mass is suspended from a vertical and very light spring the elongation, \( x \), of the spring from its natural length is proportional to the weight, \( W \), of the mass, i.e., \( W = kx \), where \( k \) is the spring constant. Now, \( W = mg \), where \( m \) is the mass and \( g = 9.8 \text{ m/s}^2 \) is the acceleration due to gravity. Therefore, \( m = (k/g)x \). This means that the mass \( m \) and the elongation \( x \) are proportional to each other. If \( m \) is plotted versus \( x \) on graph paper it will look like a straight line passing through zero. The slope of the line (rise over run) is simply \( k/g \).

One procedure that could be followed is to simply record several values of the elongation when known masses are suspended and produce the \( m \)-versus-\( x \) plot. Then one can suspend the unknown mass, measure the elongation it produces (always from the low-end of the spring) and use the plot to find the unknown mass. Each known mass has an uncertainty (error) associated with it. For this example, we’ll assume that each provided 100-g mass has an uncertainty of \( \pm 5 \) g. Similarly reading the spring elongation with a ruler includes an error, typically taken as the smallest division the ruler can measure. The measurements can be summarized in the table.

<table>
<thead>
<tr>
<th>elongation (( x )) in cm</th>
<th>mass (( m )) in grams</th>
<th>( x )-error in cm</th>
<th>( m )-error in g</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.9</td>
<td>100</td>
<td>0.2</td>
<td>5</td>
</tr>
<tr>
<td>10.2</td>
<td>200</td>
<td>0.2</td>
<td>10</td>
</tr>
<tr>
<td>14.9</td>
<td>300</td>
<td>0.2</td>
<td>15</td>
</tr>
<tr>
<td>20.1</td>
<td>400</td>
<td>0.2</td>
<td>20</td>
</tr>
<tr>
<td>24.8</td>
<td>500</td>
<td>0.2</td>
<td>25</td>
</tr>
<tr>
<td>29.7</td>
<td>600</td>
<td>0.2</td>
<td>30</td>
</tr>
</tbody>
</table>
The plot of $m$ versus $x$ for these data is shown below. The central line can be drawn by eye to best fit the data. The two other lines represent the two extreme limit lines that could be drawn and can be used to estimate the error in the measurement of the unknown mass.

Now the unknown mass is suspended and, say, an elongation of 18.2 cm is measured with the error of ± 0.2 cm. On the same graph we draw a line perpendicular to the $x$-axis at 18.2 cm. This intercepts the three lines drawn earlier. The central line gives a value of $m = 365$ g. Similarly the upper line gives $m_{\text{max}} = 390$ g and the lower line gives $m_{\text{min}} = 345$ g. Therefore, the experimental uncertainty in the mass measurement is given by $(390 \text{ g} - 345 \text{ g}) ÷ 2 = 22.5$ g.

(Note that there are several variations possible: finding the best-fit line equation to algebraically calculate the predicted mass instead of tracing lines on the graph, measuring the mass several times and calculating the average mass and standard deviation of the mass for uncertainty, etc. In addition, given the provided equipment, there are usually 2-3 additional experiments that could be performed to determine mass, such as building a lever and balancing torques, recording the oscillation frequency of a mass-spring oscillator, using water displacement to determine volume, then using density (assuming the composition of the mass is known) to calculate mass, etc.)

A sample challenge problem worksheet with scoring is included for this technique. A second sample challenge problem worksheet with scoring illustrating a different approach and poor reporting is also included for contrast.
Challenge Problem Worksheet and Scoring Rubric - Good Example

Team Members’ Names: Albert Einstein, Isaac Newton

School: Anytown High School, Anytown, Iowa

Table or Station: 1

<table>
<thead>
<tr>
<th>Reported Values - be sure to include appropriate units!</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best Estimate of the Mass: <strong>365 grams</strong></td>
</tr>
<tr>
<td>High Estimate of the Mass (accounting for experimental uncertainty): <strong>390 grams</strong></td>
</tr>
<tr>
<td>Low Estimate of the Mass (accounting for experimental uncertainty): <strong>345 grams</strong></td>
</tr>
<tr>
<td>Experimental Uncertainty ([high estimate – low estimate] ÷ 2): <strong>22.5 grams</strong></td>
</tr>
</tbody>
</table>

Experimental Approach

Briefly describe, in paragraph form, the physics theory you used to determine your reported value for the mass:

Hooke’s Law tells us that the force exerted by an elongated spring is $F = kx$, where $x$ is the distance the spring is stretched. Using known forces and measured displacements, one can determine the unknown spring constant of a spring.

