Active Learning Techniques and Online Tools Applied to the Educational Experience of 2nd Year Materials Science and Engineering Students

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1 introduction

This paper presents lessons learned from implementing active learning techniques, online assessment technologies, and new classroom space into a redesigned undergraduate course. The content of the course was developed as the gateway course for further study in the newly revamped undergraduate curriculum for the Materials Science and Engineering (MSE) Department at Case Western Reserve University. The new curriculum was designed to accommodate contemporary ideologies, a material agnostic approach, computational materials science and engineering, and prepare students to work on interdisciplinary teams. With the above stated goals, a sophomore year course was redesigned and renamed from "Introduction to Materials Science" to "Materials Properties and Design". The instructor chose to both add additional content and use pedagogies to address each of the goals of the newly redesign curriculum. Contemporary ideologies were brought into the classroom by adding content at the end of each section to discussion how the topics presented in class were applicable to existing and new real-world applications. A materials agnostic approach was implemented by utilizing the integrated version of the Callister textbook.[1] Computational materials science and engineering was accomplished by utilizing the Granta CES EduPack software[2] and the Edison Welding Institutes time-temperature-transformation/ continuous-cooling-transformation (EWI TTT/CCT) diagram calculator tool.[3]

The pedagogies applied to the course structure relied heavily on the results from a multi-year teaching and learning study conducted at The Ohio State University. In that study, a multi-year assessment was conducted to determine which scientific and engineering concepts sophomore students experienced the most difficulty understanding.[4-6] Those assessments were subsequently used to build guided team-based learning activities to help students gain proficiency in these previously determined difficult scientific concepts. These activities also help prepare students to work in interdisciplinary teams when they enter the engineering workforce. The data indicated that students who participated in these team-based learning activities achieved greater understanding by a statistical significant margin in assessment scores.[7,8] For the study performed at Case Western Reserve University, the objective was to apply these previously developed activities into a course structure that did not have a dedicated recitation section. This paper will present and discuss the effectiveness of the implementation of these different learning tools.

2 course structure

Thirty-six students signed up for the course (scheduled for 8:30 am); seventeen students were majoring in MSE and were taking the course because it was required for their major of study, and the remainder of the students were engineering students studying Biomedical Engineering or Chemical Engineering. Non-MSE students were taking the course voluntarily as a technical

elective. There were four seniors, nine juniors, and twenty three sophomore in the class.

Several teaching approaches were implemented into the course structure by the instructor during her first year of teaching: think-pair-share, team-based learning, and case studies as described by the Vanderbilt University Center for Teaching.[9] The applied pedagogies were based on a teaching-and-learning study conducted over multiple years at The Ohio State University.[10] Learning expectations (enumerated below), and assessment rubric (Table 1), were presented to the students on the first day of class. The learning objectives of the course were designed such that the course would adequately prepare the students for subsequent department courses, and directly assess certain ABET curriculum objectives (particularly: a, e, g, h, and k).[11]

primary learning objectives:

1. Identify how levels of structure (from atomic to microstructure) affects the physical mechanisms (the science) that dictate material properties. Particularly mechanisms of diffusion, mechanical behavior, and phase transformations

2. Be able to describe how processing methods can be used to optimize structure for the desired material properties for a particular application.

3. Assess engineering applications for the necessary material constraints and utilize materials databases to select optimum materials for that particular application.

ancillary learning objectives:

1. Communicate your understanding of structure-processing-properties relationships to fellow engineers.

2. Work as a group to decide the best course of action to solve a particular problem.

3. Apply critical thinking skills to engineering design applications.

2.1 lecture and team-based structure

The course was primarily structured to accommodate three weekly 50 minute sessions which were split, 66% of which were lectures with interspersed think-pair-share activities, and 33% of which were team-based learning activities. Think-pair-share activities were facilitated using Turning Technologies clickers,[12] this technology provides an opportunity to ascertain active student participation. This data provided the lecturer the opportunity to assess student learning, and quantify the lecture participation points for each student.

Table 1: Direct Assessment Rubric

Assessment	Grade Percentage
Lecture Participation	5%
Group Work	5%
Homework	20%
CES: Design	10%
Exam #1	20%
Exam #2	20%
Exam #3	20%

Team-based learning activities were designed to accomplish two goals: to allow students to work through topics that were previously identified as difficult for students to comprehend;[7] and provide an opportunity for students to interact with

course topics in open-ended, case-study, materials engineering design situation. Case-study activities were designed for topics related to diffusion (coke-bottle study[13]), steel processing using the EWI virtual TTT/CTT diagram tool,[3] and composite materials. The steel processing and composite design activity questions are provided in the Appendices 6.1 and 6.2. Students were allowed to self-assemble into groups for these activities, the instructor did not assign groups.

