Group-Work Tutorials for an Introductory Materials Engineering Course

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Abstract - **We report on findings of a project to improve student learning in a university-level introductory materials science course for engineers. In a related preparatory project, we identified student difficulties with basic topics in materials science through interviews and/or testing of over 1000 students at The Ohio State University. Here, we report on the implementation of concept oriented group-work lessons or "tutorials" designed to address student difficulties identified in our prior work and improve student understanding of core concepts in materials science. The lessons were designed for weekly 48 minute recitations in which students work together in small groups on the tutorials in the presence of teaching assistants who assess and facilitate student progress. To determine the learning outcome, we analyzed scores on the final exam and found that even accounting for the fact that slightly "better" students tended to attend recitations more often, there was a valued-added effect of the recitations on final exam performance. These results suggest that these recitation methods and materials are effective in teaching students the difficult and important conceptual materials which they were designed to address.**

Index Terms – Conceptual difficulties, Group-work, Materials Science, Tutorials

INTRODUCTION

We report on findings of a project to improve student learning through the implementation of nine concept-oriented tutorial worksheets used during the weekly recitation sections in the quarter-long introductory materials science course for engineers offered at The Ohio State University. Topics covered in the tutorials include crystal structure, the nature of atomic bonds, diffusion, the mechanical properties of metals, stress-strain curves, the effects of processing on properties, failure, phase diagrams, phase transitions, properties of ceramics, and properties of polymers. The tutorials generally follow the chapters of Callister [1], the text used for the course.

The design and implementation of the tutorials used in this study were modeled after successful introductory physics education reforms, for example at the University of Washington [2], as well as other schools [3]. These programs were able to achieve significant gains in students' conceptual understanding of physics by redesigning the weekly recitation session into an active learning session in which students worked in small groups on concept-oriented worksheets called "tutorials". Typically, there were no changes to the lectures, which were taught via traditional methods. In this sense, these education reforms are relatively easy to implement in the course because they require limited extra work or changes to the lecturer's teaching methods [2].

In the following sections we will describe the design methods for the tutorials, describe the format of the recitations, present specific examples of tutorial materials developed, present some general themes common to many of the tutorials based on goals for the course, and finally discuss the results of implementation.

DESIGN METHODS FOR THE CREATION OF THE TUTORIALS

The first stage in designing the tutorials was to identify instructional goals and areas of student difficulty. This was done through several stages of interviews with instructors and students and extensive testing, as reported in our previous work [4]-[5] as well as a companion paper in these proceedings [6]. The second stage was to iteratively develop, implement, and assess possible tutorial activities. This was done through one quarter of small mock recitations, to try out some of the instructional material, and two quarters of full course implementation and subsequent redesigning of the tutorials. Tutorials were redesigned based on in-class observations, assessments of submitted group responses to the activities, instructor feedback, and assessments of the tutorial's effectiveness based on exam scores.

RECITATION FORMAT

Recitations for the course are held once per week and are 48 minutes in duration. The recitation attendance is voluntary. The number of the students per class varies but is on average 20 to 25 students. A senior experienced instructor, usually a faculty member, and two teaching assistants, typically graduate or undergraduate students, are present for each recitation. Students work in groups of 3 or 4 to complete the tutorials and instructors circulate to answer questions, ask questions of the groups, and in general facilitate the activities. About 37% percent of students typically attended recitations, or every student attends on average 3.4 recitations out of nine total. This attendance rate is similar to the attendance rate of the traditional recitations used before the tutorials, which typically consisted of mini-lectures and discussion of solutions to homework problems.

Therefore the tutorials themselves do not appear to significantly affect attendance.

