Hands-on classroom learning in material engineering

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Abstract

Several hands-on, classroom based activities have been developed for use in a material science and engineering course taught at the University of Minnesota Duluth, Department of Chemical Engineering. These short (10 to 20 minute) in-class activities are inexpensive, easy, safe and do not require access to a laboratory, nor expensive testing equipment. The activities include: disassembling of consumer goods, building unit cells, crystallizing a super cooled liquid, testing tensile and compressive strength, testing ductility, cold working, concentrating stress, and observing electro-chemical corrosion. The designed activities highlight basic fundamental ideas from material science and help students build their working knowledge of materials behavior. This project has been implemented twice and results of student surveys show an increase in student interest and reported motivation. However, classroom assessment showed little difference in student achievement on exams.

Introduction

Several short, simple, inexpensive, hands on activities have been developed. The activities promote interest in the course material and provide students opportunities to experience a range of properties and materials. Students work alone or in small groups to explore a material or set of properties. The students complete the activity in the classroom without need for laboratory space or time. The activities provide hands on kinesthetic experiences to enhance traditional classroom lecture. Mixing active learning activities with lectures increases student learning.[13]

This project was developed in a traditional lecture course, Material Science and Engineering, at the University of Minnesota Duluth, in the Department of Chemical Engineering. The course is a second semester, junior level course, with prerequisites of one year of general chemistry and one year of calculus. Typical class size has ranged from 20 to 35 students over the past five years, approximately 70 % of students are male, 90% are traditional students, and 15% are minorities.

There are several reasons for doing these small scale, simple, and inexpensive experiments in the classroom rather than as part of a laboratory:

Overcoming university limitations:

1) The chemical engineering curricula is full and there is no room to add another lab class without dropping some other course.
2) Funding is limited and equipping a new lab is expensive.
3) The available space is limited for placing new equipment.

Overcoming time constraints:

1) The exercises take only 10 to 30 minutes from start to finish and do not need the expanded time offering available in the lab.
2) The student's have the hands on experience at nearly the same time as learning about the material in the lecture, and the information is from the same person giving the lecture which provides better control of concept, timing, and teaching methodology.

However, since each activity can take from 10 to 30, some course content must be altered. I have reduced the amount of time spent in doing example problems, and have reduced some lecture content in order to make time available.

The ideas for these activities originate from many different sources including the course textbook[3] which includes a section entitled 'Classroom Demonstrations and Laboratory Experiments' that lists a huge number of ideas from the National Educators' Workshop--Standard Experiments in Engineering Materials, Science, and Technology, proceedings from 1988 to 1999. Additional idea sources originated from students, colleagues, and the author's daily experience with the world. References for similar activities and ideas are included in the following experimental procedures. All of the ideas discussed in this paper have been fine-tuned and applied to local constraints by the author and his students.

Procedures

The following section lists the hands on activities used during the course. Along with each is included the classroom procedure, the materials needed, discussion of what topic to do the project with (timing), what the specific student goal is, safety and cleanup special concerns, and any additional comments unique to the specific activity.

a. Diskette parts inventory

Procedure: Each student is given an old floppy diskette (often available free from many offices or IT departments on campus). Students are asked to disassemble the unit, count each part, identify the materials used, describe why a particular material was chosen, and determine the function of each piece.

Material list: Old floppy diskette, plastic bags - one per student.

Timing: The first or second class meeting.

Goal: Students observe how a study of materials intersects with everyday objects. Perhaps to realize for the first time that every human made object had someone thinking about / choosing / designing every part.

Safety: Each student should be given safety glasses for eye protection and a plastic bag for disposal of parts.

Other: Conclusion of demonstration leads into introductory class discussion of multiple design considerations (cost, longevity, friction, environment, evolution of technology …)

b. Unit cell construction

Procedure: Students assemble a unit cell from a few simple materials such as toothpicks and gumdrops or marshmallows. Students may then use their unit cell to help locate vectors and planes in the cell.[1]

Material list: 8 gumdrops, 12 toothpicks or equivalent for each student to create a simple cubic unit cell. Additional toothpicks and small sheets of paper can be used to help locate vectors and planes. Plastic bags.

Timing: Discussion of unit cell vectors and planes.

Goal: Students experience the three dimensional aspects of vectors and planes in the unit cell. Many engineering students have difficulties in visualizing three-dimensional objects from two-dimensional drawings.

Safety: Plastic bags are distributed for cleanup.

Other considerations: Have a single, unique color for one corner to allow students to locate the origin easily.

c. Crystallization

Procedure: Hand out a test tube with molten sodium thiosulfate to each student – tell them not to shake or drop it. Each student should then add a small seed crystal to the test tube (give each a small crystal of sodium thiosulfate). Have students observe the crystallization of the melt, which may take up to 5 minutes. Note that the solidification is exothermic (gives off heat), which acts to slow the crystallization.[14, 15]

Material list: Test tubes (one per student), a beaker of warm water (75^{o}C) large enough to hold the test tubes, a hot plate for heating the water in the beaker.