2.2 flipped classroom

An experiment was conducted in the middle of the semester to assess the effectiveness of flipped-classroom on the student learning of the topic of "phase diagrams" and "phase transformations". During this two week period, students were given specific reading assignments and lecture materials to be reviewed prior to attending class (quizzed at the beginning of class) and then were given guided team-based learning activities in class to assess the learning objectives for the topic as listed by the textbook.[1] The activities for this flipped-classroom section are presented in Appendices 6.3 and 6.4.

2.3 online homeworks

Homework assessments were assigned and submitted online using Blackboard learning management system.[14] Homework assessments were designed in two parts: Part A was multiple choice and matching type questions, and Part B was computational based questions that required students to apply formulas to solve engineering problems. In an effort to curb copying, the computational based problems were designed so that the numerical values changed with each attempt. Homeworks were graded with a two part mastery score, meaning students only received credit for the homework if they mastered each part of the assignment. Students were permitted two attempts to achieve the necessary mastery for Part A and an unlimited number attempts were permitted to achieve mastery of Part B. The online submission process allowed students multiple attempts to work on problem solving skills and deductive reasoning to determine where errors in their work could occur. Additionally, three homework assignments using Granta's CES EduPack 2013 software[2] were interspersed through the semester to assess student understanding of how materials properties need to be considered during the engineering design process; particularly strength-to-weight, energy of productions, and recyclability were considered.[15]

2.4 classroom

The classroom space was developed to promote active learning for groups up to six students. It was loosely based on the popular nine student SCALE-UP model developed at North Carolina State University. The SCALE-UP classroom space employs large round tables for students (pod-style), laptop connections and projectors that can be used to share student work.[16] SCALE-UP classrooms also include abundant white-board space, an audio system designed to allow the students to both hear the instructor and to respond (e.g., by having microphones located at the tables), and lighting that can be adjusted depending on the task.[17] In the Case Western Reserve University classroom space, each configurable pod of up to six had a large-format interactive touch-screen computer (i.e. MondoPad) that was connected with a wireless application allowing the students to share their laptop/mobile content to the group computers or to the room projectors. These interactive displays also provided students access to online databases for case-study activities, Fig. 1. The classroom design features (e.g. wall color, furniture, etc.) were chosen so that the classroom space had a unique "feel" as compared with other campus classroom spaces and would indicate to

students that there are different expectations of how they were going to be asked to learn in these spaces.

3 assessment of techniques

Direct and indirect assessment of the teaching approaches, online technologies, and learning space were conducted through comparison of student scores on assignments, instructor weekly journaling, and student surveys at mid- and end of the semester. The primary learning objectives were directly assessed by student performance on exams and homework activities, and were indirectly assessed by surveys at the middle and end of the semester. The ancillary learning objectives were assessed through team learning activities, and CES design assignments. The average exam scores for the semester were $73\% \pm 8\%$, $80\% \pm 18\%$, and $80\% \pm 10\%$ for exam 1, 2, and 3 respectively. The average overall course grade was an $85\% \pm 8\%$, and the median grade was an 86%, indicating an even distribution around a B grade.

Figure 1: Pod-style classroom with "orange" brainstorming wall, set-up for team-based learning activity. Each pod has its own MondoPad for facilitating content sharing.

3.1 lecture and team-based structure

The course was structured to facilitate active participation during all aspects of the learning process. The clicker technology utilized to facilitate think-pair-share activities interspersed through the lecture environment was a useful technology to provide direct assessment of student understanding of topics from the lecture. There was no trend between total number of questions answered and student performance on the clicker questions. All students answered questions correctly at a rate of $75\% \pm 5\%$. When "correctness" was calculated based on the total number correct answers vs the total number of questions answered. Anecdotal evidence, based on tracking total number of answered questions, indicates that students that participated in these think-pair share activities were more likely to attend class and participate in the team-based learning activities and perform better in the class. A weak correlation existed between grades and participation in clicker questions.

