
AC 2012-4346: A CREATIVE INTRODUCTION TO ENTROPY

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A Creative Introduction to Entropy

Abstract

Developing pedagogical tools to explain engineering principles is a continuous process. A collaborative effort between The League of Imaginary Scientists and the University Departments of Art and Mechanical Engineering created a multi-level, interactive art installation introducing entropy and the second law of thermodynamics. This installation allows the visitor to stand on a platform to simulate an earthquake causing damage to a building. As this happens, a graphical representation demonstrates the level of disorder or entropy as a fan levitates ping-pong balls. The amount of disorder is decreased when the building is reconstructed. Another product of this collaboration was a 99 second video explaining entropy. The video can be used as a pedagogical tool across all disciplines to initiate discussion topics such as ethics and global issues facing society. Additionally, entropy can be a portal into some questions about deeper issues such as: 1) what is the cause of disorder, 2) do we live in an isolated system, and 3) how can order be restored?

Last, a multiple choice test was developed to measure the students' understanding of entropy after visiting the exhibit. This test evaluated their understanding of how entropy relates to mechanical systems, health, interpersonal and international relations. The test was administered to all levels of undergraduates in three different courses. A mean test score above 80% for all the courses show that most of the students properly understood the definition of entropy. Understanding improved by 8 to 10 percentage points with additional requirements to write an essay and another 3 to 6 percentage points with a 50 minute lecture.

Although it may not be necessary to use for every topic, integrating experiential pedagogical tools is an excellent way to enhance a student's knowledge.

Introduction

Providing proper educational needs for engineering students requires an understanding of basic foundational principles and laws. Some students start learning this information through a shroud of confusion or partial understanding. In this technological society, professors are inventing ways to engage their students while maintaining the integrity of engineering education. The discussion of results from a collaboration between several universities determined that students may not always understand a topic or how it can be applied in industry. ⁽¹⁾ Additionally, professors believe that once students matriculate through their program an increased interest in the discipline would occur. ⁽¹⁾

Engaging students through interactive learning is not a onetime occurrence. Heller et. al. investigated student and faculty perceptions of engineering engagement. ⁽²⁾ It was found that first year students defined engagement as faculty interest and involvement along with interactions with faculty. Once faculties were removed from the equation, students defined engagement as their work on a project, participating in course groups, outside

work or research. Comparatively, second year engineering students defined engagement as active participation and hands-on activities.⁽²⁾

Student participation in laboratory or demonstration exercises in conjunction with a lecture produces a more positive learning outcome.⁽³⁾ Although these demonstrations are useful, critical thinking skills are necessary to transform classroom knowledge into practical application. Students who are asked to explain what they experienced are better able to think critically. Unfortunately, if a student is not required to explain their experience, answers based on partial or incorrect understanding are more likely to occur.⁽³⁾

In summary, students who are engaged with various forms of learning have a richer educational experience. A combination of lectures, discussions, interactive learning and demonstrations create a learning environment which is challenging for both the instructor and the student. But this rich learning environment helps a student better understand concepts and gives them the proper tools to critically think and apply those concepts.

This paper explains how a multi-level interactive art installation was used to help students understand entropy. Often entropy is introduced as some esoteric concept which is difficult to comprehend. Sometimes the application of entropy to a particular problem can be difficult but the concept is quite simple when viewed as a measurement of disorder. This simple definition aligns well with Albert Einstein's proverb, "If you can't explain it to a six year old, you don't understand it yourself."

Before this project an assortment of marbles was used to illustrate entropy in the first semester thermodynamics course. Prior to the start of class, a large container of assorted marbles with several smaller containers labeled by color were left at the front of the classroom. The students were instructed to sort the marbles by color. During lecture, the sorted marbles would be mixed to illustrate the increase in entropy.