THE IMPORTANCE OF TAS TO FACILITATE THE TUTORIALS

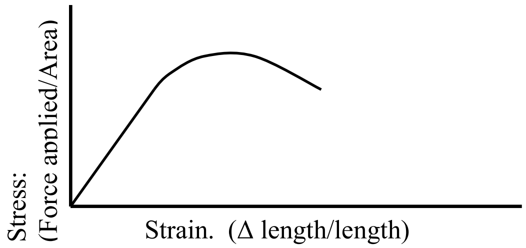
Instructor preparation for the tutorials is a critical component of the implementation. While the tutorials consist of carefully constructed questions, they are designed to be complemented by questions and dialog between the students and the teaching assistants (TAs). Every week the TAs have an hour long training session in which they discuss the correct answers to the tutorials, difficulties they can expect students to have, how to assess what difficulties the students are having, and how to guide students to overcome their difficulties by asking thoughtful and responsive questions instead of simply telling the student the correct answer. For example, some students have difficulty explaining why the alloy at point c3 in Figure 4 does not have eutectic structure. As a result of TA training, the TAs are prepared for this potential issue and have prepared ways to help students. For example, the TA might ask simpler questions such as what structure exists at b3 and how this structure would change as the alloy cools toward the α + β region. Effective dialog between the students and TAs is critical for the tutorials to be successful and preparation of methods to overcome known common difficulties is an important part of effective dialog.

TUTORIAL: MECHANICAL PROPERTIES

As reported in our related work [4]-[6], students often have difficulties learning and distinguishing among the many new terms and definitions that are introduced in a survey course. This seems especially true for students learning the mechanical properties of materials. Students often have three main issues with these technical terms. First, they have difficulties recalling and applying the correct scientific definition to the correct scientific term. Second, they confound everyday definitions and uses of the terms with the similar but distinct scientific uses of the terms. Finally, they incorrectly correlate these properties with each other.

A portion of the tutorial designed to address these difficulties is shown in Figure 1. The tutorial provides various ways in which to apply and practice definitions and explanations of elastic deformation, Young's modulus, yield strength, and tensile strength. Special attention is given to terms students frequently confuse such as stiffness and strength or yield and tensile strength, and students were asked to explain the differences between these terms. The tutorial also provides a set of quotes commonly made by students during interviews. Students are asked to comment on the correctness of the quotes. These questions are designed to demonstrate the necessity of precision in language and raise student awareness of common incorrectly stated definitions or generalizations, such as, "A tougher material is stronger," or, "A stiffer material is harder to break."

1. What is the difference between a material's strength and a material's stiffness?
2. What is elastic deformation? (Please give a description that a 2nd year engineering student who has not taken this class yet would understand.)
3. How is elastic deformation related to Young's modulus, E?
4. A tensile stress is applied to a metal bar such that is deforms **elastically**. Draw a sample of atoms in the bar.
   a) Before deformation
   b) During deformation while under stress
   c) After the stress is released
5. While the bar is under stress, is its volume different than before being deformed? Explain.
6. How is the strength of a metal defined? (Please give description that a 2nd year engineering student who has not taken this class yet would understand.)
7. What is the difference between yield strength and tensile strength?
8. Student C says: "Steel has a yield strength of 180 MPa and Nickel only has a yield strength of 130 MPa. Steel is therefore stronger and more force is needed to break it." This student is: Correct, Partially Correct, Incorrect. Explain.
9. Indicate the features which would characterize the Young's modulus, yield strength, tensile strength, ductility, and toughness.



10. Rank the two curves:

Modulus, E: **A** (> , < , =) **B**
Yield strength: **A** (> , < , =) **B**
Tensile strength: **A** (> , < , =) **B**
Ductility: **A** (> , < , =) **B**

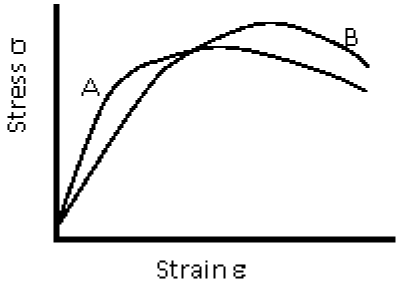


FIGURE 1
EXAMPLES FROM THE MECHANICAL PROPERTIES TUTORIAL

The mechanical properties tutorial also asks students to apply their mechanical properties definitions to stress-strain plots. This serves several purposes. It gives students experience deriving information from, and plotting information on, graphs which is itself a goal of instruction. It also provides a second way to think about the definitions and thus acts as both a check to students understanding and an additional way for students to distinguish exactly what parts of their written definitions were of importance. The easily separable dimensions of the graph (i.e. slope, height, peak, and line length) provide a clear visual aid for discussion, as a group or with a TA, of the exact differences in the properties and how one property does not necessarily affect another property. A sample of the tutorial's questions is shown in Figure 1. The tutorial has room for students' answers but this has been deleted to save space.