A key lesson learned relating to the 'clicker' approach was the students' misunderstanding of the reason behind the method. Students were frustrated with the 'fairness' of being graded on topics that they had not been fully instructed on. It was necessary to reiterate that lecture participation credit (5% of total grade) consisted of primarily participating and secondarily from correct answers, with a 75:25 split in the score criteria. Students had to be reminded bi-weekly that they were allowed, and encouraged, to discuss the topic with their peers prior to answering a clicker question.

For the weekly team-based learning activities, students chose to stay in the same group of three for the whole semester, with some minor shifting of groups. The instructor allowed students to start the activity whenever a group of three students naturally synthesized. Therefore, students would gravitate towards pods with one or two students already present so they could start the assignment early. In this study we did not keep track of the group development, but this is something to monitor in the future. The team-based learning activities were generally well received. Students showed appreciation at the opportunity to work through difficult topics in a friendly environment, and expressed excitement at their ability to "get it" with the help of guided team-based learning activities. Again, there was a correlation between student score and participation in these group activities. There was an interesting group dynamic that was unexpected; though most groups worked together through the group work activities, conferring ideas and theories before moving forward. Other groups that tried a "divide-and-conquer" approach, where each team member would work through a subsection and then try to bring the information together at the end. This secondary approach was not as successful in helping guide students to a broader understanding, since they missed connecting ideas between subsections. The instructor strategically developed the "design" group work activities to reduce the ability for groups to tackle the assignment with this "divide-and-conquer" approach since one of the primary objectives of the group work activities was to get students comfortable making group decisions.

3.2 flipped classroom

The flipped classroom experiment was conducted for two weeks, and was designed to help students learning the topics of phase diagrams and phase transformations. It was assumed that these sections would easily facilitate a flipped classroom approach since they rely heavily on students interacting with graphical representations. The direct assessment of this technique was done by comparing scores on the exam, and homework mastery. Figure 2, shows the average and standard deviation of the scores for the three topics assessed during the second exam of the semester. The first two topics were taught using the lecture-lecture-active learning session approach, while the third topic was taught using the flipped classroom approach. The average score on this third exam problem was slightly lower than the other two questions. Of greater concern to the instructor was the shape of the grade distribution. Though problem three and one had similarly large deviation in the scores, the student scores for problem one created a left skewed distribution and the student scores for the third problem produced a bimodal distribution centered around the highest and lowest scores.

Indirect assessment of the flipped-classroom approach was done through the midsemester survey. Students felt that "The instructor wasn't doing her job" of teaching them. They felt that they were "learning" more when the lecturer lectured. There was even one student complaint to the department chair that their education was being adversely affected by the experiment. At this
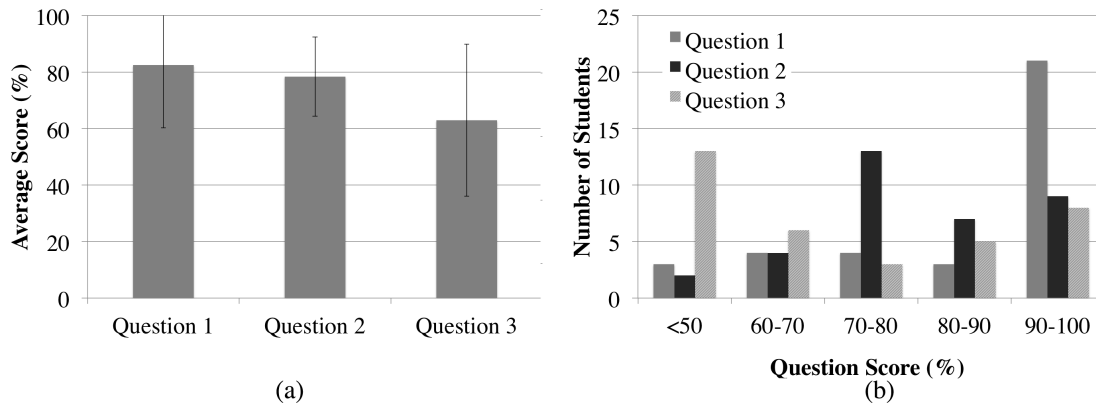
Figure 2: (a). Average student score on each of the three question topics from exam 2. (b) The histogram showing the distribution of student scores for each question. Question 1 has a left skewed distribution, Question 2 has a more normal distribution and Question 3 has a bimodal distribution.

point, it is believed that the flipped-classroom experiment was ineffective because it wasn't the course structure that was outlined at the beginning of the semester, and was therefore unexpected by the students. This is of course testable in the future by utilizing a flipped-classroom approach from the first day of class.

