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Use of Bratwurst Sausage as a Model Cadaver in Introductory Physics for the Life Sciences Lab Experiments

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The general physics course that is taught in most departments as a service course for pre-med or pre-health students is undergoing a large shift in course content[1,2] to better appeal to this group of learners. This revision also extends to the laboratory component, where more emphasis is being placed on teaching physics through biological examples. Here, two undergraduate-level lab experiments, one dealing with buoyancy and the other with heat transfer, are described. The two labs were designed specifically to appeal to pre-med students taking introductory physics, and their novelty arises from the use of a bratwurst sausage as a miniature model cadaver. Results suggest that the sausage provides a suitable approximation to the mass density and thermal properties of the human body.

The challenge of teaching physics to pre-health students

For some decades now, pre-med and pre-health students have viewed physics as largely irrelevant to their discipline,[3,4] as compared with, say, the content of an introductory or advanced biology course. Many consider their physics course as merely a necessary hurdle that they have to overcome in order to show aptitude for entering medical school or other advanced degree programs. As a result, these students are largely unmotivated by anything other than the course grades they will have affixed to their academic transcripts, and pose a formidable challenge for the instructor. Such is the situation at Creighton University, a modest liberal arts institution that is affiliated with a medical school, where roughly 70% of the students enrolling in introductory physics describe themselves as pre-health (many of these majoring in biology or exercise science).

Recently, several faculty in the physics department at Creighton attended a conference[5] on Introductory Physics for the Life Sciences (IPLS) and returned with a rejuvenated attitude toward reaching these challenging students. Motivated also by impending changes to the Medical College Admission Test (MCAT) to be launched in 2015, the department decided to rebrand its preexisting calculus-based introductory physics course as an algebra-based IPLS course targeted to pre-med enrollees. Along with this revision came a careful reflection about what course content to keep or discard, and where in the course (lecture or lab) the remaining content might best be delivered. All of this necessitated the invention of or, at the very least, the revision of lab activities to more clearly connect the physics principle under investigation to some life or health sciences context in the hopes that students would better engage with the subject. The development of these labs was initiated in fall 2014 for those first-semester topics including statistics, fluids, and thermodynamics. Out of this project came the development of two rather novel lab activities, one on buoyancy and the other on thermal conduction, in which a bratwurst sausage successfully performed the duty of a miniature cadaver model.

Fig. 1. Photograph of a typical bratwurst sausage next to a meterstick for scale.

Lab format

The lab was offered as an independent one-credit course, intended to be taken concurrently with the lecture course, that consisted of two hours of lab activity and one hour (common) weekly recitation. The enrollment in fall 2014 was 108 students. The recitation was used primarily to introduce and reinforce the subject content on statistics, fluids, and thermodynamics—developing both concepts and problem-solving skills—but also served as a common timeslot for the lecture course to administer its three exams during the semester. During the two-hour lab activity, students were each given a lab handout that provided a guided inquiry through the day's experiment(s). Students worked in four groups of three under the supervision of a teaching assistant and each was assigned a role: leader (keeps the group on task), analyst (in charge of properly collecting data), or scribe (responsible for completing the handout). Each group submitted a single completed handout at the end of the session, which their lab instructor would grade and return the following week.

Lab handouts

Examples of most of the lab handouts that were used in fall 2014 can be downloaded at *TPT Online*.[6] While not uniformly applied, an effort was made to start the lab activities with a conceptual-level investigation before proceeding to the main, more data-intensive experiment. In preparation for the lab, a pre-lab exercise and reading assignment were posted online the week before. Often these pre-lab activities took the form of focused tutorials on learning how to, for example, use Excel or Tracker[7] or use logarithmic-scaled graph paper. A brief description of all the labs used during the fall 2014 is provided in Table I.[8]

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Labs that employed a bratwurst sausage to model a human cadaver