TUTORIAL: DIFFUSION

In addition to students' difficulties with material properties, students have several areas of difficulty with diffusion. A majority of these difficulties seem to arise from students not having strong consistent models for diffusion and the terminology used.

For example, as reported in our related work [4]-[6] students often believe that higher concentration implies higher diffusion rates (rather than higher concentration *gradient*), and for questions relating to concentration vs. position graphs, students often believe that a positive slope results in diffusion in the positive direction.

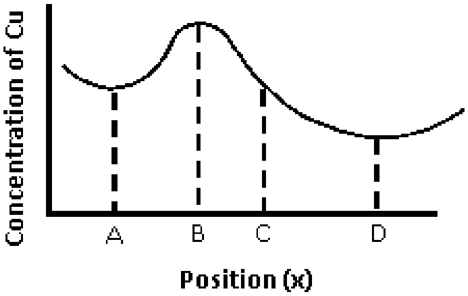


FIGURE 2
STUDENTS HAD DIFFICULTY DETERMINING THE RELATIVE RATES OF CHANGE OF CONCENTRATION WITH TIME AND WHETHER CONCENTRATION WAS INCREASING OR DECREASING WITH TIME.

1. In Fick's First Law, why is J, the diffusion flux, proportional to the concentration gradient, rather than being proportional to the concentration, C?
2. What does the minus sign in Fick's First Law mean physically? What would happen if the minus were to become a plus sign?
3. In steady state diffusion, what quantity is "steady"? Is it "steady" with respect to position, time, or both?
4. Are atoms moving in steady state diffusion?
5. Is there anything that is changing in steady state diffusion?
6. How does the concentration of material change with position when diffusion is in steady state?
7. How does the diffusion flux, J, change with position when diffusion is in steady state?
8. Rewrite Fick's First and Second Laws for steady state diffusion.
9. A slab of Ni atoms (gray) are perfectly sandwiched between two slabs of Cu atoms (white), as shown on the first graph marked "t = 0 seconds". Draw graphs for the Cu concentration and the <u>magnitude</u> of the Cu diffusion flux as a function of position at t = 0 seconds. Then, for t = a few hours later (non-steady state) and t = long time after (equilibrium), show how the atoms would be distributed (i.e. color in Ni atoms) and draw the graphs for the Cu concentration and the <u>magnitude</u> of the Cu diffusion flux as a function of position

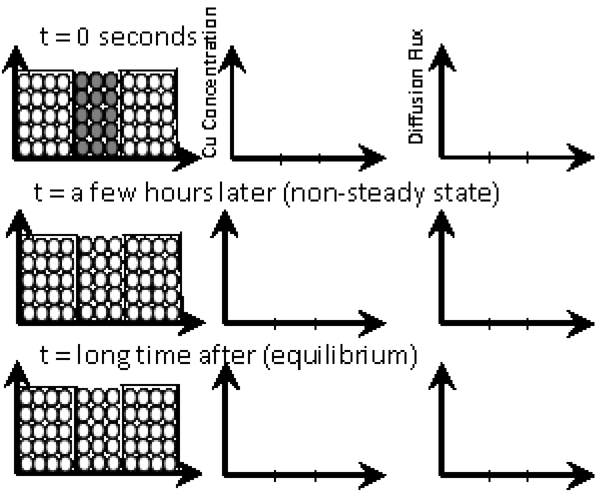


FIGURE 3
EXAMPLES FROM THE DIFFUSION TUTORIAL

For the case of non-steady state diffusion, the scope of students' difficulties becomes more pronounced. For example, when students were given the concentration vs. position graph in Figure 2 and were asked questions regarding how the concentration was changing with time at points A-D, only about 30% of students correctly responded that the concentration would increase at point A and be changing fastest at point B. The most common solution to the questions, about 40%, was to use slope responding that the concentration would be constant at A and be changing the fastest at C. Also, a significant number of students, 15-25%, did not think that they could use the concentration as a function of position to gain information concerning time.

Thus, it becomes clear that students do not have a good model of diffusion flux on an atomic or macroscopic level, or how diffusion influences concentration as a function of both time and position. To address these issues, the tutorial provides students with a series of conceptual questions about diffusion, such as questions concerning diffusion flux, concentration, and steady state diffusion. These questions highlight not only basic definitions and units of critical terms, but also how and why these terms are interrelated.

