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Course Portfolio for Assessing Student Learning Surrounding Biological Examples in BSEN244: Thermodynamics of Biological Systems

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Thermodynamics is a course required in many engineering disciplines as it covers concepts utilized in many upper level engineering courses. In the Biological Systems Engineering Department at the University of Nebraska – Lincoln, this course, in a way, acts as a gateway to the major since this will be one of the first classes where the students must apply and hone their problem-solving skills. This course was developed to allow students in the department to have access to a thermodynamics course that relates to their major area of interest – biological systems. However, many concepts in thermodynamics do not have a good, direct biological correlate that can be used to engage student interest. Therefore, my goal in putting together this portfolio was to assess whether introducing thermodynamics concepts within a biological framework improved student learning. To do this, two separate but related concepts were introduced, one without any biological examples and one with. The students were then quizzed on the concepts at the end of the week they were introduced in class. Overall, the class performed significantly better on the quiz assessing concepts that were introduced within a framework of biological systems. This was most pronounced for students with average performance in the quiz assessing concepts introduced without biological examples, whereas high performing students performed well regardless of how the concepts were introduced. These findings suggest that introducing thermodynamics concepts within the framework of biological systems to Biological Systems Engineering majors improves student learning.

Keywords: engineering, bioengineering, thermodynamics

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MEMO 1: Objectives of Peer Review Course Portfolio

Description of the Course

BSEN244, Thermodynamics of Biological Systems, is a course all Biological Systems Engineering students (typically 30–40 but this year had 60) take in the Spring of their sophomore year. It is a prerequisite for BSEN344 that is taken in the Spring of Junior year. The overall goal of BSEN244 is to introduce students to the basic concepts of thermodynamics within the framework of biological systems. In a way, the course acts as a gateway to the major since this will be one of the first classes where the students must apply and hone their problem-solving skills. Prerequisites for the course include introductory biology, chemistry, physics, and calculus. Thus, all the students that enter the class should have had some formal problem-solving skill training, although there is significant variability in their ability to apply these skills. Students who find they do not enjoy problem-solving will likely find the rest of the major difficult as problem-solving becomes more in depth in later courses. Students who do well in this course will have developed the skills necessary to thrive in later engineering courses as well as the basic concepts of thermodynamics that will be required in future courses and careers.

Learning objectives:

- Applied problem-solving skills
    - Learn when and how to utilize equations for solving thermodynamics problems
- Basic thermodynamic concepts
    - Zeroth, first, second, third laws of thermodynamics
    - Open and closed systems, pure substances
    - Specific heat, enthalpy, entropy
    - Gibb’s free energy
- Relation between these thermodynamic concepts and biological systems

This course was developed by an established BSEN faculty member, George Meyer, who taught it for nearly 15 years before I took it over. I chose to write a portfolio about this course since it already provides a strong framework for applying problem-solving skills, but may greatly increase student interest, learning, and retention of basic thermodynamic concepts if was better kept within the framework of biological systems, the students’ major. Teaching the course this last year, I noticed students were most engaged when I would go through example problems on the board. However, I seemed to lose many students when introducing new concepts unless these concepts were introduced well within a biological framework. As an engineering student myself, thermodynamics was a course I thoroughly did not enjoy, and I could not see its relevance to later courses in the curriculum. Thus, I did poorly compared to my other courses and didn’t fully appreciate the concepts that were introduced. It wasn’t until I took a later elective course that utilized thermodynamics to describe a biological phenomenon of interest to me (protein folding) that these basic concepts made sense and have stuck with me since then. Therefore, my goal for BSEN244 is to increase the likelihood of each student meeting the basic thermodynamics concepts learning objective by increasing the relevance to students within the major.

Objectives for this Portfolio

By creating this portfolio, I hope to establish strategies to improve relation of thermodynamic concepts with biological systems as well as determine how these strategies affect student engagement, learning, and short-term retention. Thus, I will use this portfolio as a formal way of refining this course by measuring how the changes I make impact outcome and establishing how to make changes that will result in a positive impact on outcome. This will allow the portfolio to be used by other faculty looking to develop a similar course or that will one day take over this course. The portfolio will also be used for promotion and tenure.

MEMO 2: Teaching Methods, Activities, and Materials

In the Classroom

On the first day of class students are given a “get to know you” sheet with questions about previous engineering courses they have taken (if any), their major interest in and reason for majoring in Biological Systems Engineering, and their hobbies. This sheet has been incredibly useful for introducing concepts in a way that is hopefully engaging for the student and writing problems that are also familiar and interesting to them. After this, the syllabus is reviewed in class to reduce as much as possible any confusion about expectations, and the objectives and brief overview of the course are given. For the remaining classes, the majority of in class time is used for traditional lectures with PowerPoint slides, example problems worked through on the board and as small groups, and in class demonstrations of thermodynamic tools and devices, and small amount of time given to quizzes to continually assess learning.

Introduction to concepts

The largest change in this course as compared to previous years is the greater use of biological examples to introduce basic thermodynamic concepts. It is hoped that students’ interest in biology will aid in their understanding of these newer concepts. Students are expected to be first introduced to concepts through assigned readings (*vida infra*) that will prepare them for lecture; however, depending on the student this isn’t always necessary and many students use the readings as a supplement to concepts that weren’t fully clear from the lecture. Lectures on concepts are PowerPoint based and take students through the concept background and how it is applied. Many of these concepts do not have direct, obvious biological counterpart and thus have been introduced without a biological example. The goal of this portfolio is to determine if the inclusion of biological examples helps with student learning and retention. This will be done initially by comparing student learning between concepts that are introduced with and without a biological example. This should also eventually be assessed by comparing student performance on quizzes when questions are posed within or out of a biological framework.

PowerPoint lectures are used to introduce concepts as they provide a visual basis for the students to take notes on and make it easier for the instructor to keep focus on the material during class rather than trying to remember the order to present it in. PowerPoint slides are also made available to the students so that they can review concepts using the visual aids to remember specific lecture components and provide them a material to take notes on.

Example problems

Problem solving is a large component of this course and the students find the examples worked out in class to be useful. These example problems are chosen from problems at the end of each chapter in the textbook, examples given in the chapter that are highly important for understanding the material, or made up to be relevant and interesting to the current class.

The problem is introduced during class time similar to how a problem would be presented in a homework assignment. The students are then typically asked where they would start to solve the problem, and at times students are asked to work individually or in small groups to try to solve the problem. It is always made very clear that this is the place for mistakes to be made as these students are typically terrified of making a mistake. By making these early, low-risk mistakes, students can really solidify their understanding of the material and problem-solving process. Depending on the prior understanding of the material, the problem is then either briefly gone through or worked out in detail on the board.

In class demos

In class demonstrations are used to expose students to real-world applications of the thermodynamic concepts and problems they are currently working through. These can include humidity and dew point calculations from psychrometer measurements (dry bulb and wet bulb temperature) they make, thermal camera measurements, manometers, etc. Especially with the psychrometer measurements and subsequent calculations, students can use the data they generate to practice their problem-solving using concepts very familiar to them in different terms. This can allow them to self-correct if they find their answer doesn't match what they know it should (e.g., a hot, humid day in the late spring should not give a low wet bulb temperature, which would suggest low humidity. Thus, students should recognize their low humidity calculation seems inaccurate.). This activity also allows students to work together and learn these concepts from one another.