A. Buoyancy in hydrostatic weighing for percent body fat determination

Motivation

In an era when more than 50% of adult Americans are clinically obese, methods for accurately determining the percentage of body fat in a patient have gained renewed significance. Although largely replaced by more convenient air displacement[9] or electrical impedance[10,11] methods, for many years the gold standard for measuring body fat was hydrodensitometry or "hydrostatic weighing." In this approach, the clinical protocol involves obtaining the patient's mass (usually employing a hanging scale) and apparent mass, or "wet" mass, when fully submerged in a tank of water. Archimedes' principle then allows the displaced volume to be determined and, after small corrections in the volume are made for internal gas pockets (lungs, intestine), the average density of the patient's nongaseous matter, ρ_{body}, is obtained. The percent body fat (PBF) is often calculated using a commonly cited formula[12] that assumes fat, with a density $\rho_{\text{fat}} = 0.9$ g/cm^3, is intermixed with composite matter (bones, tissues, organs, etc.), with a density $\rho_{\text{tissue}} = 1.1$ g/cm^3,

$$\text{PBF} = (495/\rho_{\text{body}} - 450)\%, \tag{1}$$

where ρ_{body} is expressed in g/cm^3. The derivation of this formula is straightforward and relies on equivalent expressions of the body mass,

$$M_{\text{body}} = \rho_{\text{body}} V_{\text{body}} = \rho_{\text{fat}} V_{\text{fat}} + \rho_{\text{tissue}} V_{\text{tissue}} = \rho_{\text{fat}} V_{\text{fat}} + \rho_{\text{tissue}} \left(V_{\text{body}} - V_{\text{fat}} \right),$$

where V_{body} is the total volume of the body (excluding gaseous voids), V_{fat} is the volume of fat, and V_{tissue} the volume of tissue. This can be rearranged to obtain

$$\text{PBF} = \frac{M_{\text{fat}}}{M_{\text{body}}} = \frac{\rho_{\text{fat}}}{\rho_{\text{body}}} \frac{V_{\text{fat}}}{V_{body}} = \frac{\rho_{\text{fat}}}{\rho_{\text{body}}} \left(\frac{\rho_{\text{tissue}} - \rho_{\text{body}}}{\rho_{\text{tissue}} - \rho_{\text{fat}}} \right),$$

from which the Siri formula arises.

Bratwurst sausage (each approx. 90 g, 13 cm x 2.5 cm diameter) were purchased at a local grocery store in packages of five. An example is shown in Fig. 1. These sausages have an average density of 1.06 ± 0.01 g/cc that corresponds to a percent body fat of approximately 20 (± 5), which is consistent with the fat content listed on the package labeling. A complete list of equipment required for the lab is given in Table II.

Activity

The first 10 minutes of activity focused on conceptual understanding using interactive examples like the Cartesian diver and/or baking soda submarines that required students to explain the observed phenomena in the context of Archimedes' principle. This was then followed by a more quantitative study lasting roughly 40 minutes in which students partially

Table II. List of equipment for the two bratwurst labs.

Lab 5: Buoyancy and Hydrostatic Weighing	Lab 8: Heat Transfer and Time of Death
digital balances (2000 g max, ±0.1-g resolution)	blocks of wood and metal
Cartesian divers	digital balances (2000 g max, ±0.1-g resolution)
Graduated cylinders (100 ml)	two digital thermometers (meat probe style)
Aluminum and plastic round rods on fishing line able to fit cylinders	package of bratwurst sausages (refrigerated in an ice chest)
package of bratwurst sausages (refrigerated in an ice chest)	two Styrofoam cups (20 oz) capable of submerging a sausage
tall soda cup (32 oz) capable of submerging a sausage	microwave oven
string with small hook for supporting sausage	dispensing cooler of iced water
lab post and cross beam for securing support string	disposable gloves
disposable gloves	stopwatches

submerged either aluminum or plastic rods into a graduated cylinder of water and recorded both the buoyant force and volume displacement. Here the emphasis was on developing skills in data collection and graphical data analysis (a plot of buoyant force versus displaced volume produces a line with slope related to the density of water), and this second task generally consumed the remainder of the first hour of the session.

It is worth mentioning that students did not determine buoyant force from the apparent weight (equal to the tension in the supporting string) as is often illustrated in textbooks. Because the density of the bratwurst sausage is so nearly equal that of water, this tension becomes vanishingly small in comparison with the dry weight and challenging to measure accurately. Instead, students were guided by a pre-lab exercise to recognize how the buoyant force of the water on the sausage produces an equal but opposite, third law force of the sausage on the water. As a result, this buoyant force just equals the increase in the apparent weight of the water that can be readily measured by a digital scale placed beneath the container.