Students also work through a series of questions related to Fick's equations, physical descriptions of diffusion, and the drawing of concentration vs. position graphs for the special case of steady state diffusion. In addition, students work through an activity designed to help them connect the macroscopic properties of concentration and diffusion flux with what is happening at the atomic level through drawing of a very simplified atoms-in-a-bin picture of concentration and connecting this with a concentration vs. position graph (see Figure 3). As a final activity, the tutorial guides students through a non-steady state concentration graph very much like the one in Figure 2. Students are asked several questions to check their understanding like, "Where is the diffusion flux greatest, where is the concentration greatest, …" A sample of the tutorial's questions is shown in Figure 3. The tutorial has room for students' answer but this has been deleted to save space.

TUTORIAL: PHASE DIAGRAMS

Perhaps not unexpectedly, students have a number of difficulties with phase diagrams. As discussed in our related work [4]-[6], these difficulties appear to arise from both an inability to understand the nature of the diagrammatic representation of phases and a lack of understanding of phases and concepts relating to phases such as the difference between composition of a phase and the phase fraction of an alloy.

In general, many students have significant difficulty extracting relevant information from phase diagrams, and performance decreases rapidly with increasing complexity of the diagram. For example, over 75% of students can typically answer simple questions about binary phase diagrams involving solid solutions. However, student performance dramatically decreases (less than 30% correct) for questions about binary eutectic diagrams.

The tutorial guides students through a series of general questions about the nature of phases, the meaning of solubility for metallic alloys, and the meaning of the regions of the phase diagram. The tutorial also guides the students to describe the phases on both an atomic and macroscopic level at various temperatures and compositions as well as transformations that occur as an alloy of a given composition changes temperature. Exercises include drawing pictures of microstructure and calculations of composition and fraction. A sample of the tutorial's questions is shown in Figure 4. The tutorial has room for students' answer but this has been deleted.

1. What is a phase? Write a definition that a 2nd year engineering student who has not taken this class yet would understand. Give 3 or 4 examples.
2. Some binary alloys (alloys with two species) have only one solid phase such as a Copper and Nickel system. Others have two solid phases such as a Lead and Tin system.
    a. Why is this?
    b. Under what conditions will a Lead Tin alloy have only one phase?
3. Draw pictures of the microstructure of this Copper-Silver alloy as you slowly cool the solution
   At 24% Ag: a1, b1, c1
   At 72% Ag: a2, b2, c2
   At 94% Ag: a3, b3, c3
4. At point b1 in the diagram, estimate the composition of the α?
5. At point b1 in the diagram, estimate the composition of the Liquid?
6. At point b1 in the above diagram, use your estimates above to calculate the fraction of the microstructure that is α?
7. In the eutectic phase diagram, what is alpha? Draw a picture of alpha at the atomic level.

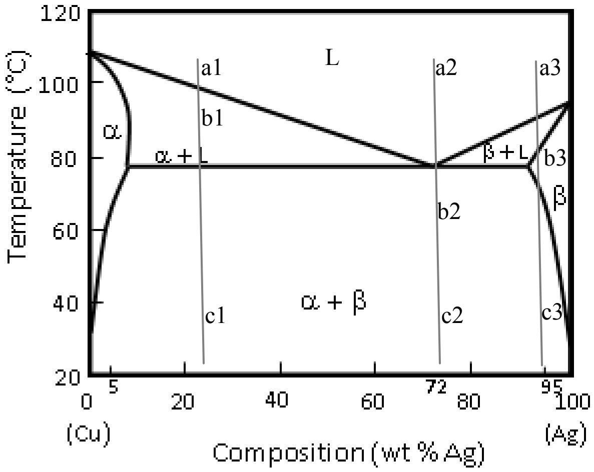


FIGURE 4
EXAMPLES FROM THE PHASE DIAGRAMS TUTORIAL

GOALS FOR THE COURSE AS A WHOLE

We have so far discussed the tutorials as separate units with specific difficulties each is aimed at counter acting. However, there are also several themes that run through the tutorials which are aimed at goals the faculty and instructors identified for the course as a whole. These goals are the understanding of basic definitions and terminology especially those used for mechanical properties, the visualization of materials' structure and how processing changes that structure, and the ability to interpret and apply meaning to graphical and diagrammatic information.