If a mass is hung from a spring with a known mass, we can use Newton’s 2nd Law (noting the mass is hanging at rest, making the acceleration 0) to equate the spring force to the gravitational force, and algebraically rearrange to determine mass.

<table>
<thead>
<tr>
<th>Experimental Approach (Theory) Score - Judges Use Only</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Could the method described be used to measure or calculate mass?</td>
<td>□ Yes (5 pts) □ No (0 pts)</td>
</tr>
<tr>
<td>Does the description of the method incorporate and correctly use physics terminology?</td>
<td>□ Yes (5 pts) □ No (0 pts)</td>
</tr>
<tr>
<td>Is the description of the method written in paragraph form, employing good grammar?</td>
<td>□ Yes (5 pts) □ No (0 pts)</td>
</tr>
</tbody>
</table>

Briefly describe any measurements you will make, any calculations you anticipate performing, and any equations or formulas you plan to use:
We plan on attaching the spring to the lab stand, hanging vertically. We will then hang a few different known masses from the spring, measuring the displacement of the spring for each mass. Plotting the mass as a function of spring displacement should produce a linear graph. The slope of this graph is the spring constant/g (since mg = kx).

Once we know the spring constant, we’ll hang the unknown mass from the spring and measure the displacement of the spring. We can use the linear graph to determine the value of the unknown mass by finding where it’s elongation intercepts the best-fit line, and tracing that position over to the mass axis.

### Experimental Approach (Measurements) Score - Judges Use Only

| Does the description include discussion of how data will be or was collected? | ☐ Yes (5 pts) | ☐ No (0 pts) | 5 |
| Does the description connect physics theory to the experimental measurements (to be) performed? | ☐ Yes (5 pts) | ☐ No (0 pts) | 5 |
| Does the description mention all measurements that will need to be performed, and all constants that will be used to determine mass? | ☐ Yes (5 pts) | ☐ No (0 pts) | 5 |

**Experimental Approach Subtotal:** 30/30

### Measurements & Calculations

Record all measured data used in your determination of the unknown mass, including appropriate units:

We hung several known masses from the spring and measured the elongation of the spring for each mass:

<table>
<thead>
<tr>
<th>Elongation (x) (cm)</th>
<th>Mass (m) (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.9</td>
<td>100</td>
</tr>
<tr>
<td>10.2</td>
<td>200</td>
</tr>
<tr>
<td>14.9</td>
<td>300</td>
</tr>
<tr>
<td>20.1</td>
<td>400</td>
</tr>
<tr>
<td>24.8</td>
<td>500</td>
</tr>
<tr>
<td>29.7</td>
<td>600</td>
</tr>
</tbody>
</table>

We also hung the unknown mass from the same spring and noted that the elongation was 18.2 cm.

### Measurements & Calculations (Data) Score - Judges Use Only

<table>
<thead>
<tr>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
</tr>
</tbody>
</table>
Are all measurements used to determine the reported mass value recorded? □ Yes (5 pts) □ No (0 pts) 5

Are all measurements reported with appropriate units? □ Yes (5 pts) □ No (0 pts) 5

Show all calculations used to determine your reported best estimate for mass. Include appropriate equations and units for any measured or calculated values.

We made a graph of the mass hung from the spring as a function of elongation and connected the data points for a best-fit line:

![Graph of mass vs. elongation]

We then traced a line from the measured elongation of the unknown mass up to the best-fit line, then traced a horizontal line over to the vertical mass axis to find the estimated mass of 365 g.

Did you prepare any graphs used to determine your solution? □ yes □ no (If yes, please append.)

<table>
<thead>
<tr>
<th>Measurements &amp; Calculations (Calculations) Score - Judges Use Only</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do all calculations and/or conversions utilize the correct physics or mathematical formula(s)?</td>
<td>□ Yes (5 pts) □ No (0 pts) 5</td>
</tr>
<tr>
<td>Are the measurements and calculations consistent with the previously described experimental method?</td>
<td>□ Yes (5 pts) □ No (0 pts) 5</td>
</tr>
<tr>
<td>Are the calculations free from error?</td>
<td>□ Yes (5 pts) □ No (0 pts) 5</td>
</tr>
<tr>
<td>Are all calculations presented in a clear, step-by-step manner that is easy for the reader to follow?</td>
<td>□ Yes (5 pts) □ No (0 pts) 5</td>
</tr>
<tr>
<td>Is the final value for the best estimate of the mass clearly</td>
<td>□ Yes (5 pts) □ No (0 pts) 5</td>
</tr>
</tbody>
</table>
indicated, with appropriate units, showing how it was derived from the measurement(s)?