The remaining hour of the lab time was devoted to determining the percent body fat of the sausage, affectionately referred to as "Brat" (masculine) or "Brathy" (feminine) in the lab handout.[13] Modeling the clinical protocol, students first obtained the dry mass of the sausage using the digital scale. Next they filled a tall container with a sufficient amount of water for the sausage to be completely submerged without touching the bottom of the container. As illustrated in Fig. 2, the sausage was suspended in the water by a string with a hook and its vertical position could be controlled using a support post. The container was placed on the digital scale

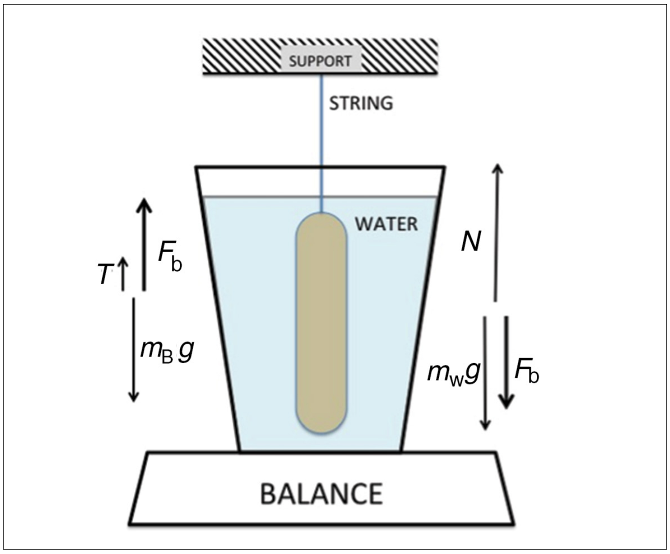

Fig. 2. Drawing of the hydrostatic weighing of Brat described in the text. A free-body diagram for the bratwurst sausage is depicted on the left and a free-body diagram of the water is shown on the right. The buoyant force acts as a third law force between these two objects and causes the normal force of the balance to increase by an amount equal to the buoyant force.

and the wet (i.e., apparent) mass of the sausage was then determined. From these two measurements, students then determined the displaced volume of the sausage and the average body density. Lastly, students determined the percent body fat using the standard formula [Eq. (1) above], but they were also coaxed to show how this relation could be derived.

Results and reflections

Students generally obtained average densities between 1.05 and 1.08 g/cc and reported body fat percentages between 20 and 30, which are on the lower edge of clinical obesity for humans.[14] Lab instructors were encouraged to reveal the packaging information to students after they had obtained their result to help confirm their findings. The lab handout asked students to reflect both on the relevance of the model to actual measurements conducted on a human subject and on the challenges of correcting for gaseous voids like the lungs. Students were also asked to reflect on how their understanding of obesity in the average American adult might have changed as a result of their study. Many students were surprised to learn that the truly obese patients have, pound for pound, more fat than a bratwurst sausage. The most common error some students made was allowing the sausage to contact the bottom of the container when submerged, and this introduced an unintended error in measuring the buoyant force.

B. Heat transfer and determining the time of death

Motivation

Algor mortis is the Latin term used by forensic pathologists to describe the gradual cooling of the body following death, and measurements of the body's core temperature are often used to estimate the approximate time at which death occurred.[15,16] The physics of the cooling process combines Newton's law of cooling with the finite heat capacity of the body and predicts an exponential decay of body temperature (difference from ambient) with time,

$$\Delta T = \Delta T_0 \, e^{-\lambda t}, \tag{2}$$

where ΔT_0 is the initial temperature difference and λ is the decay constant. Of course, in real situations the process is complicated by details of the environmental conditions and contact surfaces as well as insulating properties of the corpse itself. Nevertheless, an often-referenced rule of thumb[16] treats the cooling as a linear process with an average rate of 0.8 °C per hour for typical room temperature conditions (20 °C). Thus for a body temperature near 37 °C, the body is halfway cooled in roughly 10–12 hours and this provides an order of magnitude estimate for the corresponding time constant ($\tau = \lambda^{-1}$) expected in the exponential decay.

