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Use of Collaborative Learning Exercises to Increase Student Motivation and Learning in an Introduction to Materials Engineering Course

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Abstract

A collection of collaborative, in-class exercises have been designed for use in a freshmen/ sophomore level Introduction to Materials Science and Engineering class. The activities are team based problems that include open ended design problems, calculation questions, and thought problems on unanswered research questions. The activities have been designed with the goal of having one or two a week embedded in a more traditional lecture setting. The exercises relate to the topics covered in most standard Introduction to Materials classes (crystal structure, mechanical properties, polymers, phase diagrams…). Each activity is designed specifically to engage the students in the lecture and excite them about the material. This is accomplished by relating the lecture material to a modern application. For example, students learn about the mechanical properties of different polymer structures by comparing plastic bags and milk bottles. The author has found that one major tool needed for the success of the collaborative learning exercises has been the implementation of reading quizzes. The reading quizzes are quick, five minute quizzes on the assigned reading done at the beginning of class. The students are then ready (and excited) to work on higher level problems in-class. Survey results of student's opinion show that the reading quizzes and collaborative learning exercises increase the student's learning (in their opinion) and increase their motivation to read prior to class and attend class.

Introduction to Materials Engineering Course Overview

Throughout history, from the Stone Age to the Silicon Age, major advancements in technology have been marked by materials. Each new technical innovation has required discoveries in materials to surmount barriers and limitations. This leads to an overlap between materials science and almost every other engineering field. Electrical engineers use materials science and engineering to produce computer chips, lasers, and superconductors. Structural materials such as concretes for roads and metals for buildings and bridges are crucial to civil engineers. Mechanical engineers must consider the strength and long term reliability of the materials used in their designs. Light weight, strong materials are continuously researched and tested by aerospace engineers. Biomedical engineers investigate alternative materials for transplants, artificial limbs, and surgical tools.

For this reason, most engineering programs require their students to take an introductory materials class. This includes community colleges with engineering transfer programs. In the U.S. alone, the "Introduction to Materials" course enrolls over 50,000 students a year.[1] The primary goal of the class is to provide a foundation in materials science and engineering that the students can build upon in their major classes and future careers.

The curriculum and lab content for the existing "Introduction to Materials" course taught at San Jose State University is given in Table 1. The class is a freshman/ sophomore level class required for engineering students in mechanical, aerospace, civil, chemical, materials, industrial, and environmental health and safety. It is a fifteen week course that meets for two, 50 minute "lecture" sessions and a 3 hour lab each week. The lecture sections have 75 students in them, and the lab sections have on average 17 students.

Table 1: Outline for San Jose State's Fall 2003 "Introduction to Materials" course.

Lecture Topics	Lab Topics
Atomic Structure & Bonding	Crystal Models & Defects
Crystal Structure	Hardness Test
Imperfections	Fracture Test
Diffusion	Tensile Test
Mechanical Properties	Cold Working
Strengthening Mechanisms	Pb/Sn Phase Diagram
Phase Diagrams	Tempering of Steel
Electrical & Magnetic Properties	Ductile to Brittle Transitions
Ceramics	Corrosion
Polymers	Polymer/ Composites
Composites	Electrical & Magnetic Properties

Background on Collaborative Learning

During the lecture sessions, the traditional lecture is frequently supplemented with collaborative learning exercises (CLEs). Collaborative learning is when students work together in groups to improve the overall learning of the group. Collaborative learning involves positive interdependence (all members must cooperate to complete the task) and individual and group accountability. Many detailed publications exist defining collaborative learning and assessing its role in the classroom.[2-5] The effectiveness of collaborative learning has been extensively documented (over 700 studies during the past 90 years). More is known about the quantitative benefits of collaborative learning than is known about the effectiveness of traditional lecturing! The highlights of these studies are explained in Johnson, Johnson, and Smith.[2]