For example, one in class activity was use of a simple sling psychrometer to measure dry and wet bulb temperatures. The students were shown how to use the device and then formed teams to measure these temperatures outside. They then needed to use these measurements to initially calculate specific and relative humidity as well as the enthalpy and specific volume of the moist air, which they turned in as a group quiz. This was followed up a couple weeks later with another group quiz activity where the students again used the sling psychrometers to measure dry and wet bulb temperatures, but this time use the psychrometric chart to determine specific and relative humidity, enthalpy, specific volume, and dew point of the moist air.

Weekly quizzes

Quizzes are given approximately weekly and take 15 minutes of in class time. Questions on student understanding of concepts, problem solving ability, and real-world application are possible. These quizzes provide the major tool for gauging student learning during the semester in this class. If a large portion of class struggles with the quiz question, we will typically spend the next 15-30 minutes of class solving and explaining the quiz question/s.

Final exam

The final exam is comprehensive and is the only real exam in this course. We typically spend the last week of class reviewing previous concepts and solving example problems on the board. The final homework also includes questions from each concept presented throughout.

Outside of Classroom

Students are expected to spend time out of class preparing themselves for lecture and practicing solving problems. This is motivated by assigned readings and graded homework problem sets. The textbook used for this course is a custom printing of Thermodynamics for Living Systems, BSEN 244, ISBN 13:9780390929808, prepared by McGraw-Hill Create. Students may also use the hard copy Fourth Edition of Thermodynamics - an Engineering Approach by Y.A. Cengel and M.A. Boles.

Homework

Homework sets typically include between 5 and 10 problems depending on the complexity of the problem. Problems are chosen to guide students through out-of-class learning of concepts and to give practice problem-solving. They are either chosen from problems given in the back of the book, are altered versions of example problems given in the text or during class, or are made up to be relevant and interesting to the current class. Homework problems that give a large number of students a problem are typically solved and explained in class to ensure understanding.

Assigned readings

Readings are assigned prior to the class that will be covering the concepts. These are provided to students to help supplement their understanding of the material so that questions can be asked during class to clear up any confusion. However, the readings are not required nor are there ever reading checks to ensure they have been completed. Oftentimes, students find the readings more useful after class to help solve or answer the homework problems.

MEMO 3: Analysis of Student Learning

To compare how inclusion of a biological example to present a thermodynamics concept may help students learn, understand, and retain this information, I utilized the pure substances lectures and work lectures. Pure substances lectures present very important concepts that are used throughout the rest of the semester, so understanding these concepts is critical to do well in the class. Most importantly, these lectures are used to introduce students to the use of the property tables in the back of the book and what each of the properties mean and tell us about the state of the substance. Work lectures provide an early introduction into the types of calculations that will be used throughout the semester as well as teaching the students how to determine which equation to use for the problem they are trying to solve. While the work equations aren't specifically used throughout the rest of the semester, the experience with learning how to plan a strategy for solving thermodynamics problems is important and used throughout the rest of the semester.

Pure Substances Lecture Leading to Quiz 5

The lectures presenting the pure substances concepts were not presented with any biological examples, but familiar examples were used. These include looking at specific property changes of water and steam in a closed boiling pot as well as property changes of refrigerant R-134a after heating, cooling, compression, and expasion.

Work Lecture Leading to Quiz 6

The lectures presenting the thermodynamics work concepts did include some biological examples. These included contractile forces of muscles, boundary work in pulmonary ventilation, and examples of work against gravity to lift something off the ground. There were also examples presented that were not biologically related including calculations with springs, shaft rotations, and acceleration of vehicles.

Quiz 5 and 6 Questions

Quiz 5 and quiz 6 require similar calculations but assess concepts presented in their respective lecture sets. Quiz 6 did require understanding of material assessed in quiz 5 in order to do well. Neither quiz used a biologically-related question or problem to solve. Problems given for quiz 5 and 6 are shown in **Figure 1**. Both questions require the use and understanding of the properties tables in the back of the book as well as an understanding what the terms quality factor, saturated liquid, and saturated vapor mean in the context of thermodynamics. Quiz 6 required the additional understanding of the concept of thermodynamic work, and specifically which equation is appropriate to use to calculate boundary work.

QUIZ #5 (1 question, 20 points total)
(***Clearly show all equations, units, calculations, and mark answers***)

1. You have two closed systems each contained within its own 20L rigid tank. Tank (a) contains water at 200 kPa with a quality factor of 0.0327. Tank (b) contains R-134a at 1 MPa and 124.1414ºC.

   1.1. What are the phase descriptions of the substances in the two tanks?

   1.2. How do the temperatures of the two tanks compare?

   1.3. Which tank contains more mass of substance?

   1.4. What are the internal energies of the two tanks and which is higher?

QUIZ #6 (1 question, 20 points total)
(***Clearly show all equations, units, calculations, where you found values, and mark answers***)

1. A frictionless piston-cylinder device has an initial volume of 10 L and contains saturated liquid water at 200 kPa. You add heat to this system until all the water has become a saturated vapor. Determine the boundary work during this isobaric process.

Figure 1. Problems given to students for quizzes 5 and 6.

Quiz Score Analyses

The grade distributions for quizzes 5 and 6 are shown in **Figure 2**. Many students did quite poorly on quiz 5 showing a lack of understanding of key terms and how they relate to the properties tables. There is a major shift in scores outside of the mid-range and up into the high-range between quizzes 5 and 6 showing the marked increase in scores when assessing concepts that were introduced within a biological framework.

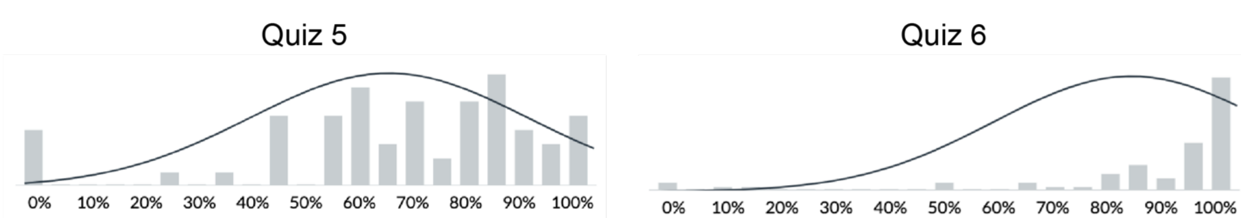


Figure 2. Distributions of student scores for quizzes 5 and 6.

The average score for quiz 5 was 67 ± 25% with a median of 70% and the average score for quiz 6 was 84 ± 24% with a median of 90% (**Figure 3**). Out of 60 total students, four students did not take quiz 5 and two students did not take quiz 6. This 17% increase in average score was statistically significant ($p < 0.001$) as determined by a paired t test where student scores were paired between quizzes. This suggests that inclusion of biological examples when introducing concepts in class may be helpful for student learning and retention likely because of increased interest in the subject.