3.3 online homeworks

The assessment of the online homework technique is multifaceted: 1) do the homeworks effectively assess student learning, 2) how did the student assess the success/failure of the "new" homework format. Over the course of the semester, it was observed that most students only required three to five attempts on the part B assignments before achieving the necessary mastery. By requiring students to work through Part B assignments until mastery was achieved the instructor could facilitate discussions of effective problem solving and error checking. This was an important teaching tool to convince students of the importance of consistent units, since these errors were correctable. Nine students received homework mastery scores less than 80%. Five of these students received the five lowest grades in the class, the other four students received overall grades in the middle of the overall grade spectra. This would indicate that there was no correlation between homework mastery grade and overall course grade. A similar format (Part A: multiple choice, and Part B: design/computational) was utilized for the structure of exams.

The students' indirect assessment of the online homeworks was intricately related to the particular technology used. The survey responses during and after the course indicate that students both like and dislike this homework format. Many students expressed their excitement at having instant feedback, but also expressed concern that there was no value for partial credit. They were also frustrated with the Blackboard interface for doing the homework assignments. This was primarily caused by instructor errors with setting up the problems, particularly: incorporating appropriate error bars on acceptable answers to account for rounding errors, and accurately applying rules for significant figures for numerical answers. The next time Blackboard homework problems are used, the instructor will need to follow the guidelines for selecting appropriate significant figures

for computational problems. During the midsemester survey students expressed frustration with being required to attempt the entire homework set multiple times to achieve mastery (meaning they still had to do #1 each time even if they got it right in a previous attempt). This frustration was alleviated when the instructor reminded students that since the computer had to grade the assignment, the entire assignment could be worked out in an Excel sheet or MatLab code to remove unexpected calculation errors. They were all hesitant to believe that mastery grading was helping them learn. After the midsemester survey, the student were reminded that learning from their mistakes was a valuable lesson that is difficult to learn with conventional assignments where there is no opportunity to check for mistakes. Once this discussion occurred, students indicated a higher level of comfort and continued to provide constructive comments on the homework assignments. Several students who regularly worked on the homework early in the week started talking with the instructor early enough that if errors in the assignment existed that they could be fixed before other students experienced that same errors. The most common errors that the students made on the homeworks were unit conversions (eg. GPa to MPa, or Celsius to Kelvin), and converting from given quantities (e.g. using radius instead of diameter, resistivity instead of conductivity).

3.4   classroom

The classroom space was part of a university effort that created two redesigned active learning classrooms. Similar to the TILE program at the University of Iowa, where a key component was that faculty under went intensive training before they are allowed to teach their courses in these classrooms,[17] Case Western established a similar summer training program entitled "Active Learning Faculty Fellowship" to support faculty as they apply new pedagogical approaches, and training in the technologies in the new classrooms. An extensive assessment to determine the effectiveness of the new spaces and program was also conducted during and following the semester. A variety of data collection methods were utilized to assess the classroom (eg, class observations, faculty interviews, student focus groups, student surveys). In interviews, faculty noted an increased workload was required to sustain a class with a redesigned active pedagogy. In some cases, faculty came to class much earlier to prepare, stating that the new course format and the potential risk to the students had them feeling anxious. Over the course of the semester the anxiety decreased and confidence increased. Despite many concerns from faculty, student interviews indicated that the two new classrooms successfully created an open and comfortable environment and promoted active engagement and preparation for real-world applications of knowledge such as group collaboration. They also appreciated the focus on student and faculty dialog versus traditional lecturing. The facilitators of the Active Learning Faculty Fellowship are currently working on compiling data to present a full assessment of the classroom space in the future.

With regard to this particular MSE introductory course, the indirect assessment of the classroom indicates that the active learning space is both functional and exciting for student learning. This conclusion comes from instructor journaling, student interviews, and outsider shadowing during team-based learning activities. The initially planned course structure only included active-learning activities every other Friday, but the students expressed disappointment, and confusion the first week there wasn't a Friday activity. Weekly active-learning activities, instead of biweekly activities, provided a predictable structure with clear expectations. As the semester progressed, the students began to take ownership of the space, rearranging the pods to help facilitate group work

activities Fig. 3. The large-format interactive touch-screen computers allowed students to more efficiently work in group on computer intensive design activities. With the current trend of incorporating computational materials science and engineering into undergraduate curriculum, these interactive systems will help facilitate teaching and learning of these emerging engineering tools.