Does the reported value of best estimate of the mass match the results of calculation(s)?

<table>
<thead>
<tr>
<th></th>
<th>Yes (5 pts)</th>
<th>No (0 pts)</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes (5 pts)</td>
<td>No (0 pts)</td>
<td>5</td>
</tr>
</tbody>
</table>

**Measurements & Calculations Subtotal:** 40/40

**Uncertainty**

All measured data (or calculated values based on measured data) have some uncertainty associated with them. Briefly describe, in paragraph form, how you determined or estimated the high and low mass values you reported on this worksheet.

We estimated that the provided masses were good to within +/- 5 grams for each 100 g mass, and the measured elongations were good to within +/- 0.2 cm. Using these estimates of the precision of our equipment, we plotted error bars on the graph of mass vs. elongation. This allowed us two draw two additional lines, illustrating a range of uncertainty. Tracing to the edge of this zone from the measured elongation allowed us to estimate the lower value of the mass (345 g) and the higher value of the mass (390 g).

**Uncertainty Score - Judges Use Only**

<table>
<thead>
<tr>
<th></th>
<th>Yes (5 pts)</th>
<th>No (0 pts)</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does the report include a description of how uncertainty was determined?</td>
<td>Yes (5 pts)</td>
<td>No (0 pts)</td>
<td>5</td>
</tr>
<tr>
<td>Is the description of uncertainty written in paragraph form, employing good grammar?</td>
<td>Yes (5 pts)</td>
<td>No (0 pts)</td>
<td>5</td>
</tr>
<tr>
<td>Has uncertainty been determined either by (i) analyzing several independent measurements of the system (multiple trials), or (ii) analysis of the measurement limitations of the device(s) used for collecting data?</td>
<td>Yes (5 pts)</td>
<td>No (0 pts)</td>
<td>5</td>
</tr>
<tr>
<td>Do the calculations or other determination of uncertainty presented agree with the reported values?</td>
<td>Yes (5 pts)</td>
<td>No (0 pts)</td>
<td>5</td>
</tr>
<tr>
<td>Is the reported uncertainty reasonable relative to the data?</td>
<td>Yes (5 pts)</td>
<td>No (0 pts)</td>
<td>5</td>
</tr>
<tr>
<td>Is the uncertainty reported with appropriate units?</td>
<td>Yes (5 pts)</td>
<td>No (0 pts)</td>
<td>5</td>
</tr>
</tbody>
</table>

**Uncertainty Subtotal:** 30/30

**Work Done Total:** 100/100
Assuming the “real” value for the mass was determined to be 371.2 g:

\[
\text{fractional absolute error} = \frac{|\text{real value} - \text{best estimate}|}{\text{real value}} \times 100 = \frac{|371.2 g - 365 g|}{371.2 g} \times 100 = 1.67
\]

\[
\text{fractional uncertainty} = \frac{\text{measurement uncertainty}}{\text{best estimate}} \times 100 = \frac{22.5 g}{365 g} \times 100 = 6.16
\]

\[
\text{statistical success} = |\text{high estimate} - \text{real value}| + |\text{real value} - \text{low estimate}| - (\text{high estimate} - \text{low estimate}) \\
\text{statistical success} = |390 g - 365 g| + |365 g - 345 g| - (390 g - 345 g) = 0
\]

\[
\text{measurement score} = 100 - \text{fractional absolute error} - \text{fractional uncertainty} - \text{statistical success} \\
\text{measurement score} = 100 - 1.67 - 6.16 - 0 = 92.17
\]

The total score would be 92.17 + 100 = 192.17.
Challenge Problem Worksheet and Scoring Rubric - Poor Sample

Team Members’ Names: Albert Einstein, Isaac Newton

School: Anytown High School, Anytown, Iowa

Table or Station: 2

<table>
<thead>
<tr>
<th>Reported Values - be sure to include appropriate units!</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best Estimate of the Mass: 450 grams</td>
</tr>
<tr>
<td>High Estimate of the Mass (accounting for experimental uncertainty): 500</td>
</tr>
<tr>
<td>Low Estimate of the Mass (accounting for experimental uncertainty): 440</td>
</tr>
<tr>
<td>Experimental Uncertainty ([high estimate – low estimate] ÷ 2): 50</td>
</tr>
</tbody>
</table>

Experimental Approach

Briefly describe, in paragraph form, the physics theory you used to determine your reported value for the mass:

You can balance on a teeter-totter with someone who has a different weight than you as long as you have the same force.