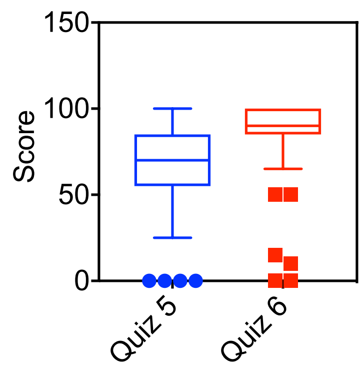


Figure 3. Box and whisker plots for student scores on quizzes 5 and 6. Outliers determined using the Tukey method are shown, but were still used in the data analyses. There was a significant increase ($p < 0.001$) in student score for quiz 6 as determined by paired t test.

To dig a little deeper into the data, low-performing, average-performing, and high-performing individuals were placed into these three categories based on being below the 25th percentile (low-performing), near median between the 25th and 75th percentiles (average-performing), and at or above the 75th percentile (high-performing) on quiz 5. For quiz 5 the 25th percentile was 55% and the 75th percentile was 85%. Low, high, and average performer average scores are shown in **Figure 4**. Examples of student work are provided in the Appendix. Out of all 12 of the low performers on quiz 5, all but two performed better on quiz 6. Average scores for these low performers on quiz 5 was 46.7%, which improved to 67% on quiz 6. This suggests the low performers improved their understanding of the material when it was presented within the framework of a biological example, improving their scores from an average of failing to a high D grade. Out of all 20 of the high performers on quiz 5, all but 6 performed better on quiz 6. Average scores for these high performers on quiz 5 was 91.4% and on quiz 6 was 92.5%, showing no statistical difference. This shows the high performers learned the material regardless of how it was presented in class. Of the 24 average performers that scored between the 25th and 75th percentile, all but one scored better on quiz 6. Average scores for these average performers on quiz 5 was 69.8%, which significantly improved to 93.1% on quiz 6. This suggests that the inclusion of biological examples while presenting thermodynamics concepts is most helpful for the average performing students. These students improved theirs scores from a high D to an A letter grade when biological examples were included in the lecture, strongly supporting improved learning and retention.

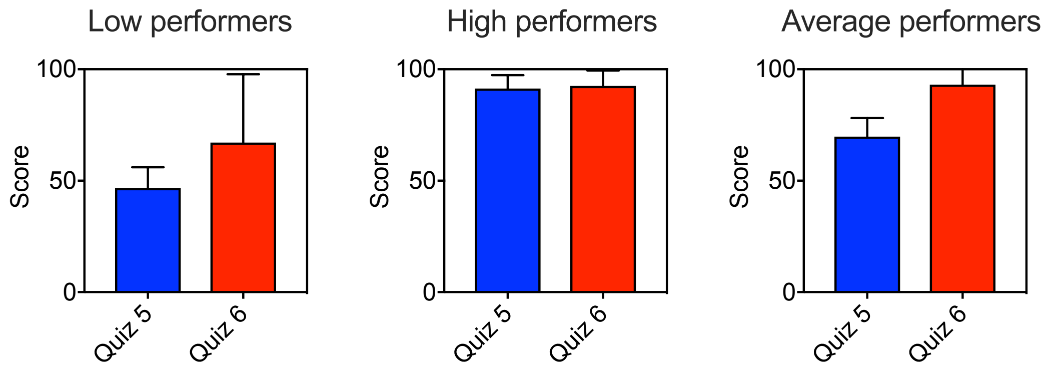


Figure 4. Box plots of average scores for low, high, and average performers on quiz 5 and how their scores changed on quiz 6. There was a significant increase in score for the low ($p < 0.05$) and average performers ($p < 0.001$), but no significant difference in scores for the high performers ($p = 0.47$) as determined by paired t test.

SUMMARY: Reflection on the Course

The first class "get to know you" sheet was helpful for finding common student interests to tailor example problems and quiz questions around. When concepts were introduced around the framework of student hobbies and interests and when example problems related to these hobbies and interests were solved, students seemed to be much more engaged during class time. Additionally, introducing concepts and example problems using biological examples maintained student focus during lecture and helped them better understand and retain the information, as I found from comparing quiz scores between concepts introduced with and without a biological example.

The sling psychrometer in class activity was very well received and should be repeated. Having this as a team/group quiz allowed students to teach each other humidity calculations and use of the psychrometric chart. Although the sling psychrometer in class activity went well for the most part, some groups still had poor performance on the quiz they turned in. Perhaps not allowing the students to self-select groups will help next year so I can place students that seem to be struggling with the concept with those that seem to understand it well. However, there was once instance this year with the self-selected groups that the one knowledgeable student obviously did all the work while the other struggling students paid no attention to the activity. Nevertheless, placing students in groups could help with those mid-performers that actually care to learn the materials and would benefit from being paired with a high-performer.

The short weekly quizzes forced the students to keep up on the materials and reduced the need for larger homework assignments. The quizzes also allowed me to see how well the students were keeping up on the material and where additional time should be spent in class. These were instrumental in ensuring students were staying caught up on lecture materials. I gave detailed feedback to each student on their quiz so that they could review how to best solve the problem and where they made any mistakes. Many students claimed to readily check these graded quizzes and found the feedback helpful. While the weekly quizzes were incredibly useful, grading these quizzes to see what concepts might need to be repeated took a lot of time, especially where detailed information on how to better or accurately solve the problem was included. Perhaps solving every quiz in class right after they finish will help solidify understanding and prevent the need for detailed grading.

The current objectives for this course are relevant for what the students need to achieve in passing this course and moving on to upper level engineering courses. By putting together this portfolio, I was able to strategically think about and plan how to achieve these objectives through in and out of class activities as well as continually assessing how the class was progressing. This backwards design of the course made tailoring each lecture, activity, and quiz related to help meet the overall objectives of the course much clearer. Intentionally framing lectures and assessments around the course objectives gave me a large boost in confidence in teaching this course to provide students with their best chance of success in later courses. After this formal portfolio process, I definitely plan to use this process to improve teaching and student outcomes in my other courses although perhaps in a less formal layout. However, there are many other questions I have regarding changes I want to or have thought of making to this class. Therefore, I look forward to becoming involved in the second year program to learn how to design a more formal and scientific assessment of course redesign.

The data generated while putting this portfolio together suggest that both low and average performing students benefit from including a biological example relevant to their interests while introducing concepts and that high performers score well regardless. However, there are many possible confounding variables that need to be considered when analyzing this data. First, the students may have had another large homework or exam in another class they are taking around the same time as quiz 5 was given. This could have led to reduced time spent reviewing material for this course prior to the quiz. Additionally, the low scores the average and low performing students got on quiz 5 may have given them additional motivation to study for quiz 6 to improve their overall grade in the class. There could also be differences in student perception of difficulty when they first saw quiz 5 that could have led to lower scores. For example, perhaps the four part question, which was given to help the students navigate to the final answer, caused the students to freeze up, or the non-round numbers, which were used to give a nice round final answer, may have made the problem seem overly complicated. Finally, after the overall poor performance on quiz 5, I told the students I would shave my beard in any style they choose if they performed better on quiz 6, which may have given them additional motivation to do better. Therefore, these findings, although interesting, should be validated by repeating the same lead-up lectures and similar quiz questions for next year's course. Additionally, data should be generated to determine if framing the quiz question around a biological framework helps with student performance.