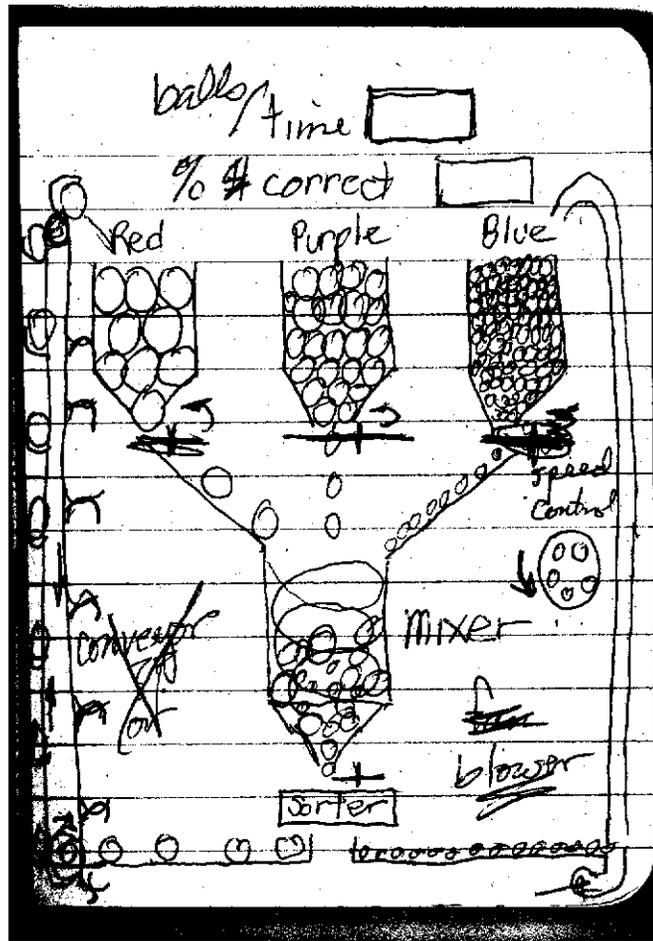
The League of Imaginary Scientists and the Department of Art solicited the Science and Engineering Departments for ideas about collaborative projects. In response to their solicitation, it was suggested by this paper's first author to develop an interactive device to better explain the thermodynamic term entropy. They liked the idea and a new collaboration with the Department of Mechanical Engineering was born.

The outcomes of this collaboration included an art installation and a video. The video uses the definition of entropy as a portal to understanding life on this planet. Others have made this connection in the areas of biology⁽⁴⁾, veterinary science⁽⁵⁾, linguistics⁽⁶⁾, manufacturing⁽⁷⁾, medicine⁽⁸⁾, biomedical⁽⁹⁾ and library science⁽¹⁰⁾.

Procedure

Figure 1 contains a sketch of the initial concept. This portable device would be automated in order to mix and sort the various colors of balls.