4   conclusions

The exam scores indicate that students were able to meet the desired learning objectives. The total grade distribution was as follows: 8 students performed at an A level, 20 students performed at a B level, 5 students performed at a C level, and one student failed the course. Only one student dropped/withdrew from the course, indicating that the teaching and learning approaches that were implemented this semester did not frustrate the students enough that they would choose to take the course the following semester when the instructor was not teaching the course. The instructor was concerned that the new approaches coupled with the early course meeting time would be a deterrent, but this did not appear to affect the classroom population.

Figure 3: Team-based active learning activity early in the semester. Students arranged the room to best suit their learning needs. This activity did not require the use of the large-format interactive touch-screen computers so the students didn't arrange the pods around them.

The active learning environment promoted student involvement with the material being studied, their peers, and the instructor. By the end of the course, students were relying on each other for support and discussion in the classroom space before and after class. It was evident from the overall high grades and student survey results that the active learning environment helped the students build a community of support that they will continue beyond this course. These anecdotal finding are consistent with more rigorous statistical studies of student involvement in active learning classroom spaces.[18] As the instructor is also the academic advisor for the sophomore class that experienced this active learning environment, she plans to ask students in two years if they think the active learning experience changed how they interact with their peers.

The flipped-classroom approach was not successful for this semester. There was marked change in student performance on formal assessments, both on the exam on the homework activities. The students appear to have become disengaged and frustrated with the topic and lost trust in the

instructor. The engineering students complained that with homeworks and reading assignments, that the necessary workload outside of class became unmanageable, as they were taking five or more classes concurrently.

The online homework approach was a marginal success. It provided an opportunity to interact with the course materials until they achieved mastery of a particular concept. The instructor learned valuable lessons associated with setting-up the problems using the Blackboard interface; including the importance of setting up acceptable error brackets to account for rounding errors, and using logical significant figures in the expected solutions. The online assignments and in-class active learning activities provide complementary learning opportunities.

The newly designed classroom space was highly effective at promoting an active learning environment. The instructor looks forward to teaching in the space in the future, and learning more about how the technologies can be used to facilitate student learning.

5 acknowledgments

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6 appendix

6.1 Steel Design Scenario

Two rival steel mills, Minneapolis Steel Inc. (MSI) and St. Paul Steel Corp. (SPS), have each received funding from a government grant to study heat treatments of various steel compositions. As an outside authority, you are tasked with reviewing the work that these two companies have accomplished so far. Having done your research ahead of time, you decide to use this tool to calculate TTT and CCT diagrams: http://calculations.ewi.org/vjp/secure/TTTCCTPlots.asp.

For all chemistries, assume 0.01wt% of all un-specified components.

1. 1045 Steel (Carbon steel): This composition has $0.45wt\%C$, $0.75wt\%Mn$, and no other measurable alloy components. While MSI formulated the composition correctly, SPS misread the requirements, and used $0.65wt\%C$ instead.

   (a) An austenitic steel bar is cooled rapidly to $550K$, held for $1000s$, and then cooled rapidly to room temperature.

      i. What is the final microstructure of the bar for each company?
      ii. How is the hardness affected by this mistake?

   (b) An austenitic steel bar is cooled rapidly to $800K$, held for $100s$, and then cooled rapidly to room temperature.

      i. What is the final microstructure of the bar for each company?
      ii. How is the hardness affected by this mistake?

2. (1045 Steel continued) To try and correct their mistake, SPS reduces the carbon content down to 0.48wt%.

   (a) Will the microstructure of SPS's steel from (1a) change? If so, how?

   (b) Both companies create a steel bar with 100% fine pearlite, but neither list the processing methods used to obtain it.

      i. Give a processing method used by MSI to obtain this microstructure.
      ii. How would SPS's process be different?

3. 4041 Steel (Low alloy steel): This composition has $0.41wt\%C$, $0.95wt\%Cr$, $0.3wt\%Mo$, $0.85wt\%Mn$, and $0.2wt\%Si$, and no other appreciable components. SPS is able to measure carbon correctly this time, and gets the composition exactly right. However, MSI's furnace is contaminated with nickel, resulting in a composition with an additional $1wt\%Ni$.

   (a) For pearlite, what is the minimum time/temperature for the onset of formation

      i. For MSI's steel?
      ii. For SPS's steel?

   (b) How does the addition of vanadium (instead of nickel) change?

      i. The onset time of pearlite formation
      ii. The bainite formation temperature

4. 5140 Steel (low alloy chrome steel): This composition has $0.4wt\%C$, $0.75wt\%Mn$, and $0.8wt\%Cr$. MSI's spell checker was broken, so they added cobalt instead of chromium.