<table>
<thead>
<tr>
<th>Experimental Approach (Theory) Score - Judges Use Only</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Could the method described be used to measure or calculate time?</td>
<td>☐ Yes (5 pts) ☐ No (0 pts) 5</td>
</tr>
<tr>
<td>Does the description of the method incorporate and correctly use physics terminology?</td>
<td>☐ Yes (5 pts) ☑ No (0 pts) 0</td>
</tr>
<tr>
<td>Is the description of the method written in paragraph form, employing good grammar?</td>
<td>☑ Yes (5 pts) ☐ No (0 pts) 5</td>
</tr>
</tbody>
</table>

Judging comments: Balancing torques on either side of a lever is indeed one way you could determine the unknown mass. This response was judged to not use correct physics terminology (force in place of torque,) but the judges viewed the method (lever balance) as acceptable.

Briefly describe any measurements you will make, any calculations you anticipate performing, and any equations or formulas you plan to use:
We are going to hang a meter stick from the lab stand and put the unknown mass on one side with the known mass on the other side.

**Experimental Approach (Measurements) Score - Judges Use Only**

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes (5 pts)</th>
<th>No (0 pts)</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does the description include discussion of how data will be or was collected?</td>
<td>□</td>
<td>■</td>
<td>0</td>
</tr>
<tr>
<td>Does the description connect physics theory to the experimental measurements (to be) performed?</td>
<td>□</td>
<td>■</td>
<td>0</td>
</tr>
<tr>
<td>Does the description mention all measurements that will need to be performed, and all constants that will be used to determine mass?</td>
<td>□</td>
<td>■</td>
<td>0</td>
</tr>
</tbody>
</table>

**Experimental Approach Subtotal:** 10/30

Judging comments: The necessary data involves measured distances and noting the known mass; neither are mentioned. Additionally, the concept of torque is not connected to what is written. It's possible to use this technique without using any physical constants, but no explicit explanation of measurement is given.

**Measurements & Calculations**

Record all measured data used in your determination of the unknown mass, including appropriate units:

We put 200 grams 50 centimeters from the center string of our meter stick on one side, and the unknown mass 21 cm on the other side - this made the meter stick balance.

**Measurements & Calculations (Data) Score - Judges Use Only**

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes (5 pts)</th>
<th>No (0 pts)</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are all measurements used to determine the reported mass value recorded?</td>
<td>■</td>
<td>□</td>
<td>5</td>
</tr>
<tr>
<td>Are all measurements reported with appropriate units?</td>
<td>■</td>
<td>□</td>
<td>5</td>
</tr>
</tbody>
</table>

Judging comments: To determine torques, one needs to measure both lengths and masses - both are reported here. Additionally, all the numbers have units here.
Show all calculations used to determine your reported best estimate for mass. Include appropriate equations and units for any measured or calculated values.

\[(200 \text{ g})(50 \text{ cm}) = (?) \text{ g}(21 \text{ cm})\]

\[? = 476 \text{ g}\]

Did you prepare any graphs used to determine your solution? □ yes ▣ no (If yes, please append.)

<table>
<thead>
<tr>
<th>Measurements &amp; Calculations (Calculations) Score - Judges Use Only</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do all calculations and/or conversions utilize the correct physics or mathematical formula(s)?</td>
<td>□ Yes (5 pts) □ No (0 pts) 5</td>
</tr>
<tr>
<td>Are the measurements and calculations consistent with the previously described experimental method?</td>
<td>□ Yes (5 pts) □ No (0 pts) 5</td>
</tr>
<tr>
<td>Are the calculations free from error?</td>
<td>□ Yes (5 pts) □ No (0 pts) 5</td>
</tr>
<tr>
<td>Are all calculations presented in a clear, step-by-step manner that is easy for the reader to follow?</td>
<td>□ Yes (5 pts) □ No (0 pts) 5</td>
</tr>
<tr>
<td>Is the final value for the best estimate of the mass clearly indicated, with appropriate units, showing how it was derived from the measurement(s)?</td>
<td>□ Yes (5 pts) □ No (0 pts) 5</td>
</tr>
<tr>
<td>Does the reported value of best estimate of the time match the results of calculation(s)?</td>
<td>□ Yes (5 pts) □ No (0 pts) 0</td>
</tr>
</tbody>
</table>