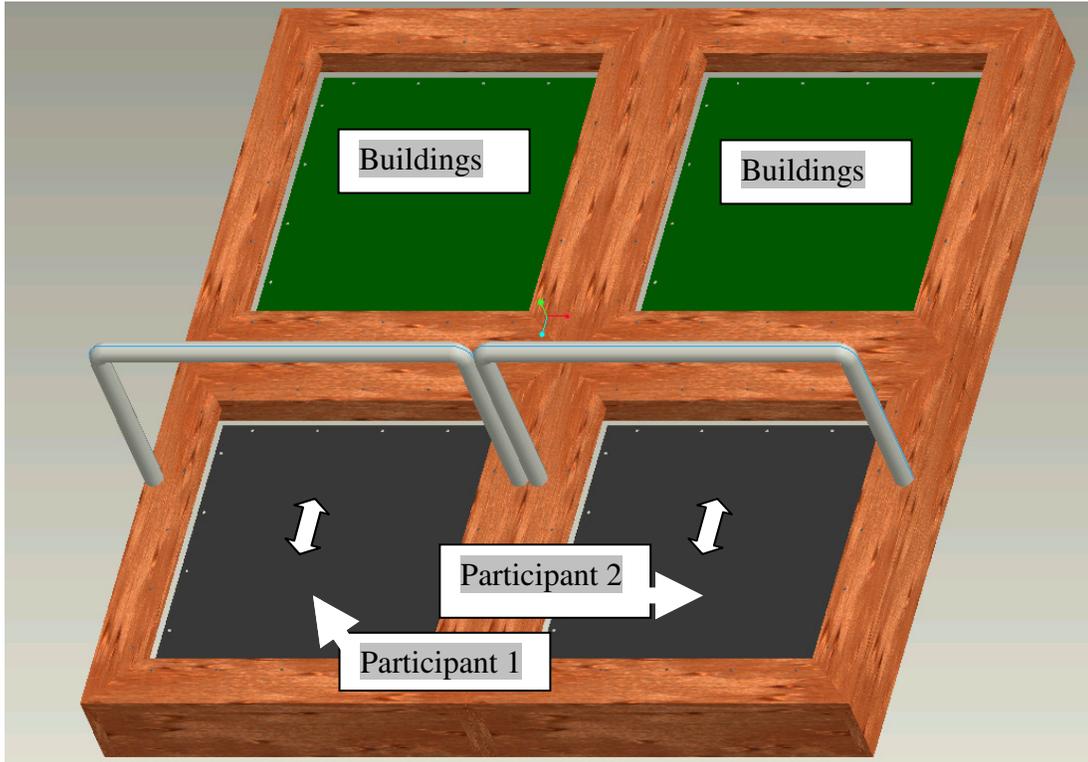
Figure 1. Sketch of initial concept



As with any collaboration there is a period of brain storming and negotiation. When the hand-picked team of engineering students presented the concept to the art students, the art students thought the initial device defined entropy too clearly. This is where the cultures of engineering and art differed. The engineers wanted the students to leave with answers while the artists wanted students to leave with questions. After a period of brainstorming, a multi-level and interactive art installation emerged. Albert Einstein once said “Everything must be made as simple as possible. But not simpler.” A schematic of the final design is given in Figure 2.

The installation consisted of a shaker table on which the participant can simulate an earthquake by shaking back and forth. The vibrations cause blocks to fall out of buildings thus increasing disorder. Since each block is used to keep a switch with a preloaded spring trigger open, as a block falls from a building, the switch closes and a power supply energizes a fan. This fan is mounted at the base of a nozzle which directs air flow up a tube and consequently elevates a ping-pong ball. This elevation of the balls models the increase of disorder in the system. When the participant repairs the damage by replacing the ten blocks into the buildings, the electrical circuit is deenergized and the ping-pong balls drop to their original state.

Figure 2. Schematic of the art installation



To provide for portability, a professional video was produced which demonstrates the art installation and leaves the viewer with three key questions; 1) what is the cause of disorder, 2) do we live in an isolated system and 3) how can order be restored?

Two assessment tools were developed and administered to three different courses. As seen in Appendix A, students were required to take a multiple choice test asking them to apply their perceived definition of entropy with respect to automobile, health, interpersonal and international relationships. The second assessment tool was an essay where the students needed to have a deeper understanding of entropy to properly communicate. The essay questions were different between the introductory mechanical engineering and thermodynamic students. Students in the introductory course were asked to provide a definition of what they remembered from their prior exposure to entropy. The students in thermodynamics were given more directed questions relating entropy to engineering and life. On the other hand, heat transfer students were not asked to write an essay.