Appendix

Examples of student work

Name Low-performer

Biological Systems Engineering 244
Thermodynamics for Living Systems

QUIZ #5 (1 question, 20 points total)
(***Clearly show all equations, units, calculations, and mark answers***)

1. You have two closed systems each contained within its own 20L rigid tank. Tank (a) contains water at 200 kPa with a quality factor of 0.0327. Tank (b) contains R-134a at 1 MPa and 124.1414°C.

1.1. What are the phase descriptions of the substances in the two tanks?

Water: Liquid-vapor ✓ R-134a: Superheated vapor ✓

x = quality factor = $\frac{m_{vapor}}{m_{total}}$ = .0327

↳ must have vapor + liquid

1.2. How do the temperatures of the two tanks compare?

-5 The temperature of the tank with water is at a higher temperature

What are the temperatures? R-134a is at a higher temperature

1.3. Which tank contains more mass of substance?

Tank w/ Water contains more mass of substance.

show calculations

-5 $m = \frac{V}{v}$

1.4. What are the internal energies of the two tanks and which is higher?

water ≈ 950 kJ/kg R-134a ≈ 330 kJ/kg

$u = u_f + x \cdot u_{fg}$ = 570.7 kJ/kg u ⇒ interpolate from table = 331 kJ/kg

Water has the higher internal energy of the two show calculations

-5

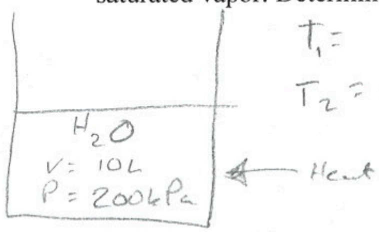
This low-performer on quiz 5 student showed a basic understanding of certain concepts, but did not fully grasp the terms and their exact meaning and how to use them in calculations. For example, "liquid-vapor" was used instead of the correct term, "saturated mixture" although no points were taken off since they showed an understanding of the phase of the substance. However, the student showed no comprehension on how to apply terms such as quality factor, superheated vapor, and specific volume to perform the necessary calculations. Overall, the student scored 5 points out of a total 20 points possible – a 25%.

Name Low-performer

Biological Systems Engineering 244
Thermodynamics for Living Systems

QUIZ #6 (1 question, 20 points total)
(***Clearly show all equations, units, calculations, where you found values, and mark answers***)

1. A frictionless piston-cylinder device has an initial volume of 10 L and contains saturated liquid water at 200 kPa. You add heat to this system until all the water has become a saturated vapor. Determine the boundary work during this isobaric process.



$T_1 = 120.23°C$

$T_2 = 150°C$ (to get to vapor)

$P_1 = 200$ kPa

$V = 10$ L

$P_2 = 200$ kPa

not at 200kPa

10 L = 10kg $m = \frac{V_1}{v_1}$

Density = 1 for water

$v_1 = v_f@200kPa = 0.001061\ m^3/kg$

$V_1 = \frac{.8857 m^3}{kg}$ (10 L)

$v_2 = v_g@200kPa = 0.8857\ m^3/kg$

$V_2 = \frac{.9596 m^3}{kg}$ (10 L)

Can't assume $V_2 = V_1$, otherwise $W_b = 0$

$W_b = P\,dV$ ✓

$W_b = 200(9.596 - 8.857) = 147.8$

This low-performer student from quiz 5 performed much better on quiz 6 although still did not show a strong grasp of the material. The student still showed an inability to apply terms such as saturated liquid and saturated vapor to find the correct values in the table to perform the correct calculations. However, the student was able to correctly identify the correct equation to use for boundary work in an isobaric process, a concept that was presented within a biological framework, perhaps suggesting a greater interest and retention in concepts presented in these more biological-related lectures. Overall, the student scored 10 points out of a total 20 points possible – a 50%.

Name Mid-performer

Biological Systems Engineering 244
Thermodynamics for Living Systems

QUIZ #5 (1 question, 20 points total)
(***Clearly show all equations, units, calculations, and mark answers***)

1. You have two closed systems each contained within its own 20L rigid tank. Tank (a) contains water at 200 kPa with a quality factor of 0.0327. Tank (b) contains R-134a at 1 MPa and 124.1414ºC.

1.1. What are the phase descriptions of the substances in the two tanks?

(a) go to P table for water, since $u_f < u < u_g$ its a saturated mixture ✓

(b) go to P table for R-134a, since $T > T_{sat}$ its a superheated vapor ✓

1.2. How do the temperatures of the two tanks compare?

(a) P table H_2O (sat. mix.) – 120.23°C ✓

(b) T table R-134a (sup. vap.) – 39.39°C

−2 $T_B \neq T_{sat} @ 1MPa$ because it is superheated $T_B = 124.1414°C$

1.3. Which tank contains more mass of substance?

(a) 20L | kg / 1L = 20 kg

$P = \rho g h$

$200000 = 1(9.8)h$

use v from tables $m = \frac{V}{v}$

(b) $PV = RT$

$1000(20) =$

20L | kg / 0.03L? = 667 kg

−5

1.4. What are the internal energies of the two tanks and which is higher?

(a) P table water (sat. mix) ≠ u_f – 504.49 kJ/kg

$U = U_f + x \cdot U_{fg}$ −1.5

(b) T table R-134a (sup. vap.) ~ interpolate

$y = 326.93 + \left(\frac{124.1414 - 120}{130 - 120}\right)(336.88 - 326.93)$ ✓

$y = 331.05\ kJ/kg$ ✓

This mid-performer on quiz 5 student grasped certain concepts and made a series of similar mistakes seen with many of the mid-performers. The student showed they understood how to use the table, but was not quite comfortable with how to apply terms such as quality factor, superheated vapor, and specific volume to perform the necessary calculations. Overall, the student scored 11.5 points out of a total 20 points possible – a 57.5%.

Name Mid-performer

Biological Systems Engineering 244
Thermodynamics for Living Systems

QUIZ #6 (1 question, 20 points total)
(***Clearly show all equations, units, calculations, where you found values, and mark answers***)

1. A frictionless piston-cylinder device has an initial volume of 10 L and contains saturated liquid water at 400 kPa. You add heat to this system until all the water has become a saturated vapor. Determine the boundary work during this isobaric process. * assume constant P

1L = 0.0001 m^3

$\frac{10L}{} \frac{0.0001 m^3}{1L}$

H_2O @ 400kPa | * Table A5 |

Isobaric: $W_b = P_o(V_2 - V_1)$ ✓

$V_i = 0.001 m^3 = V_1$ -0.5

* $v_i = 0.001084 m^3/kg$ ✓ v_2 = sat. vap. = 0.4625 m^3/kg * ✓

$V_i = m v_i$ ✓

0.001 = 0.001084 m

m = 0.923 kg H_2O

off by 10x

$V_2 = m v_2$ ✓

$V_2 = 0.4625(0.923)$

$V_2 = 0.4269 m^3$

off by 10x

$W_b = 400(0.4269 - 0.001)$

$W_b = 170.36 kJ$ off by 10x.

This mid-performer student from quiz 5 performed much better on quiz 6. The student showed a much stronger grasp of how to apply terms such as saturated liquid and saturated vapor to find the correct values in the table to perform the correct calculations. Additionally, the student was able to correctly identify the correct equation to use for boundary work in an isobaric process, a concept that was presented within a biological framework. The student was deducted half a point for use of the wrong conversion factor for converting between cubic meters and liters, which was given to them (likely just copied down wrong). Overall, the student scored 19.5 points out of a total 20 points possible – a 97.5%. The mid-performing students typically performed significantly better in the quiz that assessed concepts presented within a biological framework suggesting increased engagement in the material and retention of concepts.