Use of CLEs changes the format of the lecture and appeals to a broader range of learning styles than just traditional lecturing. The four main ways of classifying learning styles (Myers-Briggs type Indicator, Kolb's Learning Style Model, Herrmann Brain Dominance Instrument, and Felder-Silverman Learning Style Model) all classify learners as either introverted/ reflective or extroverted/ active.[6,7] Traditional classroom lectures are tailored towards reflective learners. Actively engaging students through CLEs allows every student time to learn in a mode they are most comfortable with and time in a mode that challenges them to expand their learning styles. Also, based on the fact that the average attention span of an adult is 15-20 minutes,[8] switching between active and passive modes of lecturing will improve the attention of the student during both parts of the class.

Working on problems in class gives a means of assessing the learning that is taking place and adapting the material covered and the teaching style.[3,9] This immediate feedback allows for the gaps in the student's understanding to be addressed before a homework or exam. Also, using group problem solving as an in-class assessment may show that the students understand the material and the pace of the lecture can be accelerated.

Collaborative Learning Exercises' Content

Table 2 lists a brief description of the formal collaborative learning exercises used in the Introduction to Materials Engineering course. The full questions and solutions can be found online at http://www.engr.sjsu.edu/sgleixner/ASEE. All of the exercises are designed to highlight the main fundamental topic of the week and to bring in modern technologies related to materials engineering. The dual goal is to actively engage the students in the lecture as well as excite them about materials engineering in general. In some of the exercises, students brainstorm about how a technology relates to the fundamental principles they are learning about (such as the atomic force microscope and the solar cell/ LED examples). Other exercises involve design or calculation problems related to modern technologies such as the examples of diffusion of dopants in a semiconductor or stress in a ceramic composite for jet engine turbine blades.

Table 2: Brief description of the formal collaborative learning exercises developed for an Introduction to Materials Engineering course.

Topic	**Brief Description of Students' Task**	**Learning Objectives:** Upon completion of this exercise, student should be able to…
Introduction to Materials Engineering	**Brainstorm** the role materials engineers had in developing and manufacturing cell phones.	**List** different roles of materials engineers.
Atomic Forces	**Discuss** technically how an atomic force microscope generates an image of surface roughness.	**Describe** interatomic forces and **relate** how an AFM uses these forces to generate an image of surface roughness.
Crystal Structure	**Define** the lattice type, number of atoms per unit cell, and basis of several compounds.	**Define** FCC, SC, and BCC lattice types. **Differentiate** between lattice type and unit cell. **Determine** the number of atoms per unit cell and the number of atoms per basis.
Steady State Diffusion	**Calculate** the flux of plutonium through a holding tank for nuclear waste.	**Calculate** the flux in a steady state diffusion problem.

Non-steady State Diffusion	**Calculate** the anneal time needed to give a desired junction depth for the diffusion of dopants into a semiconductor.	**Calculate** the diffusion coefficient for a given temperature. **Use** an erf table. **Calculate** the time needed to generate a given, non-steady state diffusion profile.
Stress strain diagrams	**Interpret** stress strain diagrams for various metals and **determine** the major points of information.	**Read** a stress strain diagram. **Determine** from a stress strain diagram 0.2% yield stress, ultimate tensile stress, ductility, toughness, and resilience.
Designing for Stress	**Design** a column (choose the materials and dimensions) to meet given specifications in stress.	**Calculate** the applied stress from a given force. **Calculate** strain from an applied stress using Young's modulus. **Calculate** strain in the x direction using Poisson's ratio.
Critically Resolved Shear Stress	**Calculate** the critically resolved shear stress in a single crystal of Ni given an applied stress	**Determine** the slip plane and direction in an FCC lattice. **Calculate** ϕ, λ, and the critical shear stress.
Strengthening Mechanisms	**Deform** given paperclips, **determine** which had been annealed, and **brainstorm** on how the anneal altered the mechanical properties.	**Explain** how cold working and subsequent annealing varies the dislocation density and **explain** how this affects the mechanical properties.
Phase Diagram	**Sketch** a phase diagram of salt and water using the few data points known from life experience.	**Represent** phase changes and the influence of composition on phase changes on a phase diagram.
Phase Diagrams	**Read** a phase diagram for Al-Ni and **discuss** which compositions may be good for jet engine turbine blades.	**Determine** the phases and compositions present at given points on a phase diagram. **Identify** solvus, solidus, and liquidus lines. **Identify** the invariant and congruent points. **Determine** the fraction of phase present from the lever rule.
Defects in Ceramics	**Determine** the defect structure of carbon and fluorine doped silicon dioxide and **brainstorm** why these structures have lower dielectric constants.	**Determine** the defect type in a ceramic. **List** the factors that influence the dielectric constant in doped silicon dioxide.
Polymer Structure	**Review** definitions of polymer structure from the text and **determine** which structures apply to given polymers.	**Define** the terms used to describe polymer structure for side group attachment, chain organization, and co-polymers.