GOAL 1: BASIC DEFINITIONS AND TERMINOLOGY (ESPECIALLY MECHANICAL PROPERTIES)

As discussed in the mechanical properties section above, many of the students who take the course have significant difficulties recalling an exact meaning of a term and distinguishing it from another term or its nonscientific definition. In order to address this issue, tutorials asked students specifically to give a definition or description of key new terms for the chapter or section being covered. For example, the phase diagram tutorial starts with the question, “What is a phase?” This is often a simple question for students. However, for some students, this is a challenging question because they do not have an appropriate definition. For example, they have a definition which explains solid, liquid, gas but does not incorporate a system with two solid phases. In addition, these terms were often used over multiple tutorials, and as part of the intervention, TAs were instructed to look for and assist students in recalling and defining these terms when students were stuck on a question. For example, a student might say, “We are stuck on #4, how does cold working strengthen a material?” The TA might respond by asking the student, “Last week we talked about tensile strength. What is tensile strength? Can you recall how it differed from yield strength?”

GOAL 2: VISUALIZE MATERIAL STRUCTURE AT MACROSCOPIC, MICROSCOPIC AND ATOMIC SCALES

Many students don’t have solid conceptual visual models of the structure of metals on sub-macroscopic scales even after they finish the course. For example, many students are poor at describing or producing visual models of the crystal structure nature of metals, the grains and dislocations (and how these differ), and phases of metals at the microscopic level. This lack of correct visual models of metals on smaller scales hinders students’ abilities to understand how processing changes microstructure and thus effects material properties.

Tutorials usually include a section which addresses this goal of visualization of materials at sub-macroscopic scales. Most often this is a section which requires students to draw pictures representing important atomic or grain size features and often has questions requiring students to analyze or use their picture. As with Goal 1, examples of this can be seen in each of the tutorials above. For example, in the mechanical properties tutorial students are asked to sketch what the atoms are doing before, during, and after elastic and plastic deformation. Then they are asked to use their picture to infer how density or atomic separation changes. Another example of this can be seen in the tutorial aimed at difficulties with crystal structure and defects where students are required to both draw a dislocation and give a written description for it, or in the failure tutorial where students are asked to identify the types of failure seen in magnified facture surfaces and describe the identifying features.

GOAL 3: INTERPRETING AND APPLYING MEANING TO INFORMATION IN GRAPHS AND DIAGRAMS

A goal for many science courses, including this course, is to develop students’ skills at interpreting information from graphs. This is especially important for this course because there are numerous kinds of graphs and diagrams that students are expected to be able to understand and apply correctly. In the tutorials described above, we discuss students’ difficulties with stress-strain plots, concentration and diffusion flux graphs, and phase diagram charts, but students often have difficulties with bonding potential energy graphs, creep and fatigue life time graphs, and TTT diagrams as well. In every tutorial, there is at least one activity in which students are required to derive information from a chart or graph or to plot information on a graph. There are also usually a series of questions surrounding the chart or graph which help to work students through specific difficulties with a particular diagram.

RESULTS OF IMPLEMENTATION

These nine tutorial worksheets were implemented in weekly recitations in two separate lecture sections (same lecturer) in two separate quarters. Evaluation of the effectiveness of implementation was not a strict control-treatment design: for logistic and ethical reasons, all recitations sections experienced the same treatment. Instead, to evaluate the effectiveness of this implementation, we used a within course and within student design. As noted earlier, students attend on average only about 37% of the recitations. This variability in attendance allowed for a comparison of final exam scores of students who attended the voluntary recitations to scores of students who did not attend recitation. There was a clear linear, increasing relation between the number of recitations attended and the final exam score. Students gained about 0.10 ± 0.02 standard deviations on the final exam score for every recitation they attended. (See Figure 5 which shows similar trends in both quarters.)

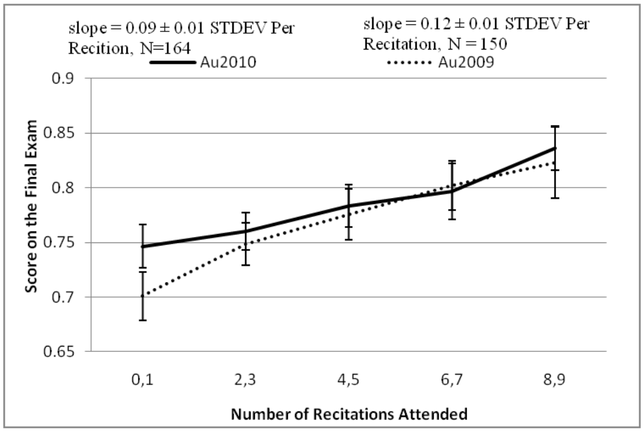


FIGURE 5
FINAL EXAM SCORE VS. RECITATION ATTENDANCE FOR TWO SEPARATE QUARTERS. THE SLOPE FOR EACH QUARTER IS ALSO PROVIDED.