Activity

A complete list of equipment needed is provided in Table II. Again, the first 15 minutes of activity focused on conceptual understanding of heat transfer. Students were asked to hold a metal block in one hand and a wooden block in the other, and judge which block "felt" colder and then reason out their sensation given the presumed common temperature of both objects. Next, the lab handout introduced students to the subject of *algor mortis*, emphasizing the dual roles of both Newton's law of cooling,

$$\frac{Q/A}{t} = -\kappa_T \frac{\Delta T}{\Delta x}, \tag{3}$$

and the specific heat of a body,

$$Q = m_B C_B \Delta T_B. \tag{4}$$

Here, Q is a quantity of heat, A is the cross-sectional area of the conduction path, κ_T is the thermal conductivity, $\Delta T/\Delta x$ is the thermal gradient, m_B is the mass of the body, C_B is its specific heat, and ΔT_B is the corresponding change in temperature. Students were cautioned that cooling rates for a real situation are complicated owing to a variety of ambient and contact conditions but that 10 hours or so represents an order of magnitude timescale for which an adult human corpse would cool halfway to ambient. The following scenario was then proposed for means of investigation:

> *Brathy decides to treat her inflammation by soaking in a tub of cold water. The water is icy cold (near 0 °C) and when she starts to get in, she suffers a massive coronary attack and dies. As her body cools it transfers its energy into the water, causing the latter to warm.*

During the next 45 minutes, students were tasked to reenact this event in a laboratory setting where measurements of both the core temperature of the sausage and the water can be carefully recorded. A typical record of observations (obtained by the author when drafting the lab) is summarized by Fig. 3 for a 90-g sausage initially heated to 40 °C in the microwave then immersed into a bath containing 410 g of water at 2 °C in a double-walled Styrofoam cup. Having obtained a set of data like that in Fig. 3, students then spend the remaining hour analyzing the results to obtain C_B, κ_T, and λ. Treating the system as isolated, students are justified in using the first law of thermodynamics to determine the effective heat capacity of the cadaver and find a typical value of $C_B = 4.06 \pm 0.05$ kJ/kg·K. Students then determine the temperature difference between the sausage and the water and plot this on a sheet of semi-log ruled paper (this is another learning goal of the labs) to obtain the slope, related to the rate constant of the exponential decay discussed above (using the data in Fig. 3, we get $\lambda = |\text{slope}/\log_{10}e| \approx 0.074\ \text{min}^{-1}/0.43 \approx 0.17\ \text{min}^{-1}$) in Eq. (2). Students are told that this temperature difference should decay exponentially, and a brief derivation is sketched to show that the decay rate is related to both the specific heat and thermal conductivity of the cadaver as

$$\lambda = \left\{ \frac{1}{m_B C_B} + \frac{1}{m_W C_W} \right\} \left[\frac{\kappa_T A}{\Delta x} \right], \tag{5}$$

where m_W is the mass of water and $C_W = 4186$ J/kg·K is the specific heat of water. Approximating the surface area of the sausage as that of a right cylinder and taking the $\Delta x \approx$ radius, students determine the thermal conductivity of the sausage to be roughly $\kappa_T = 0.85 \pm 0.05$ W/mK. Finally, students are pressed to evaluate the cadaver model more thoroughly by applying scaling concepts to infer how Eq. (5) above would change for the situation of a life-sized corpse whose mass and volume are roughly 1000 times larger. The result, assuming a similar scaling of the bathwater, is

$$\lambda' = \left\{ \frac{1}{m'_B C_B} + \frac{1}{m'_W C_W} \right\} \left[\frac{\kappa_T A'}{\Delta x'} \right]$$
$$= \frac{1}{1000} \left\{ \frac{1}{m_B C_B} + \frac{1}{m_W C_W} \right\} \left[\frac{\kappa_T (100A)}{(10\Delta x)} \right] = \frac{1}{100} \lambda$$

and results in $\lambda' = 0.0017\ \text{min}^{-1} \approx 0.1\ \text{h}^{-1}$, corresponding to a characteristic timescale ($\tau' \approx 10$ h) that is remarkably close to the order of magnitude value specified earlier.