Mechanical Properties of Plastics	**Brainstorm** on the different polymer structures used for plastic bags, milk bottles, and plastic beer bottles. **Relate** the polymer structure to the differing mechanical properties.	**Differentiate** between the structure and mechanical properties of LDPE and HDPE. **List** factors considered in the manufacturing and recycling of plastic bags, milk bottles, and plastic beer bottles.
Mechanical Properties of Composites	**Calculate** the stress in ceramic-ceramic fiber and whisker composites used for jet engine turbine blades. **Brainstorm** the role the fibers play in the reliability of the turbine blades.	**Calculate** the composite's Young's modulus and the force and stress on the fiber and matrix. **Explain** how fibers in a composite improve the fracture toughness.
Semiconductor Band Structure	Following a demonstration of LEDs and solar cells, **brainstorm** what leads to the phenomena in each.	**Draw** the band structure of a semiconductor. **Define** generation and recombination. **Explain** how light is generated in an LED and current is generated in a solar cell.
Temperature Dependence of Conductivity in Metals and Semiconductors	**Compare** the temperature dependence of conductivity of the metal and semiconductor components of an integrated circuit. **Formulate** an understanding of the physics that lead to the differences in the electrical properties.	**Differentiate** between resistance and resistivity. **Plot** the temperature dependence of conductivity for metals semiconductors. **Describe** how mobility and electron concentration change with temperature in metals and semiconductors.
Magnetic Hysteresis Loops	**Evaluate** soft and hard magnetic hysteresis loops and **determine** which would be better for use in a hard drive.	**Differentiate** between M, H, and B. **Identify** M_R, M_S, and H_C on a hysteresis loop. **Compare** the properties and applications of hard and soft magnets.

The instructor integrates the CLEs into the lectures at varying points depending on the activity. Some of the CLEs are used prior to discussing the fundamental materials in class. This is to get the students to brainstorm on why they would need to learn the material from an engineering perspective or as an alternative to lecturing on basic definitions already provided in the text. The second main use of the CLEs is to have the students apply what was just discussed in class in a design or calculation problem. This is to increase the students' understanding of the concept (doing as well as seeing/hearing) and for rapid assessment of the student's understanding of the material.

The use of CLEs in this class use a modified version of the "Best Practices" organized by the Foundation Coalition.[10] The exercises are designed to take approximately 15 minutes of class time. They are done in groups of three students each. The groups are not assigned but are formed based on where the students are sitting. The classrooms used have tables that seat three students each. While there are advantages to assigning groups, the instructor found that the logistics in a large class (75 students per lecture session) made assigning groups too time consuming. Each student is assigned a specific role. The roles used are leader (who manages the group's time and assures all students participate), recorder (who fills out and returns the worksheet), and spokesperson (who conveys the group's questions and answers). To promote the students working together, only one copy of the worksheet is given out per group. While the students are working on the assignment, the instructor circulates the room, answering questions and engaging students in the activity. After the students have worked on it, the instructor calls on students to go over the answers. The accountability has helped to insure that all students work on the assignment and understand their group's solution. The solutions are then posted on the course website.