However, because the recitations were voluntary, it might be argued that the gain in score could be due to the fact that better students may have more often attended recitation. While this is a plausible contributing factor to the score-attendance relation measured, we argue that there is evidence of additional learning due to recitation participation. In particular, we made a within student comparison of performance on exam questions that were related to the recitation material vs. exam questions that were not related to recitation material. If one interprets the score on the non-recitation related questions as a measure of the mastery level of the student, then one can use this information to factor out the quality of the student and determine if there is any residual effect of recitation attendance alone.

We performed a 2 x 2 repeated measures analysis of variance, with high/low attendance (greater or less than 50% attendance) as the between student factor, and question type (recitation related vs. not recitation related question) as the repeated (within student) factor. Figure 6 presents the data separated into these factors. Perhaps unsurprisingly, there was a main effect of attendance, with high attenders outscoring low attenders by 0.4 standard deviations on all questions on average ($F(1, 331) = 19.10$, $p < 0.001$). There was no main effect of question type, thus students performed on average equally well on recitation vs. non-recitation related questions, 76% vs. 77% ($F(1, 331) = 1.93$, $p = 0.116$). Most interestingly, as seen in Figure 6 there was a significant interaction between attendance and question type ($F(1, 331) = 12.20$, $p = 0.001$), with a clear value added on recitation related questions for those attending recitation. Thus, even accounting for the fact that slightly "better" students attended the recitations there was a valued-added effect of the recitations that improved relative student performance on recitation related questions.

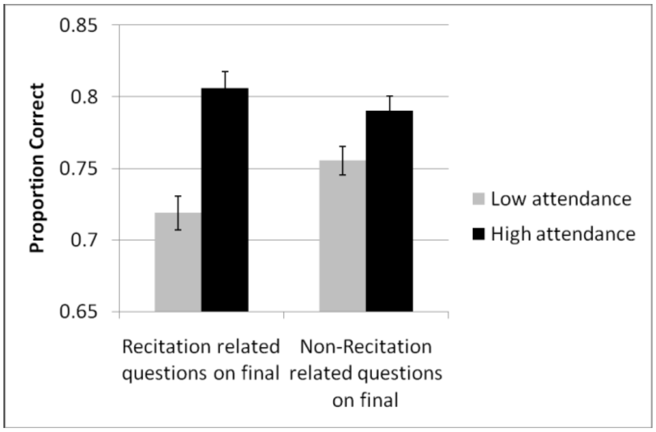


FIGURE 6
INTERACTION OF RECITATION ATTENDANCE AND RECITATION RELATED VS. NON-RECITATION RELATED QUESTIONS (N=333).

CONCLUSION

We reported here on the effectiveness of the implementation of weekly 48 minute group-work recitation activities for the introductory materials science course offered at the Ohio State University. These tutorials are aimed at correcting conceptual difficulties we found that students had after traditional lecture and homework on the topic. The tutorials specifically address the difficulties students have with traditional materials science lessons such as atomic bonding, crystal structure, diffusion, mechanical properties, plastic deformation, coldworking, creep, fatigue, failure, phase diagrams, TTT plots, ceramics, and polymers. The tutorials guide student through a series of questions which are designed to elicit known student difficulties and encourage students to explicitly confront these difficulties via group discussions of posed questions and/or dialog with a TA. In addition, the tutorials address larger course goals - including understanding basic materials science terms, visualizing the microstructure of materials, and expertise with graphs and diagrams - through incorporating these skills in each of the tutorials. While the tutorials do not appear to improve attendance in these non-mandatory recitations, the students are usually actively engaged in the tutorials. Further, our analysis suggests that attending the tutorial based recitations does improve student performance on final exam questions. In all, these results suggest that these recitation methods and materials are effective in teaching students the difficult and important conceptual materials which they were designed to address.

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