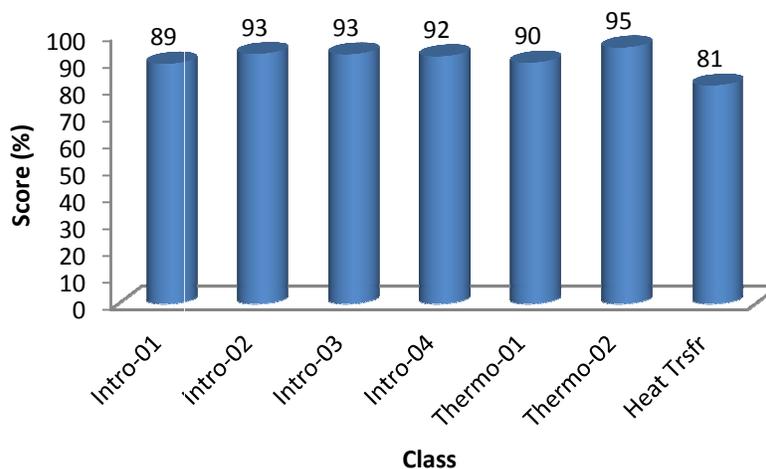
Results

From the introductory class entitled “Foundation to Mechanical Engineering,” the 104 students completing the multiple choice test were identified as freshman (89.4 %), sophomores (9.6 %) and juniors (1.0 %). Since this is the first required mechanical engineering course, exposure to entropy was limited. Only 50% stated they had heard of entropy. Additionally, high school chemistry and physics courses, 31% and 20% respectively, provided an introduction to the topic. The demographics of the 30 thermodynamic students who completed the test were 20% sophomores, 73% juniors and 7% seniors. From the heat transfer class of 32 participating students, 6% were juniors and 94% seniors.

The vast majority (90%) of the sophomores and juniors currently in the first semester of thermodynamics had been exposed to the second law and entropy in both high school and college science classes. In addition, the seniors had two semesters of thermodynamics.

As seen in Figure 3, student multiple choice answers ranged from a high mean score of 95% to a low mean score of 81%. It was surprising to find the students in the introductory classes (Intro-01 through 04) and thermodynamics classes (Thermo-01 and 02) did significantly better (8%) than the heat transfer students (Heat Trsfr) on the multiple choice test. There were several differences between the groups: the heat transfer students were not required to write an essay and the second thermodynamics group, which scored the highest, had a 50 minute lecture on entropy before the multiple choice test was administered. Additionally, the introductory course interacted with the exhibit, completed the test and wrote most of the essay during the regularly scheduled lecture/laboratory time. Therefore, each student had the opportunity to interact with the exhibit and its creator, and return, if necessary, for additional information before completing the test and short essay. The remaining students visited the exhibit and completed the test outside of the regularly scheduled class.

Figure 3. Results from the multiple choice test-mean test score



Each student in the Foundation to Mechanical Engineering course was required to provide previous knowledge of entropy (see appendix A question 2). Their answers were evaluated based on a three levels 1) correct, 2) partially correct, and 3) incorrect. A correct answer would identify entropy as a measure of disorder. If the second law was addressed, a constraint that entropy will continue to increase only in an isolated system had to be included. An example of a partially correct answer would be if the student discussed the second law without mentioning the assumption of an isolated system.

Figure 4. Definition of Entropy from Previous Knowledge

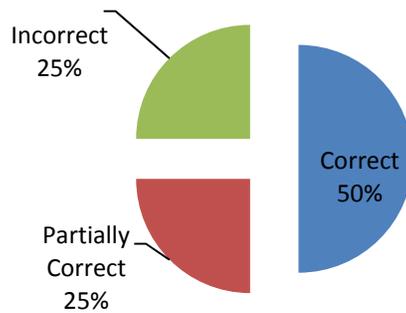
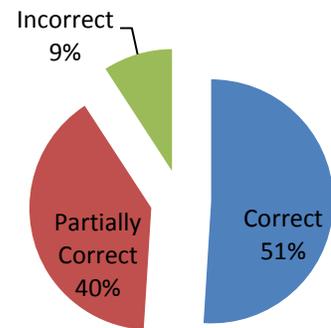


Figure 5. Definition of Entropy from Art Exhibit



Next, the introductory students were instructed to explain their understanding of entropy in a one page paper. This paper was written after interacting with the installation, and addressed how entropy is experienced in life, and a comparison of how entropy can be positive or negative in a system, event or activity. A representative sample containing 98 statements from the essays were evaluated on how well they defined the term entropy. Figure 5 classifies the assessment of student understanding into three categories: 1) correct, 2) partially correct and 3) incorrect. An example of a partially correct answer is “Entropy is the lack of order or predictability; gradual decline into disorder.” This is partially correct because they did not specify that the gradual decline into disorder is only for an isolated system.