Timing: Discussion of arrangement of molecules into crystal structures.

Goal: Students observe the crystallization process.

Safety: Sodium thiosulfate is a skin and eye irritant. Care should be used around heated water and hot plates. All materials are collected afterwards and disposed of properly.

Other considerations: Place approximately 3 grams of the sodium thiosulfate into each test-tube, place the tubes in warm water (50 to 75 ^{o}C) to melt. Allow the melt to super cool before class (The melt will remain liquid for several hours, even if the temperature goes to 20^{o}C.) Have students discuss which type of crystal system this crystal belongs. Have them discuss why it gives off heat as it solidifies (Is it 'normal'?)

d. Material properties – ductility, hardness, and tensile strength.

Procedure: Each student is given a set of materials that can be broken, bent, twisted, scratched and pulled apart by hand. Each student is asked to rate all of the materials in terms of ductility, hardness, and tensile strength.[19, 20, 21]

Material list: Several soft/hard and ductile/brittle materials. Everyday objects, such as chocolate, taffy, hards, licorice, and fruit leathers make excellent choices.

Timing: Discussion of mechanical properties.

Goal: Students get a hands-on feel for how forces from their own hands can shape and distort materials.

Safety: Depends on chosen materials; as a minimum, students need safety glasses and a plastic sheet to work on to aid with cleanup.

Other considerations: Hardness is a simple scratching test between the materials. Ductility is measured by how much a material elongates under tension before breaking. Tensile strength can be measured qualitatively by noting the pulling force required to stretch and break a material. Students may discover that each property does not directly correlate with the others. It will make interesting discussion to have students rank each material for each property before and after testing.

e. Material properties – compressive strength

Procedure: Each student is given a hammer, underlay and overlay dies and a few materials to deform as a result of a sudden applied force. Students may share equipment as necessary. Each is given several parts to test – a soft and a hard plastic candy, a soft metal like copper, and a hard metal like steel. First, the student measures the thickness of the part with a micrometer. Next, the student places the part onto the underlay, places the overlay on top, then hits the overlay die with the hammer a single time. The thickness of the part is again measured and compared to the original. If identical forces are used in deforming each part, the materials compressive strengths can be rated. If variable force is used, previously made calibrations can be used to determine the force the student applied.[4, 5, 11, 18]

Material list: soft plastic candy (taffy) hard plastic candy (starburst) soft metal (copper) hard metal (steel). Hammer. Underlay die (wood board 12"x12"with a flat steel plate 2" x 2") and overlay die (wood board or steel plate). A Micrometer is used to measure the deformation of the materials.

Timing: Discussion of plastic deformation.

Goal: Students measure the force applied to a material based on level of deformation (based on previous calibration) or rank materials by compressive strength.

Safety: safety goggles for eye protection and plastic bags for cleanup

Other considerations: A primary concern is to protect the classroom furniture when allowing students to use hammers – this is the point of having the underlay board larger than the steel plate. One way to apply a consistent force is to drop a dead weight from a known height – this will require a special apparatus to be constructed, and you may need several copies for the classroom. If instead a variable force is allowed such as from a hammer blow, a set of data can be generated beforehand using a drop weight from several known heights to create a calibration, which allows a student to measure the amount of deformation, and determine what force was applied.

f. Cold working and failure by plastic deformations

Procedure: Each student is given a set of copper and aluminum wires or rods (steel and bronze are also easily available from any hardware store), with at least two different diameters for each material. Students are also given two pliers (sharing may be required) to aid in the deformations. Students use the pliers to place a 90^{o} bend and to then unbend the sample in the same location until failure. A count is made of the number of bends required for failure. In addition, students are asked to observe the amount of force needed for successive bends, and to observe how ductility and strength vary as a material has increasing levels of cold work. [2, 6, 10, 17]

Material list: Choose from copper, aluminum, brass, steel wire or rod each of several diameters, plastic bags, a magnifying glass. Pliers to aid bending.

Timing: Discussion of plastic deformation and/or failure, alternatively during discussion of cold working of metals.

Goal: Students will observe and compare the effects of cold-working until failure on a few metals. Students will quantify amount of cold work to compare (rank) based on material and size. Students will also examine the surface at the failure point.

Safety. When a material breaks, it may have sharp ends. Small pieces may break off (Safety glasses required). Distribute plastic bags for easy cleanup.

