tests of engineering aptitude, mathematics, and science (TEAMS): a premier engineering competition

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Introduction

The purpose of this Excelling in Engineering article is to highlight TEAMS (Tests of Engineering Aptitude, Mathematics, and Science) as a premier secondary engineering competition and provide the resources from the 2018 national competition to (a) deliver an inside look into the competitions, (b) showcase the rigor of the TEAMS engineering challenges, and (c) offer prior national challenges as a resource for teachers to engage students in authentic engineering experiences. Also, the article will pinpoint how the evaluation criteria for the 2018 TEAMS national competition align with the engineering core concepts identified by the Advancing Excellence in P-12 Engineering Education (AE3) (2018) collaborative.

TEAMS is an annual competition that gives students an opportunity to discover engineering and experience how it can help make a difference in the world. TEAMS competitions occur at the state level during February and March and at the national level in June, during the national Technology Student Association conference. TEAMS participants work collaboratively to solve real engineering challenges while applying their mathematics and science knowledge and skills in practical, rigorous, and creative ways. Therefore, TEAMS offers:

- Exciting, theme-based academic competitions.
- Real-world applications of mathematics and science.
- Collaborative skill building for teams of 4 to 8 students.
- A multipart national competition that includes design/build contests, engineering compu-

Above: **Figure 2.** Students competing in the National TEAMS Engineering Design/Build/Computation event.

tation questions, and prepared technical presentations.

- Certificates and awards for division, state, and national winners.
- Integrated STEM learning experiences.
- A unique inside look at problem solving from an engineer's viewpoint.
- Inspiration for students to consider engineering majors and careers.

TEAMS Competition Overview

STEM education is a team effort. TEAMS can be a great way for teachers to enhance STEM education at the middle and high school levels. The one-day state-level engineering competition runs from February through March each year. State rankings are posted in April, and the top-ranking teams are invited to participate in the national engineering competitions at the national TSA conference every summer. Featuring a yearly grand engineering challenge theme, the national TEAMS competition offers a three-part, real-world contest that is turn-key for teachers, with ready-to-use resources and materials. The three-part yearly competition consists of:

1. **Engineering Design/Build/Computation Event:** An on-site socially relevant engineering problem is presented to participating teams at the national TSA conference. Teams then design and build a solution to the problem while applying their mathematics and science skills to complete a series of challenging, scenario-based multiple-choice mathematics questions. The teams are ranked based on the performance of their solution prototype, design capabilities, and the correctness of their mathematical calculations.
2. **Prepared Presentation Event:** Teams research and prepare a technical poster presentation around a given prompt. Each team then presents its poster to a series of judges to be ranked based on a preestablished rubric.
3. **Digital Media Event:** Prior to the national conference, participating teams research and prepare a digital media entry response to a given prompt. A group of practicing engineers rank the digital media submissions.

Registration for the 2020 TEAMS state-level competition will be open in September. Schools affiliated with ITEEA can receive a 30% discount on the national TEAMS registration fee. More information is available on the TEAMS website at http://teams.tsaweb.org.

2018 National Competition

Each year, the national TEAMS competition focuses on a theme based on one of the National Academy of Engineering Grand Challenges. See www.engineeringchallenges.org/ for more details on the grand challenges. The 2018 theme was "Engineering a Greener World," and the main challenge revolved around passive solar home design. Tables 1 through 7 provide the Engineering Design/Build/Computation challenge from the 2018 National TEAMS competition as well as sample mathematics questions and an overview for both the prepared presentation and digital media events. Complete resources from the 2018 competition can be provided upon request. The authors hope these resources can aid in the teaching of engineering and look forward to seeing everyone at the next competition!

Figure 1. Students prototyping their engineering solution at the National TEAMS competition.

References

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Table 1: 2018 National Engineering Design/Build Challenge (Passive Solar Home Design)

Overview: The National Academy of Engineering has identified 14 grand engineering challenges considered to be of the utmost importance for our world. The development of solutions to these challenges will be essential for advancing the human race. The use of economical solar energy is one of these areas and is the focus of this competition. Participants will work as teams to design, build, and test a model passive solar home containing a thermal energy battery that can store and slowly release heat from the sun (lamp).