The next concept that was evaluated was the students understanding of the ping-pong balls in the exhibit. The purpose of the ping-pong balls was explained in the video introduction to the exhibit. Twenty statements from the essays were separated into three categories based on their correctness. An example of a partially correct answer would be if the cause and effect between the disorder of the buildings and the position of the balls were reversed or if grammatical errors were present.

Figure 6. Purpose of Ping Pong Balls

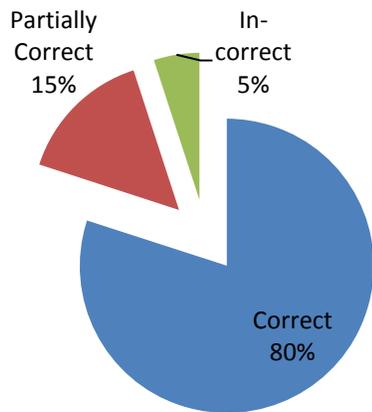
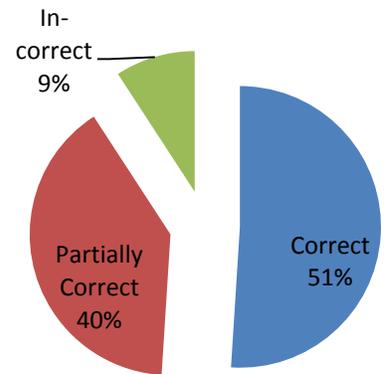


Figure 7. Applications-Introductory Class



The last category of statements extracted from the introductory students essays were related to applying entropy to a variety of applications in life ranging from the automobile to natural disasters to medical applications. The 145 statements were evaluated based on their correctness. A partially correct answer is one where the effect of entropy was not completely explained. An example of this is the statement “In weather, precipitation is a form of entropy.” A correct answer would be “In weather, precipitation creates entropy when it erodes farm soil.”

The students in the thermodynamics class were given a different assignment for their essay (Appendix B). Fifty statements from the essays were evaluated based on the correctness of the definition of entropy. The results are contained in Figure 8. Thirty five statements about the purpose of the ping pong balls were evaluated. The results are contained in Figure 9.

Figure 8. Definition of Entropy

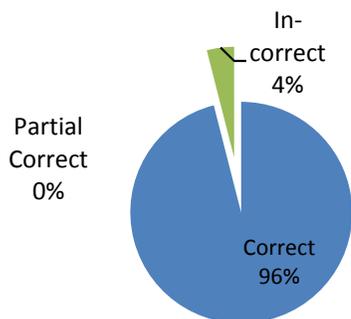
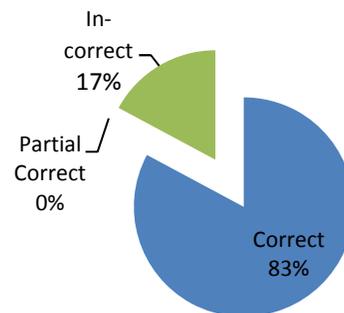


Figure 9. Purpose of Ping Pong Balls



There were three areas of application where the thermodynamic students were asked to explain the cause of disorder and how order can be restored. Thirty-two (32) responses were assessed based on how well they explained the connection between entropy and the application. A good explanation properly identified a source of disorder or restored order relevant to the application. The results of this assessment are contained in Figures 10 through 12.