At the end of class, the worksheets are collected and are graded for participation only. They comprise 5% of the overall course grade. The instructors found that grading on some level improved active engagement of the students. However, the content is not graded because the exercise is often stopped before all of the groups have had enough time to complete the entire exercise. The average participation grade for the Fall 2003 semester was 88%. (This is basically a measurement of classroom attendance.) Qualitative assessment from the instructor is that the vast majority of students are actively engaged in the activity though there is the occasional student doing other work (reading the text, doing other homework, etc…).

In order for the students to actively engage in the CLEs, they need to come to class prepared. All students are asked to bring their textbook and calculator. The largest issue in preparation is motivating the students to read the assigned reading prior to lecture. This allows student's to have already thought of the material and be somewhat prepared to answer questions about it at a higher level. To encourage reading before class, reading quizzes are administered at the start of class once a week. These are short, one question quizzes that cover major topics or basic definitions in the reading. The reading quizzes comprise 5% of the overall course grade.

Survey of Student's Opinion

The instructor's qualitative assessment of the CLEs was that they were highly successful in meeting all of their goals. The students became actively involved in the lecture and visibly enjoyed participating in the activities. Through the CLEs, students obtained more applied examples of how the material they were learning related to real world engineering situations. Frequently, the CLEs sparked more in depth questions on the topic or technology covered. From the instructor's perspective the use of the CLEs enhanced the learning of the material. The exercises were very effective as an assessment tool and frequently the lecture was re-adjusted to accommodate the level of understanding the students showed on the CLEs.

No quantitative assessment has been done at this time to compare student learning of a topic with and without CLEs. However, students' opinions were solicited in an end of semester survey. The students were asked to respond "true", "somewhat true" "neutral", "somewhat untrue", or "untrue" to the statements of whether the use of the CLEs "increased their learning of the material", "motivated them to come to class", and "motivated them to read the assigned reading before class". Figure 1 shows the results of the student surveys. There were 57 respondents. 72% of the students felt it was "true" or "somewhat true" that the CLEs increased their learning of the material. 64% and 55% felt that the use of CLEs in class motivated them to come to class and to read before class respectively.

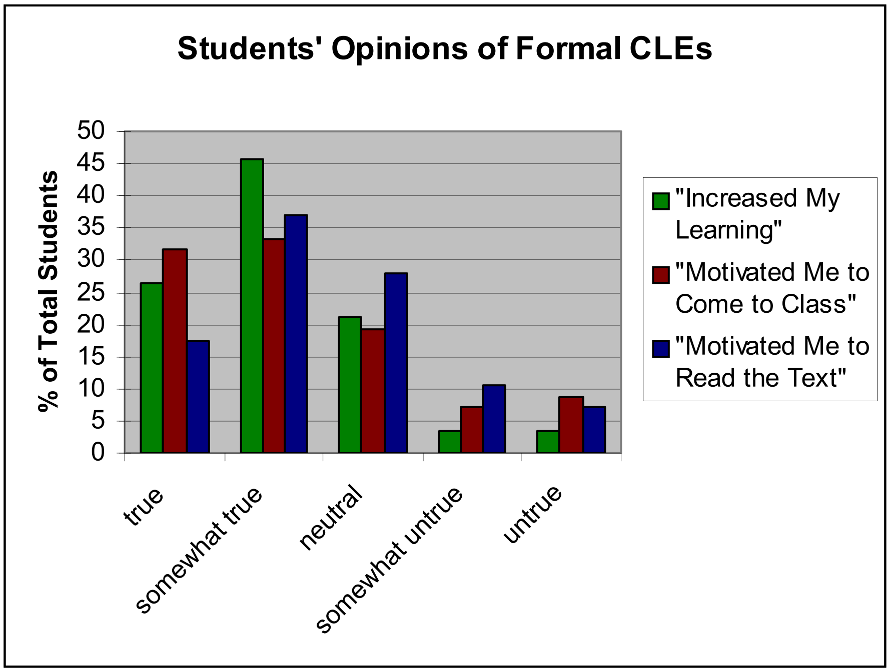

Figure 1: Survey response of students' opinions of whether the use of the CLEs in class "increased their learning", "motivated them to come to class" and "motivated them to read the text before class".