Aw-

Name High-performer

Biological Systems Engineering 244
Thermodynamics for Living Systems

QUIZ #5 (1 question, 20 points total)
(***Clearly show all equations, units, calculations, and mark answers***)

1. You have two closed systems each contained within its own 20L rigid tank. Tank (a) contains water at 200 kPa with a quality factor of 0.0327. Tank (b) contains R-134a at 1 MPa and 124.1414°C.

1.1. What are the phase descriptions of the substances in the two tanks?

a) saturated mixture (liquid-gas) ✓

b) Superheated vapor ✓

1.2. How do the temperatures of the two tanks compare?

$Temp_a = 120.23°C$ ✓ (T_{sat} @ 0.2 MPa)

Tank b is at a higher temperature ✓

(see back)

1.3. Which tank contains more mass of substance? Neither

$V_a =$ $v_g = 0.8857\ m^3/Kg$, $v_f = 0.001061\ m^3/Kg$

$v_{avg}\ (m^3/Kg) \cdot m_{tot}\ (Kg) = V_f \cdot m_f + V_g \cdot m_g$

Assume 1Kg: (Find Vm)

Volume $(m^3) = (0.001061\ m^3/Kg)(0.9673\ Kg) + (0.8857\ m^3/Kg)(0.0327\ Kg)$ ✓

Volume $(m^3) = 0.0300\ m^3$ for 1Kg mass ✓

$\frac{0.0300\ m^3}{1\ Kg} = \frac{0.02\ m^3}{x\ Kg}$ $x = 0.67\ Kg$ (a)

$V_b =$

temp / v: $\frac{130 - 120}{0.03058 - 0.02959} = \frac{124.1414 - 120}{v - 0.02959} \Rightarrow 10v - 0.2959 = 0.00410$ ✓ $\Rightarrow 10v = 0.3000 \Rightarrow v = 0.03000$

1.4. What are the internal energies of the two tanks and which is higher?

a: $u = u_f + x u_{fg} = 504.49 + 0.0327 * 2025.0 = 570.7\ KJ/Kg$ (a) ✓ (KJ/Kg)

A is higher

b: Temp / u: $\frac{130 - 120}{338.14 - 328.31} = \frac{124.1414 - 120}{u - 328.31}$ ✓ $\Rightarrow 10u - 3283.1 = 41.414$

$\Rightarrow 10u = 3241.686$ ✓

$u = 324.17\ KJ/Kg$ (b)

1

This high-performer on quiz 5 student completely grasped the concepts and showed they understood how to use the table as well as apply terms such as quality factor, superheated vapor, and specific volume to perform the necessary calculations. Overall, the student scored 20 points out of a total 20 points possible – a 100%.

Name High-performer

Biological Systems Engineering 244
Thermodynamics for Living Systems

QUIZ #6 (1 question, 20 points total)
(***Clearly show all equations, units, calculations, where you found values, and mark answers***)

1. A frictionless piston-cylinder device has an initial volume of 10 L and contains saturated liquid water at 400 kPa. You add heat to this system until all the water has become a saturated vapor. Determine the boundary work during this isobaric process.

$P = 400\ \text{KPa}$ $\quad v_f = 0.001084\ \text{m}^3/\text{Kg}$ ✓ $\quad v_g = 0.4625\ \text{m}^3/\text{Kg}$ ✓ $\quad W_b = P_0(V_2 - V_1)$ ✓ or $mP_0(v_2 - v_1)$ ✓ nice!

Find m: Initially...

$$10\,\text{L} \cdot \frac{1000\,\text{mL}}{1\,\text{L}} \cdot \frac{1\,\text{cm}^3}{1\,\text{mL}} \cdot \frac{1^3\,\text{m}^3}{100^3\,\text{cm}^3} \cdot \frac{1\,\text{Kg}}{.001084\,\text{m}^3} = 9.225\,\text{Kg} \checkmark$$

$$W_b = mP_0(v_2 - v_1) = (9.225\,\text{Kg})(400\,\text{KPa})(0.4625\,\text{m}^3/\text{Kg} - 0.001084\,\text{m}^3/\text{Kg}) \checkmark$$

$$= 1702.625\ \text{KPa}\cdot\text{m}^3 = \boxed{1702.625\ \text{KJ}} \checkmark$$

$$\frac{1\,\text{KJ}}{1\,\text{KPa}\cdot\text{m}^3} \checkmark$$

This high-performer student from quiz 5 also performed very well on quiz 6. The student still showed a strong grasp of how to apply terms such as saturated liquid and saturated vapor to find the correct values in the table to perform the correct calculations. Additionally, the student was able to correctly identify the correct equation to use for boundary work in an isobaric process, a concept that was presented within a biological framework. Overall, the student scored 20 points out of a total 20 points possible – a 100%. The high-performing students seemed to score well regardless of how the material was presented.

THERMO: LIVING SYS BSEN244 SEC 001 Spring 2019

Jump to Today ✎ Edit

Biological Systems Engineering 244

Thermodynamics for Living Systems

Syllabus—Spring Semester 2019

University of Nebraska-Lincoln

East Campus - 116 Chase Hall

Forrest Kievit, Assistant Professor

Department of Biological Systems Engineering

University of Nebraska-Lincoln

228 Chase Hall

Lincoln, NE 68583-0726

Office Phone: 402-472-2175

E-Mail: fkievit2@unl.edu

Office Hours: TBA or by CANVAS/email anytime.

COURSE DESCRIPTION

This course is an introduction to the laws of thermodynamics and their application to physical, biological, and environmental engineering systems. Topics include first, second, and third laws, open and closed systems, pure substances, specific heat, enthalpy, entropy, Gibb's free energy for selected biological and environmental systems. Applications include manometers, metabolic energy, psychrometrics, introductory heat transfer, biomechanical work, blood flow work, refrigerator and heat pump efficiencies, entropy production, water potential, surface tension, osmosis, and selected biochemical reactions. Important thermodynamic cycles are also presented as they apply to physical and living systems.

COURSE OBJECTIVES

Having successfully completed this course, students should be able to:

1. Comfortably apply problem-solving skills to engineering-based questions
2. Understand and apply basic thermodynamic concepts

- Understand the nature of heat and work as these terms apply to both closed and open physical or biological systems.
- Apply the first law to solve energy flow problems for physical, biological and environmental systems and their surroundings.
- Develop an understanding of the second law, solve problems, and that energy in different forms has different utility.
- Understand cycles in broader context of heat engines and heat production in biological systems.
- Use psychrometrics to calculate sensible and latent heat exchanges between living organisms and their aerial environment.
- Understand the concept of Gibb's free energy.

3. Apply thermodynamic concepts to biological and agricultural systems

ABET Criterion 3 outcomes:

1. An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.

6. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.

7. An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

PREREQUISITES

BIOS 101 and 101L, or BIOS 102, CHEM 110 or 114, MATH 208 and PHYS211, or instructor permission.