Figure 10. Automobile Application

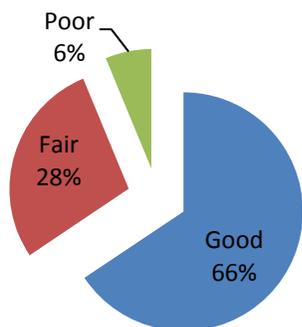


Figure 11. Interpersonal Application

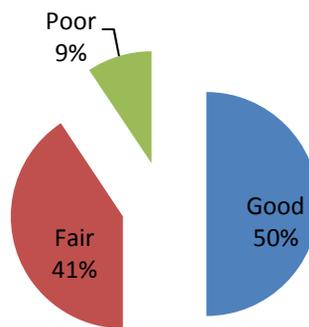


Figure 12. International Application

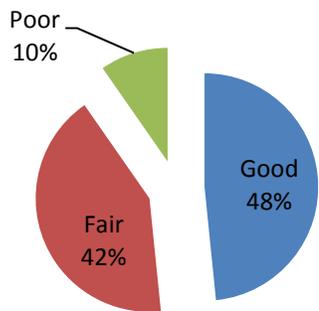
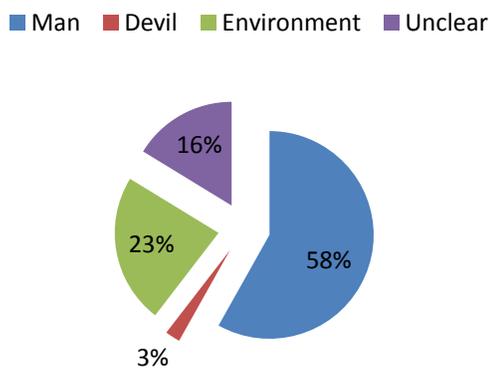


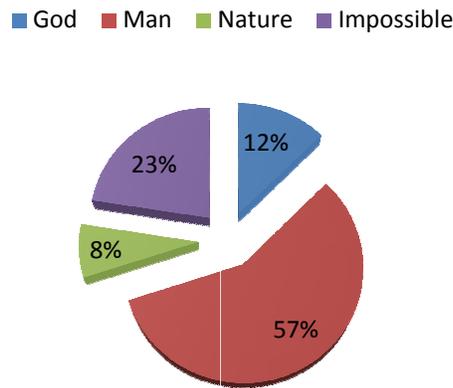
Figure 13. Source of Disorder



After considering specific applications the students were asked to contemplate the sources causing disorder in our world and what can be done to restore order. The four sources of disorder identified by 43 responses from the students are contained in Figure 13. The man category included responses such as sin and greed. Statements on natural disasters, pollution and global warming were combined into the environmental category.

Forty (40) statements to restore order were provided by the thermodynamic students. The responses are summarized in Figure 14.

Figure 14. Restore Order



Conclusions

Entropy can be explained and understood in simple terms using interactive physical and visual representations. Through a multiple choice assessment all the students exposed to the entropy exhibit scored above 80%. Requiring the students to write an essay improved their performance by 8 to 10 percentage points. Also, providing a 50 minute lecture improved their performance by 3 to 6 percentage points.

The experienced students were able to define entropy better in the essay than the introductory students as shown in Figures 5 and 8. Ninety-six percent of the students in the thermodynamics course were able to correctly define entropy while only 51 % of the introductory students were able to do so. Possible reasons for this may be the older students had more exposure to the term in college science courses and had easy access to the textbook.

Entropy is a natural bridge to critical thinking. The collaborative challenge to leave participants with questions rather than answers opened up the exploration of entropy to all areas of life. There is disorder all around us. Identifying the sources of this disorder can help restore order and improve our lives. Over ninety percent of the statements applying entropy to other areas of life were fair to good.

The overall purpose of the exhibit was reached. A non-lecture, interactive experience allowed underclassman, in an introduction to mechanical engineering course, the opportunity to experience a non-traditional learning activity. They are able to identify entropy and explain how it affects various systems. Making a principle or concept applicable to something with which they are familiar motivates students to learn more about the subject.

Albert Einstein once said, “You can never solve a problem on the level on which it was created.” This is true in engineering. Consider an automobile. It cannot fix itself. It requires knowledge from the designer of the automobile to fix it. If it is true in science and engineering perhaps it applies to life in general. In that case, order ultimately needs to be restored at a level higher than ourselves. This was identified by 12% of the thermodynamic students in Figure 14.

Recommendations

Integrate demonstrations and interactive exhibits into your pedagogy. It improves students learning outcomes. Since it is not sustainable to produce an exhibit like the one presented here for every topic discussed in an engineering curriculum, storage space alone excludes this possibility, a video of this exhibit was produced <http://youtu.be/30FikBLfOUA> for future use.