Measurements & Calculations Subtotal: 35/40

Judging comments: The formula above is a correct way to write a balanced torques equation, and the team has plugged in the values they reported measuring and correctly solved for the unknown mass. However, the result of this calculation doesn’t match the value that is reported at the top of the scoring worksheet.
All measured data (or calculated values based on measured data) have some uncertainty associated with them. Briefly describe, in paragraph form, how you determined or estimated the high and low time values you reported on this worksheet.

This method don’t seem to be real accurrit

so like it seems like we culd be off by quite a lot - maybe 25 or 50 grams or something like that.

---

### Uncertainty Score - Judges Use Only

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes (5 pts)</th>
<th>No (0 pts)</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does the report include a description of how uncertainty was determined?</td>
<td>□</td>
<td>✔</td>
<td>5</td>
</tr>
<tr>
<td>Is the description of uncertainty written in paragraph form, employing good grammar?</td>
<td>□</td>
<td>✔</td>
<td>0</td>
</tr>
<tr>
<td>Has uncertainty been determined either by (i) analyzing several independent measurements of the system (multiple trials), or (ii) analysis of the measurement limitations of the device(s) used for collecting data?</td>
<td>□</td>
<td>✔</td>
<td>0</td>
</tr>
<tr>
<td>Do the calculations or other determination of uncertainty presented agree with the reported values?</td>
<td>□</td>
<td>✔</td>
<td>0</td>
</tr>
<tr>
<td>Is the reported uncertainty reasonable relative to the data?</td>
<td>□</td>
<td>✔</td>
<td>5</td>
</tr>
<tr>
<td>Is the uncertainty reported with appropriate units?</td>
<td>□</td>
<td>✔</td>
<td>0</td>
</tr>
</tbody>
</table>

**Uncertainty Subtotal:** 10/30

**Work Done Total:** 55/100

Judging comments: The first question is obviously subjective, but their response was given credit here as the description seems to suggest they thought about the experiment and came up with a reasonable amount of mass. (Consistency among assessments of responses is what is most important for the judges to maintain.) 25-50 grams of uncertainty was also judged to not be unreasonable relative to the method and know mass. However, there are grammatical and spelling errors, the value was not arrived at by analyzing measurements OR the limitations of measuring devices, the discussion does not agree with reported values (the table at the top of
the first page has a low estimate that is only 10 g below the “best” estimate), and there are not units used when uncertainty is reported.

**Scoring Total - Challenge Problem Poor Sample**

Assuming the “real” value for the mass was determined to be 535.8 grams:

$$\frac{\text{fractional absolute error}}{\text{real value}} \times 100 = \frac{|535.8 g - 450g|}{450g} \times 100 = 19.07$$

$$\frac{\text{fractional uncertainty}}{\text{best estimate}} \times 100 = \frac{30 g}{450 g} \times 100 = 6.67$$

$$\text{statistical success} = |\text{high estimate} - \text{real value}| + |\text{real value} - \text{low estimate}| - (\text{high estimate} - \text{low estimate})$$

$$\text{statistical success} = |500 - 535.8| + |535.8 - 440| - (500 - 440) = 71.60$$

$$\text{measurement score} = 100 - \text{fractional absolute error} - \text{fractional uncertainty} - \text{statistical success}$$

$$\text{measurement score} = 100 - 19.07 - 6.67 - 71.60 = 2.66$$

The total score would be $2.66 + 55 = 57.66$. 
Judge and Event Director Checklists

CATAPULT Checklist

1. Check each device to assure that only elastic storage device (rubber bands, bungee cords, springs) and/or a gravity powered device are used.

2. Check for size compliance of the device with the following dimensions: 50 cm (l) x 40 cm (w) x 60 cm (h) in cocked or uncocked position. Note that cocked position is defined as “ready to fire”.

3. Complete 1 and 2 above for all contestants before proceeding.

4. After each device has been checked in, place it on a table and assure that students do not handle the device until it is time for that team to compete.

5. Mark the point where the ball first contacts the floor for each distance (2 m, 4 m, 8 m).

6. When all contestants have completed their three trials, measure and record each distance from the center of the target to the point of ball contact with the floor. Do not do any calculations. These are done with a computer.