Background:

- Solar design relies on the sun's relative position in the sky to regulate the temperature inside a building. The angle of the sun's rays at different times of the year must be analyzed when designing buildings according to the principles of passive solar design. Therefore, solar building designs are more energy efficient, which results in structures having a smaller carbon footprint and thus minimizing negative impacts on the environment (Energy Saver, 2018).
- Passive solar design uses only convection, radiation, and conduction to distribute the heat—it does not use mechanical or electrical components. Therefore, passive solar design can be very cost-effective. Optimal passive solar home designs allow for more sunlight to enter the building in the winter, retaining warmth, and less sunlight in the summer, keeping things cooler, or the design allows for heat to be retained during the daytime and used for heating during the nighttime. Passive solar design relies on several design elements, such as orientation of the building and windows as well as material selection for walls, roofs, and window glazing (Energy Saver, 2018).
- Thermal energy batteries or storage units allow excess thermal energy to be stored and used hours, days, or months later, at scales ranging from individual processes, buildings, towns, or regions. Thermal energy battery technologies support the balancing of energy demands between daytime and nighttime, storing summer heat for winter heating, or winter cold for summer air conditioning (Kalaiselvan & Parameshwaran, 2014).

Challenge: Effective passive solar home designs will retain the most heat during the daytime and slowly distribute the heat during nighttime. The model passive solar home must:

- Be at least 20 cm high (including the roof).
- Fit within the height of the testing area.
- Not have an area greater than 20 x 23 cm (460 cm2).
- Include a roof and a window area no larger than 20 x 20 cm (a minimum of one and a maximum of four windows).

For the home design, participants should decide the shape of walls and roof and the locations of windows to collect, store, and distribute solar heat effectively. Also, the thermal energy battery will be made using a 3 oz. cup as the container. For the thermal energy battery design, participants can decide what materials to place in or on the 3 oz. cup as well as the location of the battery inside of the house. A clear line of sight must be available for collecting the temperature on the surface of the thermal energy battery using an infrared thermometer (Figure 3).

Figure 3. Infrared Thermometer measures the surface temperature of an object.

Materials:			
▪ 4 Sheets of 8 1/2″ X 11″ black construction paper ▪ 5 Sheets of 8 1/2″ X 11″ card stock	▪ 4 Sheets of copy paper ▪ 4 Sheets of aluminum foil ▪ Plastic sheets ▪ Model magic	▪ Tacky glue ▪ Dixie cups ▪ Cotton balls ▪ Duct tape	▪ Sandwich bags ▪ Pebbles ▪ Graphing calculator ▪ Ruler

Testing: To test and analyze the passive solar home and thermal energy battery design, the temperature changes within the house at the surface of the thermal energy battery will be measured and recorded. First, a testing coordinator will place the house under a lamp (sun) for a designated period of time so that the battery inside the house can collect and store heat from the lamp, as seen in Figures 4 and 5. At this time, participants can decide the orientation of the house. After the designated time has passed, the test co-ordinator will put the house away from the lamp and then measure the initial temperature at the surface of the thermal battery using an infrared thermometer. Then, in the same way, the test coordinator will measure the temperature three more times at designated intervals. A total of four data points will be plotted in a Test Result chart. Participants will calculate the theoretical area under the line or curve of the chart, using the trapezoidal method. The trapezoidal method works by approximating the region under the graph of the function as a trapezoid and calculating its area. The calculated area will represent the performance of the thermal energy battery design (the greater the area, the better solar home design).

Participants can test and revise their design up to two times. However, teams are only guaranteed one test. Teams that have not tested will be given preference at each testing station. Therefore, your team must plan accordingly to optimize their trials during the event.

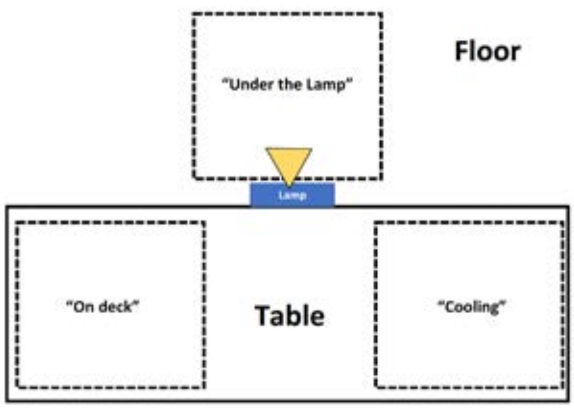


Figure 4. Testing station.

Figure 5. Students testing their prototypes.

Evaluation:

Performance (45 Points)

Teams will be placed in a Percentile Rank based on design performance.

