A Comprehensive and Culminating Thermodynamics Lab Competition

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Introduction

Lab components to engineering courses are valuable for providing students with hands-on experiences, demonstrating principles learned during lecture and developing basic experimental and measurement skills. Depending on the target learning outcomes, students in a lab class may take part in a variety of experiences including demonstrations, "cookbook" type experiments, guided inquiry exercises, and independent/design projects (Edwards & Recktenwald, 2010; Prince & Felder, 2006; Prince & Felder 2007). Typically the lab component runs concurrently with lectures throughout the semester, allowing the lab material to coincide with lecture material. As the semester nears completion student anxiety typically increases and it is common for instructors to spend the final lecture reviewing material rather than squeezing in one more topic. This allows students to revisit material learned, spot gaps in their knowledge, ask any lingering questions, and works to quell the building anxiety.

It was with this mentality that the following lab experience, nicknamed the Labstravaganza, was created for a standard thermodynamics course. As a way to review material learned throughout the lab component different elements from many of the individual labs were integrated into a comprehensive competition amongst student groups. The goal of this was to revisit the material without relying on lecture or testing and finish up the lab component with an academically rigorous yet spirited experience. The competition was based upon four challenges which incorporated energy and entropy balances, specific heat, the incompressible model, ideal gas laws, psychrometrics, thermocouple construction, unit conversions and required students to use their engineering judgment to make choices and predict outcomes. Surveys were used to assess student attitudes towards the exercise and possible improvements are discussed.

Competition Description

In preparation for the competition lab tables were spread out to the far corners of the room so that students would be less tempted to eaves-drop or interfere with other groups. Each table started out with all of the necessary materials that would or could be used throughout the competition. A list of these materials can be found in the Appendix. Teams of 3-4 students were created by drawing names from a hat and students were advised on the following rules:

- no cell phones, computers, or internet in any capacity
- textbook and teammates are your only reference materials
- if something is unclear ask for clarification
- any answer submitted is considered a final answer and cannot be changed
- no spying on other teams or purposely disrupting/interfering with them
- each team member must understand how conclusions were reached and be able to explain the process

- answers must be neat, easy to follow, and include units where appropriate

A lifeline was also available to the teams in the form of a single yes/no question asked of the instructor. Any clarifying questions were not considered as use of their lifeline. At the conclusion of each challenge the instructor judged the answers turned in and awarded a few extra credit points to the team who did the best. To ensure that all team members were participating, a member of the winning team was randomly selected to explain part of the team's answer. If it was clear that the team member did not know how or why an answer was arrived at the team would forfeit the extra credit points. The different challenges were presented to the students as follows:

Unit Conversion Challenge
A common parameter in fluid mechanics is the Reynolds number which represents a ratio of inertial to viscous forces and is defined as:

$$\mathrm{Re} = \frac{\rho V d}{\mu}$$

In the equation ρ represents fluid density, V is fluid velocity, d is a characteristic length (i.e. diameter for pipe flows) and μ represents the fluid viscosity. Determine the Reynolds number in the simplest units for the following **air** flow characteristics: (there is a 10 minute time limit for this challenge)

$V = 16{,}300$ in/hr $d = 8 \times 10^{-8}$ kJ·s^2/lb·cm $\mu = 3.74 \times 10^{-7}$ lbf·s/ft^2 $T = 45^{o}$F
$P_{gage} = 4$ Btu/ft^3 (gage Pressure)

Hot Can Challenge
In this challenge an aluminum can with a small amount of water in it will be placed on a hot plate. The water will be heated up to its boiling point and allowed to boil for a few moments so that steam is exiting the mouth of the can. The can will then be quickly flipped over so that the mouth is pointing towards the ground and partially submersed into a bucket of water at room temperature. Providing details and reasoning predict the outcome of this event (a P-ν diagram would be good to include). There is a 10 minute time limit for this challenge.

Upon receiving all the team's answers the process was demonstrated to the class. When a soda can with a small amount of boiling water is turned upside down and placed into cooler water there is a large decrease in pressure which causes the can to suddenly implode.

Heat Capacity and Humidity Challenge
On your table there are three different materials in a pot of boiling water: brass, aluminum and acrylic. The mass of each material is listed on a sheet on your table and their specific heats are:

$C_{brass} = 0.35$ kJ/kg·K
$C_{aluminum} = 0.83$ kJ/kg·K
$C_{acrylic} = 0.48$ kJ/kg·K

Also on your table is an insulated vessel with 500 mL of water inside and temperature and humidity sensors. Your goal is to add one of the different materials into the vessel with the goal of maximizing the dew point temperature inside. Providing details and reasoning, predict the final dew point temperature. After turning in your prediction place the hot material into the water, wait a couple minutes while swirling the water around then determine the actual dew point temperature. There is a 25 minute time limit for this challenge.