7. Record a distance of 2 meters for any device that does not complete its trial or takes longer than 1 minute to launch after the student has been given the ping-pong ball. Any legal trial that lands beyond the default distance will be assigned the default distance and does not have to be measured.

8. Each team is permitted one and only one additional trial for one distance. The additional trial must be selected immediately after a poor trial or may be saved until the trial at another distance. After the extra trial is attempted, the better of the two trials at that distance will be recorded as the score for that distance.

9. Please mark the "Device Entered" column on your score sheet (Y or N) for each team to aid the scorers in distinguishing between a fault and a no-show. Be sure to explain to the Physics Competition Director any confusing data.

10. Please make sure that the two table tennis balls (40 mm) official ping-pong balls are ready.
MOUSETRAP CAR Checklist

1. Check the mousetrap to see that a rat trap is NOT used and for allowed changes.

2. Check for size compliance of the device with the following dimensions: 25 cm (l) x 15 cm (w) x 15 cm (h) in either cocked or uncocked position. Cocked position is defined as when the device is in “ready to fire” position.

3. Check that students have marked with a permanent marker the front edge of their car that will act as the point from which measurement(s) will be taken and told you the location of the front edge prior to any measurements being made.

4. Complete 1 through 4 above for all contestants before proceeding. After each car has been checked in, place it on a table and assure that students do not handle the car until it is time for that team to compete.

5. For each trial, the front edge of the entire device (including the wheels) must start within the designated “start zone” defined by the interior edge of the tape.

6. As each car competes, the front edge of the car designated by the students is immediately marked by tape on the floor and the distance is measured to the closest edge of the line. The distance will be measured perpendicularly from the target line to the point on the front edge of the car. A car stopping point can be on either side of the target line with the team’s designated front edge to be measured from this line.

7. Please mark the “Device Entered” column on your score sheet (Y or N) for each team to aid the scorers in distinguishing between a fault and a no-show. Be sure to explain to the Physics Competition Director any confusing data.
BRIDGE BUILDING Checklist

1. Measure the mass of each bridge.

2. Check for the under bridge clearance with the provided gauge of a 5 cm x 5 cm x 30 cm board.

3. Check the roadway height (not more than 10 cm above the tabletop) and the roadway width (minimum of 4 cm).

4. Check for the placement of the test rod (edge within 3 cm of the center of the 30 cm span) to be placed on the roadway. The test rod must rest on the roadway and not on the rails.

5. The height of the bridge shall not exceed 20 cm from the lowest to the highest points of the bridge.

6. Check to see if the roadway is level with the board provided. (no more than 1.0 cm gap at either end)

7. Check that the only construction materials are flat, round or square wooden toothpicks; and Elmer's white. NO other glue allowed.

8. Complete 1 through 7 above for all contestants before proceeding.

9. After each bridge has been checked in, place it on a table and assure that students do not handle the bridge until it is time for that team to compete. Bridges must be clearly labeled or marked with student/team names.

10. Supervise as student(s) test each bridge for strength. The students will indicate at what point to "zero" or pre-load the scale. The event director should verbally call out the reading of the scale or the Force plate at each 1.0 kg, 1.0 lb, or 1.0 N or agreed upon kg, lb, or N (by the judges) increment. The recorder should watch for the indicator light signaling the 0.5 cm deflection and then record the largest kg, lb, or N reading as the bridge strength or measured force applied.

11. Determine the ratio of the measured force applied over mass of the bridge. The highest ratio of bridge strength to mass of bridge will be designated the winner.

12. Please mark the "Device Entered" column on your score sheet (Y or N) for each team to aid the scorers in distinguishing between a fault and a no-show. Be sure to explain to the Physics Competition Director any confusing data.
SODA STRAW ARM Checklist

1. **Students are required to bring and show the judges a sketch of their arm design prior to the start of the event.** Make sure there are no model arms brought with student teams. A team with no sketch will be disqualified from the event.

2. **Distribute** the straws and pins. It is recommended that the students be given several minutes to count the pins and straws and also to exchange any items they consider defective. Then **start timing**. Notice that students may provide their own gloves, goggles, scissors and/or pliers only. Other tools should not be allowed.

3. If students wish to cut pins they must bring and wear chemical splash goggles and gloves and move to the “pin cutting station” to complete this process.