100th = 45 pts	97th-93th = 35 pts	85th-69th = 25 pts	35th-19th = 15 pts	10th-6th = 5 pts
99th-98th = 40 pts	92th-86th = 30 pts	68th-36th = 20 pts	18th-11th = 10 pts	5th-0th = 0 pts

Math Questions (50 Points)

Design Elements (5 Points)

Criteria	Minimal Evidence 0 - 2 pts	Adequate Evidence 3 – 4 pts	Exemplary Evidence 5 pts
Engineering Design	Team documentation contained minimal evidence of engaging in an engineering design process.	Team documentation contained adequate evidence of engaging in an engineering design process.	Team documentation contained exemplary evidence of engaging in an engineering design process.

Note. This challenge specifically addresses the AE3 Core Engineering Concepts of *Thermodynamics, Engineering Algebra, Environmental Considerations, Problem Framing, Ideation, and Prototyping*.

Table 2: 2018 National Engineering Computation Challenge (Sample Question #1 – correct solution underlined)

Question: Given a 5 kg pot of water at 15 degrees C, find the amount of heat needed to raise the temperature to 20 degrees C. (The specific heat of water is 4.18 kJ/kg°C.)

a) 418 kJ b) 230 kJ c) 25 kJ d) 313 kJ e) <u>105 kJ</u>

Solution: We can use the following equation to determine the heat needed:

$$Q = mC_p\Delta T$$

Plugging in the values:

$$Q = (5\ kg)(4.18\ kJ/kg°C)(20°C - 15°C) = 104.5\ kJ$$

So, the answer is 105 kJ.

Table 3: 2018 National Engineering Computation Challenge (Sample Question #2 – correct solution underlined)

Question: Given a 4 x 6 ft single-pane window with k = 0.65 W/m K that is 3/8" thick, find the rate of heat loss from the interior to the exterior if the interior temperature is 32 degrees C and the outside temperature is 30 degrees C.

a) <u>305 W</u> b) 83.2 W c) 7.73 W d) 83.3 W e) 1.3 W

Solution: To compute the rate of heat loss, we will use:

$$Q = kA(\Delta T/L)$$

First, we need to convert the dimensions to the window to SI units to be consistent. Finding the surface area first means we only need to do two conversions instead of three.

$$A = 4\ ft \text{ x } 6\ ft = 24\ ft^2\ (0.3048\ m/1\ ft)^2 = 2.2297\ m^2$$

The thickness is the second conversion:

$$L = (3/8\ in)(0.0254\ m/1\ in) = 0.0095\ m$$

Then we use the formula:

$$Q = [0.65\ (W/m)K](2.2297\ m^2)[(32°C - 30°C)/(0.0095\ m)] = 305\ W$$

Table 4: 2018 National Engineering Computation Challenge (Sample Question #3 – correct solution underlined)

Question: Suppose there is a 10 x 12 ft hollow wall with an R-value of 0.5 $(ft2\ hr\ °F)/BTU$ insulated with a material with an R value of 7 $(ft2\ hr\ °F)/BTU$. What is the heat transfer rate through the wall if the inside temperature is 72° and the outside temperature is 63°?

a) 479 BTU/hr b) <u>135 BTU/hr</u> c) 154 BTU/hr d) 144 BTU/hr e) None of the above

Solution: Using the heat transfer rate equation:

$$Q = (A\Delta T)/R$$

Note that there are three terms in the denominator since the wall is insulated.

$$\dot{Q} = \frac{A\Delta T}{R_{inside} + R_{insulation} + R_{outside}}$$

$$\dot{Q} = \frac{(10\ ft)(12\ ft)(72°F - 63°F)}{0.5\ \frac{ft^2\ hr\ °F}{BTU} + 7\ \frac{ft^2\ hr\ °F}{BTU} + 0.5\ \frac{ft^2\ hr\ °F}{BTU}} = 135\ \frac{BTU}{hr}$$

Table 5: 2018 National Engineering Computation Challenge (Sample Question #4 – correct solution underlined)

Question: How does doubling the area of the glass in the window and frame affect the U-factor of the assembly? Assume the U-factor is the same throughout the glass.

a) <u>There is no effect.</u>
b) The U-factor doubles.
c) The U-factor is halved.
d) The U-factor is scaled up by a factor determined by the window area.
e) The U-factor is scaled down by a factor determined by the window area.