Collaborate with others. This is work, but often the benefits of interacting with others from a different perspective (increased entropy) can produce useful results (decreased entropy). This happened with this project as the questions which were developed showed how entropy relates to other areas of life.

Future work will include assessing student learning in a pretest along with the video instead of the full scale installation (which by the way is relocated in the lobby of a charter school for math and science).

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Appendix A. Multiple Choice Test (Correct answers are in bold)

1. Before this semester did you hear the term entropy?
 - A. Yes
 - B. No
2. If yes, how would you have defined entropy? {Introductory course only}
3. Where did you first hear the term entropy?
 - A. In high school chemistry class
 - B. In high school physics class
 - C. In college physics class
 - D. In the news media
 - E. On the internet
 - F. This is the first I have heard the term
 - G. Other
4. Which class are you in college?
 - A. Freshman
 - B. Sophomore
 - C. Junior
 - D. Senior
 - E. Graduate
5. What is entropy?
 - A. A measure of force per unit area
 - B. A measure of force through a distance
 - C. **A measure of disorder**
 - D. Capacity to effect change
 - E. A measure of earthquake intensity
6. How is entropy reduced in the exhibit?
 - A. When shaking the platform
 - B. When the buildings begin to fall apart
 - C. When the shaking of the platform stops
 - D. **When the buildings are being put back together**
7. What do the levels of the ping pong ball represent?
 - A. The change in temperature
 - B. The change in vibration
 - C. **The change in entropy**
 - D. The change in energy

8. When you consider the life cycle of an automobile, what evidence is there that entropy is increasing?
- A. **The body is rusting**
 - B. **The transmission breaks down**
 - C. The fuel efficiency increases
 - D. **The oil becomes dirty**
9. How can the automobile be restored to its original condition?
- A. **Recycle materials**
 - B. Store in garage
 - C. **Design new components**
 - D. **Manufacture new components**
10. In the human body, entropy increases when one consumes?
- A. **Too many calories**
 - B. **Too much alcohol**
 - C. **Cigarettes**
 - D. Vegetables
11. In the human body entropy decreases when
- A. One breathes polluted air
 - B. **One exercises regularly**
 - C. **One eats organically grown, dark green leafy vegetables**
 - D. **Visits a medical doctor on a regular basis**
 - E. One steps on a land mind
12. Entropy increases in interpersonal relationships when
- A. **One gossips about another**
 - B. One is generous with another
 - C. **One steals from another**
 - D. **One assaults another**
13. Entropy decreases in interpersonal relationships when one
- A. **Forgives another**
 - B. **Follows through with a commitment**
 - C. **Defends another from gossip**
 - D. **Seeks counseling for a difficult situation**
14. In international relations entropy increases when one country
- A. **Steals something from another country**
 - B. Sends food to another country
 - C. Sends a diplomat to resolve a dispute
 - D. **Tells lies about another country**

15. Entropy decreases in international relations when
- A. **One country shares its resources with another**
 - B. One country ignores another
 - C. **One country defends the rights of another country**
 - D. One country refuses to forgive another
16. Write a one page paper with one inch margins and a font size of 12. Explain your understanding of entropy after interacting with the display. Also, talk about how entropy is experienced in life. Compare how entropy can be positive or a negative experience to a system, event or activity. Give an example of the system, event, or activity.
{Introductory course only}

Appendix B. Essay Assignment for Thermodynamic Students (Sophomores and Juniors)

Please visit the entropy exhibit at the gallery between now and October 2, 2011. This is an interactive art piece. Please be sure to interact with it. Then write a concise essay (3 to 5 pages) addressing the following:

Define entropy

What causes entropy to increase in the exhibit?

What is the purpose of the ping-pong balls in the clear tubes?

How can entropy be reduced in the exhibit?

Give an example of how entropy increases in the following systems:

The life cycle of an automobile

Interpersonal relationships

International relations

In each of the above systems once entropy has increased how can it be reduced?

What do you think is the cause of disorder in our world?

How do you think order can be restored?