4. At the end of **15 minutes** call time. Collect and label all arms and place them on a table.

5. After each arm has been checked in, place it on a table and **assure that students do not handle the arm** until it is time for that team to compete.

6. As each arm is tested, **check** for appropriate positioning and use of **hands while sliding and holding**.

7. If an arm holds the mass on the first trial the team is immediately given a second trial. If the arm does not hold the mass on the first trial the team receives a fault and **does not get a second trial**.

8. Measure and record the **length** of each arm. Circle the length for the top five teams.

9. Please mark the "Device Entered" column on your score sheet (Y or N) for each team to aid the scorers in distinguishing between a fault and a no-show. Be sure to explain to the Physics Competition Director any **confusing data**.
CHALLENGE PROBLEM Checklist

Before the event starts
1. Make sure that all set-ups have the same items available.
2. Identify all teams. Each team must have 2 students. The event may occur in two or more installments if there are more than 4 or 5 teams.
3. For the regional competition the students may bring their own masses. Check them in advance because their masses may not be allowed. Mass sets will be provided for the regional and state competitions. **Masses provided must have a minimum 10-g resolution; finer resolutions may be provided at the judges’ discretion, provided that the same resolution is available to all teams.**

During the event
1. Start your stopwatch to count the time the teams will take to finish their work. **Please note that each team has 30 minutes to complete the event.**
2. As far as possible, ensure that teams do not copy from one another.
3. Make sure that the teams do not break or alter the equipment (except for cutting paper and strings).

Collecting student results
1. When a team finishes, record their time, and collect their challenge problem worksheet and graph paper(s) (if any). Ensure that the names of team members are included on any additional papers. Also, ensure that an uncertainty estimate is reported. Teams not including uncertainty estimates are disqualified.
2. Using the laboratory scale, determine the “real value” for the mass in grams (if not determined prior to the event.)
3. Calculate the measurement score for each team, using the following formula:

\[
measurement\ \text{score} = 100 - \frac{\text{fractional absolute error}}{\text{real value}} - \frac{\text{fractional uncertainty}}{\text{best estimate}} - \text{statistical success}
\]

where

\[
\text{fractional absolute error} = \left| \frac{\text{real value} - \text{best estimate}}{\text{real value}} \right| \times 100
\]

and

\[
\text{fractional uncertainty} = \frac{\text{measurement uncertainty}}{\text{best estimate}} \times 100
\]

and

\[
\text{statistical success} = \left| \text{high estimate} - \text{real value} \right| + \left| \text{real value} - \text{low estimate} \right| - (\text{high estimate} - \text{low estimate})
\]
IOWA PHYSICS COMPETITION
2018-19

Note that if the “real” value lies within the reported uncertainty of the reported estimate, the statistical success will be 0. (This portion was added to penalize teams when the “real” value lies outside of reported uncertainty, and to discourage teams from reporting unreasonably small uncertainties.)

4. A spreadsheet for automating calculations of the measurement score can be obtained from Jeff Morgan (jeff.morgan@uni.edu).

5. Evaluate the work done by each team. If possible, all judges should collectively score the work done by each team. If this is not possible, the judges should meet and discuss criteria for scoring prior to beginning. After completion of scoring, judges should again discuss any ambiguities or questions to ensure that all judging is as equitable as possible.
   a. Use the questions provided on the challenge problem worksheet to judge the description of the experimental approach. Is this approach valid? Do the students describe the approach correctly and thoroughly? (Maximum score of 30 points for 6 questions. If left blank, score a 0 for all questions.)
   b. Use the questions provided on the challenge problem worksheet to judge the measurements and calculations presented on the worksheet, as well as on additional papers submitted. Do they support the technique(s) previously described? Are they correct? Do they agree with the reported value? (Maximum score of 40 points for 8 questions. If left blank, score a 0 for all questions.)
   c. Use the questions provided on the challenge problem worksheet to judge the description of the determination of experimental uncertainty. Does the team justify their estimates? Are they reasonable? Are they in agreement with values reported elsewhere on the sheet? (Maximum score of 30 points for 6 questions. If left blank, score a 0 for all questions.)
   d. Determine a work done score for each team.

6. Determine the team score by summing the measurement score and the work done score.

7. In the case of a tie, the time taken to complete the task will be used. The faster team will rank higher than a team that took more time.

8. Rank the top 10 teams in descending order, giving 10 points to the first place team, 9 points to the second place team, etc. Report these results to the event coordinator.