Other considerations. Exercise will take 30 minutes if a good assortment of materials and sizes are used. Students are asked to quantify or qualify by ranking the ductility of each specimen. Comparison between students also shows the differences caused by variance in materials and testers – this creates a good opportunity to discuss statistical issues and safety margins.

g. Heat treatments

Procedure: Before class, the instructor prepares several samples of iron / low carbon steel (see other considerations for preparation). Each student is given one of each sample. The student then tries to bend and unbend the sample and notes when / if the sample breaks. Some samples may require multiple bends before failure; some will fail almost immediately.[8, 16]

Material list: Several (4) hairpins for each student. A small torch or Bunsen burner. A wax candle. Pliers and hot pad gloves. A 250 ml beaker filled with water used during preparation and/or during a visual demo. Plastic bags (small) for clean up.

Timing: Discussion of heat treatments of steel or during discussion of non-equilibrium cooling phase diagrams for iron/steel.

Goal: Students test the ductility of several forms of heat treatable steel.

Safety: The in-class demo only requires safety glasses and plastic bags for cleanup. Initial preparation requires safety glasses, lab coat, and hot pad gloves.

Other considerations: To prepare the samples, obtain several plain iron or low carbon steel hair pins (four per student). Of the four, set one aside as the control. The other three will be heat-treated. Each of the three pins is heated until glowing hot (more yellow than red). Cool one pin in air; cool the other two in water. One of the water-cooled pins is reheated in the wax candle flame (recovery or recrystallization may occur). The different quench media and treatments will affect the cooling rate and may alter the grain size or the microstructure of the iron alloy. Each pin will have different properties. Have students attempt to explain their findings as it compares to the lecture discussion on heat treatments.

h. Failure – stress concentration

Procedure: Two different knots are tied into a three-foot length of string. Each knot should be located about one foot from an end. Students are placed into groups of two. Each group is given a string with two knots tied into it. The students pull the strings until it breaks, the one with the longer piece is declared the winner, and that student advances to the next round. This continues in a sports team instant elimination format until a single winner is declared.[9]

Material list: Monofilament string (fishing line), several small metal rods (optional), knowledge of knot tying.

Timing: Failure mechanism – stress concentration.

Goal: Students examine knots to predict which will concentrate stress more, and therefore fail at a lower applied force. Students compare results with their prediction.

Safety: Plenty of space is needed as some students may pull hard and will step back when the string fails.

Other considerations. Students may want to wrap their free end of rope around a small metal rod to help get a good grip. During the rounds, quantify which knots fail more frequently. It will help to color code each of the knots. Examples of knots include: Inline figure 8, double twist, bowline, and square.

i. Electrochemistry and corrosion

Procedure: This activity is longer term requiring parts of two classes separated by approximately one week. Have students damage (bend, nick, scrape, twist, heat, cool) iron/ steel artifacts and then partially submerge in a salt-water solution along with an undamaged artifact. After several days, both artifacts are examined for localized corrosion. Comparison is made between artifacts and with the list of corrosion types.[7]

Material list: Several iron/ steel artifacts – nails, wire, rod, flat sheet. 100 ml beakers (one per student/ group), salt, water, labeling device. A microscope may be used to more closely examine the corrosion.

Timing: During study of corrosion

Goal: Have students examine how flaws can lead to changes in corrosion rate and type by direct comparison.

Safety: Safety glasses.

Other considerations: Beakers will need to be stored in a safe location between class periods.

Discussion

Student assessment of the activities includes a formal (number ranking) survey written by the student at the end of the course, an anonymous written evaluation question given to each student at the conclusion of course, comparison of midterm and final exam scores, direct instructor observation, and informal discussion with students during the semester. The activities were used in the 2003 and 2004 class offerings. The results are contrasted with classes from 2001 and 2002. Class sizes ranged from 24 to 32.

Results of the number ranking survey (scores from 1- 6, with 1 = very strongly disagree and 6 = very strongly agree) are listed in appendix 1. The number of students participating in the survey is given as N. Comparison of scores for each question between the (2001, 2002) and the (2003, 2004) data sets show no statistical difference in student perception of the overall course.

Results of the written evaluation question "Were the hands-on projects a good use of class time (as compared with additional lecture or example problems)?" are presented in Appendix 2. Results combine answers from the 2003 and 2004 classes. Multiple responses are listed as (x 2), which means that this response was given by multiple students. Examination of these comments suggests that most students enjoyed the hands-on activities, agree that they are a good use of class time, and feel they add to their educational experience. They also believe timing could be better and that perhaps some activities could be replaced. There was no agreement on which one(s) should be replaced.

Results from exam scores for the two years of this project (2003 and 2004) are presented with the two prior years (2001 and 2002) in appendix 3. All scores are normalized to 0 – 100 scale. Comparison shows no statistically significant difference between scores on the individual tests.

As the course instructor, I observed several students who would not talk or question during a typical lecture class actively participating in the activities and the follow up discussions. This observation makes the activities a success in terms of my personal teaching goals, and provides an excellent reason to continue their use.