Entropy Challenge

On your table you will find a pressurized vessel with a valve on it and an unpressurized vessel (Volume = 26.65 in^3) fitted with a thermocouple and flare fitting. Your goal in this lab is to maximize the total entropy within both vessels while bringing them into equilibrium. The vessels cannot be moved from their space, get wet, or have a heat source applied to them. Calculate the final entropy and the change in entropy for the system and provide your calculations and results to the instructor. Also provide the details and reasoning behind your method. There is a 50 minute time limit for this challenge.

Results

Following the competition a survey was administered to get feedback from the students on this experience. The first part of the survey had students rate certain aspects of the experience on a Likert scale and the results of this are shown in Table 1. It is seen that students responded very positively to the exercise and its use as a last day lab experience.

Statement rated from 1-5 (1=strongly disagree, 5= strongly agree)	**average**
The Labstravaganza helped to strengthen my understanding of material presented in this course.	3.7
The Labstravaganza is useful as a cumulative review of material.	4.1
I was challenged at the appropriate level by this exercise.	4.2
Working as part of a team of students enhanced my learning.	4.3
Working as part of a team enhanced my enjoyment.	4.4
The Labstravaganza is a good way to wrap up the lab.	4.5

Table 1. Labstravaganza survey results

When asked what they liked most about this exercise the students enjoyed: fun, friendly, while competitive, tied everything together and covered lots of material, working in teams, the open-ended nature, extra credit and applying what they learned. When asked how this exercise could be improved the students commented that they would have liked more time or less problems, more lifeline questions for the instructor, more extra credit plus food and more explosions.

Due to the overall positive response from the students it seems that using a competition such as this is a great way to wrap up the lab component of a course. In the future more time should be allowed for the challenges, perhaps an extra 30% than suggested above, while incorporating less problems. In fact only the Hot Can Challenge had all teams submit an answer within the allotted time. With some creative thinking it may be possible to cover as many topics with fewer challenges. Alternatively, an instructor could review how the class performed on different labs earlier in the semester and use this as guidance in coming up with challenges that would incorporate only material that was initially struggled with. Incorporating the student suggestion of allowing more questions of the instructor could also work in reducing the time required to complete any challenge, though this must be balanced with a desire to force the students to figure things out as a team.

Finally, on the Entropy Challenge students seemed to not think very creatively. Despite understanding causes of entropy generation such as friction, heat transfer, and sudden processes they did little to incorporate these thoughts into how they connected the different vessels. It was common to see the groups cut a short piece of copper tubing and add flare fittings to attach the vessels and then simply open the valve. Each table had 25 feet of copper tubing at their disposal plus a propane torch allowing much greater increases of entropy to be generated as the vessels were brought into equilibrium. In the future students should be prodded and encouraged to think critically about causes of entropy generation and creatively on how to incorporate them via the materials they have at their disposal for this challenge.

References

Edwards, R., & Recktenwald, G. (2010). A Guided Inquiry Approach to Teaching Fan Selection. *American Society for Engineering Education Annual Conference & Exposition*, Louisville, KY: Paper AC 2010-208.

Prince, M.J., & Felder, R.M. (2006). Inductive Teaching and Learning Methods: Definitions, Comparisons, and Research Bases, *Journal of Engineering Education*, 95(2), 123-138.

Prince, M.J., & Felder, R.M. (2007) The Many Faces of Inductive Teaching and Learning, *Journal of College Science Teaching,* 36(5), 14-20.

Appendix

Materials provided to the students included:

- boiling water with samples of brass, aluminum and acrylic
- thermocouple wire
- wire stripper
- thermocouple connector
- small screwdriver
- thermocouple reader
- relative humidity sensor
- insulated 64 oz. plastic mug with lid
- 26.65 in^3 pressurized air cylinder (50 psi) fitted with ball valve
- empty 26.65 in^3 air cylinder fitted with thermocouple and flared fitting inlet
- 25 ft. of copper tubing (1/4 in. ID)
- tools for making flared tubing connection
    - 45^o flaring block
    - tube cutter
    - ¼ in. swaging punch
    - hammer
    - flare nuts
- tools for soldering
    - propane canister and torch tip
    - flame striker
    - flux and flux brush
    - emery cloth
    - heat proof pad
    - vise
    - pliers
- eye protection