The students' opinions of the impact of the reading quizzes on increased learning, motivation to attend class, and motivation to read before class was solicited in the same survey. The results are shown in Figure 2. 63% of the students felt it "true" or "somewhat true" that the use of reading quizzes increased their learning of the material. In the students' opinions, the reading quizzes were a strong motivator both for students to attend class and to read before class (77% and 86% respectively). However, despite the fact that the reading quizzes were typically simple questions taken directly from definitions or major points of the text, the overall average on the reading quizzes for Fall 2003 was 55. Only 27% of the students got above a 70 on their overall reading quiz average for the semester.

Part of the low reading quiz grades would be due to attendance. While it was not recorded whether a "0" on the reading quiz was due to a wrong answer or absence, attendance can be approximated using the participation points for the CLEs. The average on the CLEs was 88% with 45% of the students having attended 95% or higher of the classes and 11% of the students having attended fewer than 70% of the classes. Comparing these with the reading quiz scores show that, even factoring in attendance, the grades were low.

This indicates that the majority of the students were not consistently reading the text prior to class (or at least not retaining major, pertinent information from the reading). Qualitative assessment from the instructor also supports this. Despite the reading quizzes, students were not coming to class having done the assigned reading. Further work is needed in motivating students towards this. Options may include increasing the percentage of the overall grade that the reading quizzes count towards, having the reading quizzes online so that time constraints do not affect the quiz grade, giving students alternative exercises to help them understand the textbook material such as generating an outline or flow chart of the text, or giving students more guidelines on what to focus on in the readings so that they are sure to retain the major points.

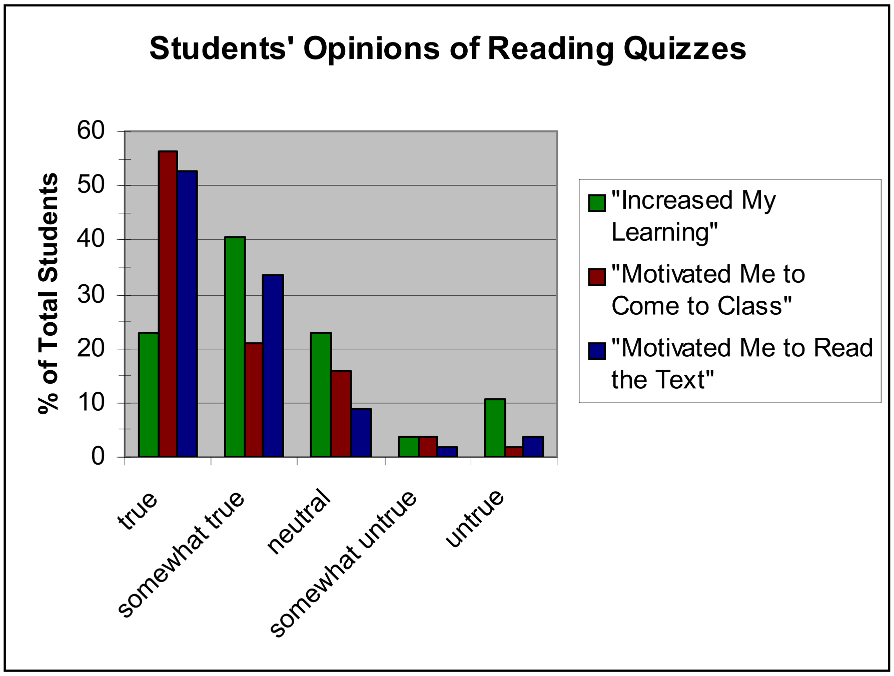

Figure 2: Survey response of students' opinions of whether the use of reading quizzes "increased their learning", "motivated them to come to class" and "motivated them to read the text before class".