FORMAT AND MEETING TIMES

3 credit hours: 3 hours of lecture per week.

Lectures: Monday/Wednesday/Friday: 3:00 - 3:50 p.m., 116 Chase, East Campus.

All cell phones and laptops must be turned off during a lecture. No exceptions.

TEXTBOOK AND CONTENT

The textbook to be purchased for this class is a custom printing of Thermodynamics for Living Systems, BSEN 244, ISBN 13:9780390929808, prepared by McGraw-Hill Create. This paperback edition is available at the bookstore (2-7300). Students may also use the hard copy Fourth Edition of Thermodynamics - an Engineering Approach by Y.A. Cengel and M.A. Boles, but that hardcover will be more expensive and may be also limited in availability. All required readings are expected to be done before the designated lecture.

Important Note: Do not purchase the fifth, sixth, or any other later editions by Cengel and Boles, because those texts will not match the content of the text used in this course.

CANVAS LEARNING SYSTEM

Each student has been assigned an account on the CANVAS Learning System at https://my.unl.edu/webapps/portal/frameset.jsp. Each student is also expected to have a current e-mail address listed on CANVAS. Be sure to check that your email address is correctly listed. During the semester, homework assignments with due dates and times, quiz schedules, general announcements, website links, and supplemental handouts will be posted on Canvas. The CANVAS calendar will be used to announce lecture topics and other significant events. Be sure to check the calendar regularly for supplemental materials including lecture slides. Students may also check their current numerical grade scores on Canvas. Letter grades will not be assigned until the end of the course.

HOMEWORK

Homework assignments are announced both on CANVAS and during class. Answers and solution steps to homework problems must be written on standard engineering paper, which may be purchased from office supply stores in Lincoln or online. All homework problems must be clearly written using only the front side only of the engineering paper. The back side of engineering paper is to be used only for graphing! Do not crowd your work.

For numerical problems, use the problem solving technique prescribed by Cengel and Boles (section 1-13). Short narrative answers need not follow this prescription. The problem solving technique consists of what information is Given, what information is Sought, the Assumptions used, Property data, a detailed Analysis with units included with the appropriate equations, and a clearly marked final answer. Answers must be presented only in the requested units for the problem assigned (either SI or English). Typically, approximately 100 home work problems will be assigned during the semester with another 50 solved, as examples during class. Therefore, weekly homework assignments will consist of 5- 15 problems, depending on the length, scope, and complexity of the problems.

SUBMISSION OF HOMEWORK (*IMPORTANT!*)

All homework is first written out on your engineering paper and then submitted electronically as a PDF document, using the Canon Image Runner found in Chase 114. A UNL Print IT kiosk may be also used to scan your homework. Scans have to be readable!

During the submission process, <u>a student first scans his/her hand written homework to a single PDF document</u> and then emails the PDF scan to his/her email account. <u>From the student's account, he/she next checks the document for scan quality and readability</u>; and finally <u>uploads the PDF homework document into Canvas</u> for grading. Use only a short 4-character reference file name (e.g., HWK1). Each student has a personal holding area in CANVAS for each homework assignment and quiz. The student keeps his/her hardcopy.

Homework is due electronically no later than 11:59 p.m. on the day posted. Please do not submit homework as a hardcopy or as an email attachment. If you have a CANVAS submission problem, first email the instructor. Late assignments are automatically marked by CANVAS! Homework not approved for submission after the due date and time will receive zero points! This policy will be strictly enforced.

EXAMINATIONS

For this class, examinations consist of approximately weekly scheduled quizzes and a final exam. Quizzes will be approximately 20 minutes in length. Prior to each quiz, students will have an opportunity to ask review questions or to clarify the material previously covered. The quizzes may be either closed or open book depending on the content. The final two hour examination (scheduled for 7:30 to 9:30 a.m., Thursday, May 2 2019 in 116 Chase Hall) will be open book and will cover the entire material for the semester.

All quizzes will be done on paper during class and uploaded to CANVAS after grading by the TA for your score review.

PROFESSIONALISM

Students will be graded on professionalism during class time and in interacting with the instructor and TAs and includes attendance, punctuality, participation, activities during class time, etc. Attendance is always expected and may be taken at anytime, unless a prior arrangement for an excused absence has been made with the instructor. If you have an upcoming excused absence planned, please notify the instructor prior to the absence. Make-up quizzes will not be given, unless that absence has been initially approved.

GRADING

Grading consists of earned numerical points, which are tabulated for each student assignment, quiz, and the final exam during the semester. An approximate overall percentage breakdown for homework, quizzes, final exam, and professionalism points is given below. However, for the purposes of assigning the student's final letter grade, the student's total earned score will be divided by the total number of possible points to arrive at a final percentage score (based on 100%).

	Approximate Percent of Final Grade
Homework Assignments	30%
Quizzes	30%
Final Exam	30%
Professionalism	10%

Assignment of letter grades:

Percentage of total points (x)	Final Grade
x ~> 90, rarely makes minor mistakes in HW and exams	A range (A-, A, A+)

80 ~< x ~< 90, rarely makes major mistakes in HW and exams	B range (B-, B, B+)
70 ~< x ~< 80, often makes major mistakes in HW and exams	C range (C-, C, C+)
60 ~< x ~< 70, major mistakes are dominant in HW and exams	D range (D-, D, D+)
x ~< 60, showed minimal effort	F

STUDENTS WITH DISABILITIES

Students with disabilities are encouraged to contact Dr. Kievit for a confidential discussion of their individual needs for academic accommodation as determined by Services for Students with Disabilities (SSD). This includes students with mental health disabilities like depression and anxiety. It is the policy of the University of Nebraska-Lincoln to provide individualized accommodations to students with documented disabilities that may affect their ability to fully participate in course activities or to meet course requirements. To receive accommodation services, students must be registered with SSD which is located in 232 Canfield Administration (472-3787).

ACADEMIC HONESTY

Academic honesty is essential to the existence and integrity of an academic institution. The responsibility for maintaining that integrity is shared by all members of the academic community. The University's **Student Code of Conduct (http://stuafs.unl.edu/DeanofStudents/Student%20Code%20of%20Conduct%20May%20Rev%202014%20a.pdf)** addresses academic dishonesty. Students who commit acts of academic dishonesty are subject to disciplinary action and are granted due process and the right to appeal any decision. The BSE Department process for grade and academic dishonesty appeals can be found at **http://bse.unl.edu/academicadvising-index (http://bse.unl.edu/academicadvising-index)** . Students are encouraged to contact the instructor for clarification of these guidelines if they have questions or concerns.