Informal discussions with students suggest these activities made the course one of their favorite undergraduate engineering courses. Most students I discussed the activities with liked this part of the course the best, and thought that most activities were a much better use of class time vs. the equivalent amount of time spent lecturing. Several were simply amazed that learning engineering could be so fun. The students appreciated the ability to do things usually only done in a laboratory (use hand tools, experiment with a variety of methods and materials). They also really liked having candy as the material of choice for several activities.

Conclusion

While these activities are seen as a beneficial use of class time by both the students and the instructor, and certainly increased student interest and motivation, they did not appear to increase student learning (based on mid-term and final exam results). Overall, the students' exam performance was not different from students that did not participate in these activities (previous year's classes). Some possible reasons include; the exams did not assess what was truly learned, 2) engineering students do not need 'fun' activities to help them learn, or 3) sample size was too small to discern a difference. It has been suggested[12] that active learning is no better than lecture when measures of knowledge are used for assessment. However, when measuring retention of information after the end of the course, measuring of the transfer of knowledge to new situations, measuring of thinking, problem solving, or attitude changes; or motivation for further learning, results show differences favoring active learning over lecture.

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Biographical Information

Dr. Steve Sternberg currently teaches Chemical Engineering at the University of Minnesota Duluth. He has previously worked at the University of North Dakota and University of Detroit Mercy. He received his MS and PhD from Purdue University in Indiana, and his BS from the University of Michigan.

Appendix 1 -- Summary of student rankings from formal evaluation of course.

		2001		2002		2003		2004	
	Question	N = 21		N = 24		N = 21		N = 24	
		Score	sd	Score	sd	Score	sd	Score	sd
	1	4.65	0.49	4.62	0.77	5.05	0.67	5.17	0.76
	2	4.80	0.70	4.71	0.75	5.14	0.65	5.25	0.61
	3	4.63	0.60	4.75	0.85	5.00	0.63	5.17	0.76
	4	5.40	0.68	4.75	0.79	5.40	0.68	5.33	0.70
	5	4.86	0.79	4.71	0.75	5.24	0.62	5.42	0.65
	6	4.55	0.60	4.62	0.82	5.24	0.70	5.08	0.72
	7	4.90	0.64	4.67	0.82	5.48	0.60	5.58	0.65
	8	4.75	0.64	4.79	0.83	5.10	0.62	5.29	0.62
	9	4.89	0.66	4.75	0.74	5.33	0.66	5.21	0.66
	10	4.74	0.65	4.88	0.68	5.48	0.60	5.33	0.64
	11	4.63	0.68	4.75	0.79	5.38	0.59	5.13	0.81

The questions:

1. The instructor presented challenging and stimulating material
2. The instructor inspired interest in the subject
3. The instructor used examples and illustrations effectively
4. The instructor referred to recent applications or developments in this area of study
5. The instructor maintained an atmosphere in the class that encouraged learning
6. The instructor designed evaluation procedures which were consistent with course goals
7. The instructor designed in-class learning activities that engaged students with the subject matter
8. The instructor encouraged students to participate in class discussions and/or activities
9. The course as a whole was good
10. Overall the instructor presented the subject effectively
11. Overall, I learned a lot in this class.

Appendix 2 -- Summary of student answers to open ended project evaluation question: Were the hands-on projects a good use of class time (as compared with additional lecture or example problems)?

- Yes, they were fun and helped us learn more about what was discussed in class
- Yes (x 11)
- Yes, projects were fun and I learned a lot from them.
- Yes, but sometimes the timing was poor (x 5)
- Yes, not only were they fun, but educational as well.
- Projects were OK idea, but also distracting.
- No.
- Yes, I liked them. Excellent use of class time (x 4)
- Yes, the projects were fun, though at times a lot of work. The end result was good.
- I think it may have been better to lecture more and do more problems.
- Most of the projects were good, some were not (x 2)
- Projects were fun, but I am not sure they were the best use of class time.
- Projects helped me learn throughout the semester.
- Some of the projects were useful to help teach the material, but not all of them.
- Yes, the projects were fun and were good demonstrations of what we learned.
- The idea was great, but sometimes needed to be taken more seriously (too much fun was had by some other students). Sometimes the concepts were hard to follow during the experiments.
- Yes, the projects were fun and most had some educational value.

Appendix 3 – Course Exam Grade Averages and Standard Deviations

	2001	2002	2003	2004
Exam 1	75.5	69.5	77.5	73.5
sd	12.5	15.0	15.0	11.5
Exam 2	73.5	60.5	68.5	75.0
sd	5.0	19.5	12.0	9.0
Final	72.5	77.2	66.8	74.4
sd	10.5	12.5	16.0	11.0