Results and reflections

Students generally obtained results in rough agreement with that obtained from the data shown in Fig. 3. Upon obtaining a value for λ^{-1} (≈ 6 min), students are asked to compare this with the order of magnitude value cited in the introduction and comment on why Brathy seems to cool off much faster than a human corpse. In a follow up, students are asked to reflect on how features of body size (mass, surface area, volume) influence the rate of cooling and consider what this means for properly clothing an infant against a winter chill.

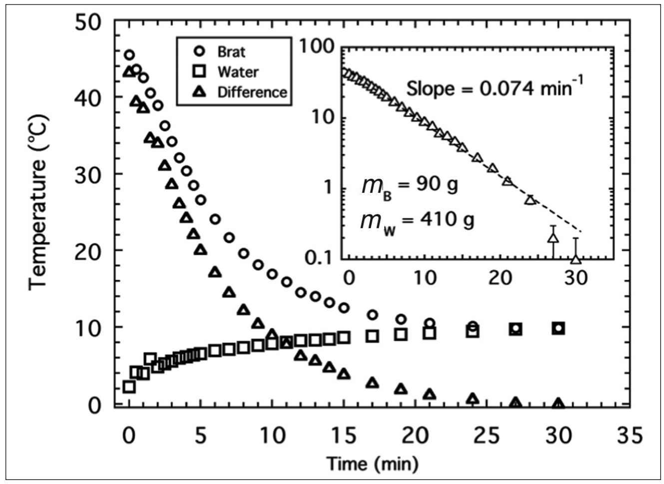

Fig. 3. Example of results for the heat transfer study of a bratwurst sausage cooling in a cup of chilled water. The temperature difference between the core temperature of the sausage and the temperature of the water (shown as open triangles) is well described by an exponential decay as illustrated by the semi-log plot inset.

Summary

Feedback collected at the semester end indicated a pleasing degree of student satisfaction with these two bratwurst lab experiments. A total of 72 valid responses to the survey question "Which lab activities did you most or least appreciate?" were tallied and contained 26 responses in favor of either or both of the bratwurst sausage labs as most enjoyable or interesting of the 10 labs that were executed during the semester:

> *I really liked all the labs that included [bratwurst sausage]. Those activities really allowed me to grasp the concepts and applied them to the human body or brat body!"*

> *"I appreciated the 'Time of Death' lab the most. I thought this lab did a good job of conveying the concepts of physics and how they apply to everyday life. I felt as if I learned the most in this lab and also enjoyed doing this lab."*

Only five responses indicated dislike for the sausage labs, citing some disgust about working with the sausages, despite the availability of disposable gloves that were provided:

> *"I didn't appreciate the [bratwurst sausage] labs very much. Out of all the labs I thought they were the least helpful. And the brats were pretty gross by the time we got to using them."*

Also, several exercise science majors who completed the buoyancy lab had earlier in the same week been taught hydrostatic weighing as part of an unrelated course in their exercise science department. Many of these students commented to their lab instructors that the buoyancy lab using a sausage was especially helpful to their understanding of this percent body fat technique. The next most popular lab activities (see Table I[8]) were Lab 4 (six favorable responses) and Lab 2 (six favorable and three unfavorable responses). The least popular was Lab 6 (one favorable and 12 unfavorable responses).

Despite the positive comments regarding these two lab activities, satisfaction with the course overall remained low. The separation of the lab and its content from the lecture course was an unfamiliar departure from how students had previously experienced other science courses. In their introductory chemistry and biology courses, the lab activities were carefully synchronized with lecture content so that students interpreted lab to function as a reinforcement of the same course content. However, in the IPLS format that was adopted in fall 2014, the lab activities did not mirror the content being covered in the (separate) lecture course. Indeed, topics in the lab were often introduced using concepts such as "force" and "energy" before these terms had yet been fully developed in the lecture. This departure from the traditional lecture/lab format, along with the perception by students that they were being forced to study additional topics beyond those being covered in the lecture course, generated a fair bit of frustration.

All in all, given the simplicity of the cadaver model, including its affordability and ready availability at most supermarkets, the density and thermal properties were remarkably lifelike and provided a good model of the human body sufficiently accurate for undergraduate-level labs. Furthermore, use of the model allowed students to better connect the underlying physics principles (buoyancy, heat transfer) to meaningful, real-life situations found in the life sciences.

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