BACKGROUND OF YOUR INSTRUCTOR

Dr. Forrest Kievit is an Assistant Professor of Biological Systems Engineering (40% teaching, 50% research, 10% service) and started at the University of Nebraska in 2016. Dr. Kievit earned his B.S. in Bioengineering (2007) and Ph.D. in Materials Science and Engineering (2011), both at the University of Washington, followed by postdoctoral and research faculty positions in the Neurological Surgery Department. His research involves developing nanoparticle-based delivery vehicles for transport into the brain for more effective brain cancer and brain injury treatments. This stems from his career goal to help translate a nanomedicine into clinical use to improve the survival and quality of life of neurosurgery patients. The vast majority of Kievit's research has focused on nanoparticle-mediated delivery of nucleic acids into brain tumors. Looking forward, he plans to continue developing nanoparticles that will allow for greater flexibility in therapeutic payload and disease targeting, including brain injury.

https://kievit.unl.edu/welcome (https://kievit.unl.edu/welcome)

BACKGROUND FOR THE COURSE (revised from Dr. Meyer)

Biological and Biomedical Engineers need to fully understand and utilize various sources of free energy in their analyses and design applications, which often involve dynamic and non-equilibrium processes. These include interactions between a resource sector (also referred to as the natural resources base typically withdrawn from the air, land, and water) and a storage, processing, or manufacturing sector. The two pieces fit together to form a single discipline. Ultimately, both physical and biological materials must return from storage, processing, or manufacturing back to the resource sector as the ultimate repository. Biological engineers are concerned with the issues associated with the sustainable operation of this and similar cycles. Biological, biomedical, and environmental applications always use the laws of classical thermodynamics, but the subject matter goes beyond thermostatics. Such approach is not an entirely new concept at the undergraduate engineering level, since chemical engineering thermodynamics and physical chemistry probe into their respective application areas, as well. Applications and energy cycles, involving biological and environmental systems have been addressed by prominent scientists and engineers over the last seventy years. It is now the time to introduce this material at the undergraduate level in an efficient, but single introductory course. “Thermodynamics of Living Systems” is, therefore, a foundation course for the Biological Engineer. Plants, animals, humans, and biological systems require a continual input of free energy. If sources of free energy are removed, organisms and other related biological processes drive toward equilibrium or consequent cessation of life. In order to understand biological and environmental processes, students must apply the Gibb's free energy function, which is the combination of the first and second laws of thermodynamics. Most classical treatments of thermodynamics are better-named “thermostatics.” Those concepts are usually covered in only a few weeks. However, most biological and environmental systems, non-equilibrium and dynamic conditions require an understanding of not only thermal, but also chemical, electrical, and diffusion potentials, as well.

The realm of thermodynamic equilibria for biological systems encompasses interactions between environmental and living systems. For bioprocessing, students study the thermal, chemical, and processing of biological materials. The study of plant growth and development is also a key part of the water and environment emphasis. Water quality and aquatic life (algae, microorganisms, and plant populations in riparian zones and wetlands) are likewise important. Bioprocesses include cell culture (microorganisms, plants, or animals) to manufacture a product. Biological engineering is a logical extension of engineering principles to the analysis of biological phenomena, and includes the area of biomedical engineering. Bioengineering resides at the interface of biological sciences, engineering sciences, mathematics and computational sciences. It focuses on biological systems for enhancing the quality and diversity of life. Health and safety of workers in industrial environments, animals in confinement, plant culture in controlled environments, and analysis of the mechanics of various physiological activities in higher level organisms are examples of topics studied. Bioinstrumentation applies to quantitative measurement of the welfare of humans and animals and enhancement of plant growth. The use of synthetic materials or biomaterials to the reconstruction of biological parts may be an important alternative to cloning. Construction of synthetic parts must include the study of mechanics, strength of materials, and thermodynamics (work).

Course Topics are subject to change according to the pace of the class. The current schedule will be updated and posted on the CANVAS calendar.

Course Summary:

Date	Details	
Mon Jan 7, 2019	BSEN 244 Introductory Lecture (https://canvas.unl.edu/calendar?event_id=64364&include_contexts=course_52868)	3pm to 3:50pm
Wed Jan 9, 2019	Closed and Open Systems, States, and Equilibrium (https://canvas.unl.edu/calendar?event_id=64378&include_contexts=course_52868)	3pm to 3:50pm
Fri Jan 11, 2019	Processes and Cycles. Forms of Energy. Energy and Environment (https://canvas.unl.edu/calendar?event_id=64379&include_contexts=course_52868)	3pm to 3:50pm
	Quiz 1 (https://canvas.unl.edu/courses/52868/assignments/386207)	due by 3pm
Mon Jan 14, 2019	Temperature and Pressure (https://canvas.unl.edu/calendar?event_id=64360&include_contexts=course_52868)	3pm to 3:50pm
Wed Jan 16, 2019	Manometers and demo (https://canvas.unl.edu/calendar?event_id=64380&include_contexts=course_52868)	3pm to 3:50pm
Fri Jan 18, 2019	Food and Exercise (https://canvas.unl.edu/calendar?event_id=64365&include_contexts=course_52868)	3pm to 3:50pm
	Quiz 2 (https://canvas.unl.edu/courses/52868/assignments/386208)	due by 3pm
Mon Jan 21, 2019	NO CLASS - Martin Luther King Day (https://canvas.unl.edu/calendar?event_id=64381&include_contexts=course_52868)	3pm to 3:50pm
Wed Jan 23, 2019	Pure Substances, Saturation Vapor, Saturation Temperature and Pressure (https://canvas.unl.edu/calendar?event_id=64366&include_contexts=course_52868)	3pm to 3:50pm
	Assignment 1 (https://canvas.unl.edu/courses/52868/assignments/386194)	due by 11:59pm

Date	Details	
Fri Jan 25, 2019	Property Diagrams Property Tables (https://canvas.unl.edu/calendar?event_id=64382&include_contexts=course_52868)	3pm to 3:50pm
	Quiz 3 (https://canvas.unl.edu/courses/52868/assignments/386209)	due by 3pm
Mon Jan 28, 2019	Equations of State Ideal Gas Law Internal Energy, Enthalpy, Specific Heat (https://canvas.unl.edu/calendar?event_id=64383&include_contexts=course_52868)	3pm to 3:50pm
Wed Jan 30, 2019	NO CLASS - Dr. Kievit on travel (https://canvas.unl.edu/calendar?event_id=64369&include_contexts=course_52868)	3pm to 3:50pm
	Assignment 2 (https://canvas.unl.edu/courses/52868/assignments/386198)	due by 11:59pm
Fri Feb 1, 2019	NO CLASS - Dr. Kievit on travel (https://canvas.unl.edu/calendar?event_id=64384&include_contexts=course_52868)	3pm to 3:50pm
	Quiz 4 (https://canvas.unl.edu/courses/52868/assignments/386210)	due by 11pm
Mon Feb 4, 2019	Mechanical and Non-mechanical Work (https://canvas.unl.edu/calendar?event_id=64385&include_contexts=course_52868)	3pm to 3:50pm
Wed Feb 6, 2019	Biological Work and Heat Special Topics (https://canvas.unl.edu/calendar?event_id=64368&include_contexts=course_52868)	3pm to 3:50pm
Fri Feb 8, 2019	Three Mechanisms of Heat Transfer (https://canvas.unl.edu/calendar?event_id=64359&include_contexts=course_52868)	3pm to 3:50pm
	Quiz 5 (https://canvas.unl.edu/courses/52868/assignments/386770)	due by 3pm
Mon Feb 11, 2019	Mechanisms of Heat Transfer (https://canvas.unl.edu/calendar?event_id=64362&include_contexts=course_52868)	3pm to 3:50pm
	Assignment 3 (https://canvas.unl.edu/courses/52868/assignments/386199)	due by 11pm
Wed Feb 13, 2019	First law of Thermodynamics Energy balance of closed system (https://canvas.unl.edu/calendar?event_id=64371&include_contexts=course_52868)	3pm to 3:50pm