In addition to the CLEs, many other active learning exercises were used in the Introduction to Materials class. One of the most frequent was in class "voting". This was when students were asked to choose the correct answer by show of hands. This was used as an assessment technique to determine if the majority of the students understood the material. The lecture was then reviewed or adjusted accordingly. Figure 3 showing the students' opinions of the in-class voting is included as a comparison to the students' opinions of the CLEs. The instructor feels this tool was a very effective learning tool. Using the in-class voting allowed for instant assessment and assured most students understood the lecture material. The students indicated that this tool had slightly less of an impact on their learning (66%) and was not a strong motivator for students to attend class or read prior to class (both 42%). Note that the survey question was worded to include the in-class voting and the subsequent review of the material if needed. The instructor feels the students may have valued this tool less because it was not graded and there was no individual accountability.

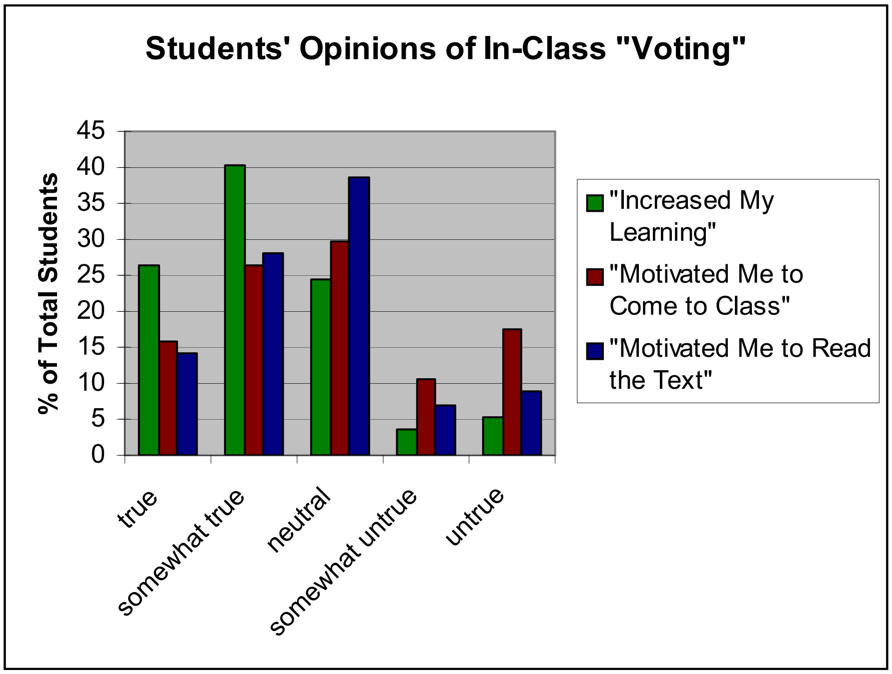

Figure 3: Survey response of students' opinions of whether the use of in class "voting" "increased their learning", "motivated them to come to class" and "motivated them to read the text before class".

Summary

Collaborative learning exercises were created for use in a freshmen/ sophomore level Introduction to Materials Engineering course. The exercises were thought questions or calculation or design problems that used modern technologies and real world examples to highlight the fundamental materials science being studied that week. The goal of the CLEs were to actively engage the students during class time, utilize different learning styles, assess whether the students understood the material, and to excite students about materials engineering in general. Reading quizzes were also used as an attempt to motivate students to read the assigned reading prior to coming to class. Qualitatively, the instructor felt the CLEs were very effective at meeting their goals. Students were actively engaged in lecture and frequently the exercises sparked visible interest in the related technologies. Surveys of student opinions found that the majority of students felt the CLEs and reading quizzes increased their learning, motivated them to come to class, and motivated them to read. However, overall low grades on the reading quiz indicated that the students were not reading (or retaining the information from the text) at the level required.

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