Solution: The overall U-factor of the assembly is:

$$U_W = \frac{U_{frame}A_{frame} + U_{COG}A_{COG} + U_{EOG}A_{EOG}}{A_{frame} + A_{COG} + A_{EOG}}$$

Since the U-factor is the same throughout the window, we can write the formula as

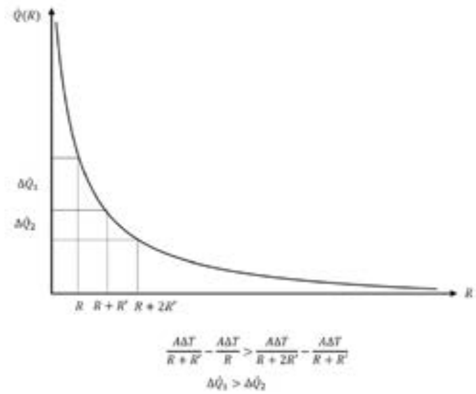
$$U_W = \frac{U_{frame}A_{frame} + U_{window}A_{window}}{A_{frame} + A_{window}}$$

Let $A'_{window} = 2A_{window}$ and $A'_{frame} = 2A_{frame}$, then:

$$U'_W = \frac{2U_{frame}A_{frame} + 2U_{window}A_{window}}{2A_{frame} + 2A_{window}} = \frac{2(U_{frame}A_{frame} + U_{window}A_{window})}{2(A_{frame} + A_{window})} = \frac{2}{2}U_w = U_w$$

So, there is no change.

Table 6: 2018 National Engineering Computation Challenge (Sample Question #5 – correct solution underlined)

Question: Suppose we increase the R-value of the window using glazing, which of the following is a true outcome of that change? a) Increasing R will give a constant decrease in heat loss. b) <u>The first addition will give the largest decrease in heat loss and smaller decreases after.</u> c) The heat loss will only decrease to a certain non-zero point as R increases. d) Increasing R will give a constant increase in heat loss. e) None of the above.
Solution: Consider the heat loss rate equation: $Q = (A\Delta T)/R$ Heat loss is not linear in R. We can make a generic plot and check what happens to heat loss. Pick three points, then examine the difference from the first to the second and from the second to the third.  So heat loss will decrease in smaller and smaller amounts as R increases, and b) is the correct statement.

Note. The mathematics in this challenge specifically address the AE3 Core Engineering Concepts of *Thermodynamics* and *Engineering Algebra*.

Table 7: 2018 National Prepared and Digital Media Challenges

2018 National Prepared Presentation Challenge	2018 National Digital Media Challenge
Overview: Participants prepare a design proposal (oral presentation accompanied by a poster) describing their solution to the design challenge. **Background:** According to a study done by the Harvard Health Watch, an average American spends 101 minutes per day driving. That means that in a lifetime, an average person spends 37,935 hours driving a car (assuming that s/he starts driving at 17 and drives until 78.7 years old). The average U.S. commuter spends 42 hours in traffic per year and loses $1,400 idling away gas. Transportation analytics firm INRIX reported that Atlanta, GA ranked among the worst traffic-congested areas in both the U.S. (ranked #4) and the world (ranked #8). Traffic congestion on roads not only increases the fuel consumption but consequently leads to an increase in carbon dioxide emissions and outdoor air pollution. **Challenge:** Design an innovation in transportation infrastructure based on sustainable criteria. Examples of innovations include new transportation methods or improvements to current transportation methods. Sustainable principles identified by the National Institute of Building Sciences include, but are not limited to: ▪ Optimize site potential ▪ Optimize energy use ▪ Protect and conserve water ▪ Optimize building space and material use ▪ Enhance indoor environmental quality (IEQ) ▪ Optimize operational and maintenance practices	**Overview:** Participants conduct research on a specified topic and, using the knowledge and resources gained through that research, develop a digital media solution for the challenge. **Challenge:** You are a member of an engineering consultation firm that works with technology companies to promote a sustainable future. Your team has been tasked with providing a promotional video to share with potential clients. Your video should promote your consulting firm and highlight areas such as services provided, successes, and expertise. Example of services that your firm may offer include, but are not limited to: ▪ Compliance with sustainability or "green" standards (e.g., LEED, Fairtrade) ▪ Cradle to Cradle (C2C) and Product Life Cycle assessments for product design ▪ Supply chain management ▪ Sustainability strategy development The digital media must include: ▪ An area of focus (e.g., product design, building design, manufacturing) ▪ Rationale or need for services ▪ Overview of services ▪ Contact information (list only the name of your fictional firm)

Note. These events specifically address the AE3 Core Engineering Concepts of *Problem Framing, Research, Ideation, Engineering Communication,* and *Environmental Considerations.*