Date	Details	
Fri Feb 15, 2019	Energy Balance for Steady-Flow Processes (https://canvas.unl.edu/calendar?event_id=64386&include_contexts=course_52868)	3pm to 3:50pm
	Quiz 6 (https://canvas.unl.edu/courses/52868/assignments/386771)	due by 3pm
Mon Feb 18, 2019	Energy Balance for Steady-Flow Processes (https://canvas.unl.edu/calendar?event_id=64363&include_contexts=course_52868)	3pm to 3:50pm
Wed Feb 20, 2019	Energy Balance for Steady-Flow Processes (https://canvas.unl.edu/calendar?event_id=64387&include_contexts=course_52868)	3pm to 3:50pm
Fri Feb 22, 2019	Non-Steady-State Flow (https://canvas.unl.edu/calendar?event_id=64372&include_contexts=course_52868)	3pm to 3:50pm
	Assignment 4 (https://canvas.unl.edu/courses/52868/assignments/386200)	due by 11:50pm
Mon Feb 25, 2019	Thermal Properties of Foods (https://canvas.unl.edu/calendar?event_id=64388&include_contexts=course_52868)	3pm to 3:50pm
Wed Feb 27, 2019	Second Law of Thermodynamics (https://canvas.unl.edu/calendar?event_id=64389&include_contexts=course_52868)	3pm to 3:50pm
Fri Mar 1, 2019	Thermal Efficiency Carnot Efficiency (https://canvas.unl.edu/calendar?event_id=64370&include_contexts=course_52868)	3pm to 3:50pm
	Quiz 7 (https://canvas.unl.edu/courses/52868/assignments/386773)	due by 3pm
Mon Mar 4, 2019	Refrigerators and Heat Pumps (https://canvas.unl.edu/calendar?event_id=64390&include_contexts=course_52868)	3pm to 3:50pm
	Assignment 5 (https://canvas.unl.edu/courses/52868/assignments/386201)	due by 11:59pm
Wed Mar 6, 2019	Carnot Cycles and Heat Engines (https://canvas.unl.edu/calendar?event_id=64391&include_contexts=course_52868)	3pm to 3:50pm
Fri Mar 8, 2019	Entropy Production and Removal (https://canvas.unl.edu/calendar?event_id=64392&include_contexts=course_52868)	3pm to 3:50pm
	Quiz 8 (https://canvas.unl.edu/courses/52868/assignments/386774)	due by 3pm

Date	Details	
Mon Mar 11, 2019	Entropy Change of Pure Substances (https://canvas.unl.edu/calendar?event_id=64367&include_contexts=course_52868)	3pm to 3:50pm
Wed Mar 13, 2019	Isentropic Processes (https://canvas.unl.edu/calendar?event_id=64393&include_contexts=course_52868)	3pm to 3:50pm
Fri Mar 15, 2019	Entropy Change of Liquids, Solids and Gases (https://canvas.unl.edu/calendar?event_id=64394&include_contexts=course_52868)	3pm to 3:50pm
	Assignment 9 (https://canvas.unl.edu/courses/52868/assignments/386205)	due by 11:59pm
	Quiz 9 (https://canvas.unl.edu/courses/52868/assignments/386775)	due by 11:59pm
Mon Mar 18, 2019	NO CLASS - Spring Vacation (https://canvas.unl.edu/calendar?event_id=64373&include_contexts=course_52868)	3pm to 3:50pm
Wed Mar 20, 2019	NO CLASS - Spring Vacation (https://canvas.unl.edu/calendar?event_id=64395&include_contexts=course_52868)	3pm to 3:50pm
Fri Mar 22, 2019	NO CLASS - Spring Vacation (https://canvas.unl.edu/calendar?event_id=64396&include_contexts=course_52868)	3pm to 3:50pm
Mon Mar 25, 2019	Psychrometric Properties (https://canvas.unl.edu/calendar?event_id=64397&include_contexts=course_52868)	3pm to 3:50pm
Wed Mar 27, 2019	Psychrometric Processes (https://canvas.unl.edu/calendar?event_id=64398&include_contexts=course_52868)	3pm to 3:50pm
Fri Mar 29, 2019	More Psychrometrics (https://canvas.unl.edu/calendar?event_id=64361&include_contexts=course_52868)	3pm to 3:50pm
	Quiz 10 (https://canvas.unl.edu/courses/52868/assignments/386776)	due by 3pm
	Informed consent (https://canvas.unl.edu/courses/52868/assignments/448612)	due by 11:59pm
Mon Apr 1, 2019	Thermodynamics of Crop Water Stress (https://canvas.unl.edu/calendar?event_id=64402&include_contexts=course_52868)	3pm to 3:50pm
Wed Apr 3, 2019	Free Energy and Chemical Potential (https://canvas.unl.edu/calendar?event_id=64403&include_contexts=course_52868)	3pm to 3:50pm

Date	Details	
Fri Apr 5, 2019	Gibb's free energy (https://canvas.unl.edu/calendar?event_id=64404&include_contexts=course_52868)	3pm to 3:50pm
	Quiz 11 (https://canvas.unl.edu/courses/52868/assignments/386777)	due by 3pm
	Assignment 10 (https://canvas.unl.edu/courses/52868/assignments/386195)	due by 11:59pm
	Assignment 6 (https://canvas.unl.edu/courses/52868/assignments/386202)	due by 11:59pm
Fri Apr 12, 2019	Quiz 12 (https://canvas.unl.edu/courses/52868/assignments/386778)	due by 3pm
	Assignment 11 (https://canvas.unl.edu/courses/52868/assignments/386196)	due by 11:59pm
Mon Apr 15, 2019	Assignment 7 (https://canvas.unl.edu/courses/52868/assignments/386203)	due by 11:59pm
Fri Apr 19, 2019	Quiz 13 (https://canvas.unl.edu/courses/52868/assignments/386779)	due by 3pm
	Quiz 14 (https://canvas.unl.edu/courses/52868/assignments/386780)	due by 3pm
	Assignment 12 (https://canvas.unl.edu/courses/52868/assignments/386197)	due by 11:59pm
Mon Apr 22, 2019	Semester Review (https://canvas.unl.edu/calendar?event_id=64399&include_contexts=course_52868)	3pm to 3:50pm
Wed Apr 24, 2019	Semester Review (https://canvas.unl.edu/calendar?event_id=64400&include_contexts=course_52868)	3pm to 3:50pm
	Assignment 8 (https://canvas.unl.edu/courses/52868/assignments/386204)	due by 11:59pm
Fri Apr 26, 2019	Semester Review (https://canvas.unl.edu/calendar?event_id=64401&include_contexts=course_52868)	3pm to 3:50pm
	Honors Contract Presentation Questions (https://canvas.unl.edu/courses/52868/assignments/468405)	due by 3:50pm
Thu May 2, 2019	Final Exam (https://canvas.unl.edu/courses/52868/assignments/386206)	due by 7:30am
	Keep-Start-Stop (https://canvas.unl.edu/courses/52868/assignments/440648)	
	Professionalism (https://canvas.unl.edu/courses/52868/assignments/389017)	
	Roll Call Attendance (https://canvas.unl.edu/courses/52868/assignments/386213)	