    (a) How does replacing the chromium with cobalt affect:

        i. The martensite and bainite onset temperatures?
        ii. The time available to quench to produce martensite?

    (b) While many iron-carbon phase diagrams have only two noses, the one with cobalt has three. What do you think the phase of each nose represents?

    (c) Cobalt is not typically found in steels except for specific applications. Some grades of steel that contain cobalt include M35 and M42. What are these steels typically used for?

5. Each of the following elements provides some unique benefits to steel properties. For each element listed below, give a short (full sentences not needed) description of how it improves the steel.

    (a) Manganese
    (b) Chromium
    (c) Lead
    (d) Molybdenum

6.2 Polymer Matrix Composite Design

The properties of fiber-reinforced composites are determined by empirical relationships assuming that fibers are either continuous, discontinuous aligned or discontinuous random. Given the following property values, make a recommendation for the following application of the following PMC's:

Build an excel sheet for this activity, a starting sheet with the tabulated data has been uploaded to blackboard. For all your work label column headings and units used. (turn in to blackboard at the end of class)

1. For each of the three composite systems, Do you expect each PMC to behave as a continuous or discontinuous fiber reinforced material? Why?

2. What equation describes how the Modulus of discontinuous fiber composite varies as a function of volume fraction? How does the fiber alignment change the calculation of modulus?

3. What are the equations that describe the Strength of a fiber reinforced PMC with either:
    (a) Continuous Fibers
    (b) Discontinuous fibers $l > l_c$
    (c) Discontinuous fibers $l < l_c$

4. What is the minimum volume fraction of reinforcement phase needed for each PMC to obtain the desired Modulus design criteria?

5. What is the minimum volume fraction of reinforcement phase needed for each PMC to obtain the desired Strength design criteria?

6. If modulus and strength were your only design criteria, what would be the minimum volume fraction of reinforcement needed to meet both criteria? Why?

7. How would you calculate the cost ($/cm^3$) from volume fraction?

8. Which PMC(s) satisfy all three design criteria?

Table 2: Tabulated Data

	Modulus (GPa)	Tensile Strength (MPa)	Density (gm/cm^3)	Cost ($\$/kg$)	τ_c (MPa)	d (mm)	l (mm)
Fiber							
Glass	72.5	3450	2.58	2	15	0.01	3.5
Carbon	230	3150	1.78	60	15	0.008	3.5
Silicon Carbide	480	15000	3.3	100	40	0.01	1
Matrix							
Polyester	3.4	80	1.3	12			
Epoxy	2.4	40	1.2	19			
Polycarbonate	2.4	65	1.2	3			

Table 3: Design Criteria

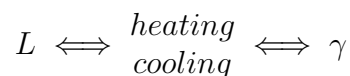| Modulus (GPa)	> 50
Strength (MPa)	> 1100
Cost ($\$/cm^3$)	< 0.1

6.3 Phase Diagrams

Reading Quizzes and Active Learning Activities were designed based on reading and learning objectives of Chapter 10 of Callister et al.[1]

Reading Quiz 1

1. What is the relationship between a component and a phase?

2. What are the variables in a Unary phase diagram?

3. How is a tie-line used in a two-phase region of a binary phase diagram?

Reading Quiz 2

1. What is the equation and meaning of Gibbs Phase Rule?

2. Why does the Iron-Carbon phase diagram in the text only go from 0 to $6.7 wt\%C$?

3. Which type of transformation is described by the following reaction? Where L indicates a liquid and γ indicates a single solid with the same composition as the liquid.

$$L \iff \frac{heating}{cooling} \iff \gamma$$

Phase Diagrams: Active Learning Activity 1

1. Sketch a simple isomorphous phase diagram
   (a) Label the different phase regions
   (b) Label the liquidus and solidus lines

2. Sketch a simple eutectic phase diagram
   (a) Label the different phase regions
   (b) Label the liquidus, solvus, and solidus lines

3. Given the Ag-Cu binary phase diagram.
   (a) What are the components of this system? Label each of the unlabeled phase regions
   (b) Indicate the point on the diagram for: $30at\%Ag$ and $1000°C$, what phase(s) are present, what is the composition(s) of the phase(s) and the mass fraction(s) of the phase(s)
   (c) Indicate the point on the diagram for: $20at\%Cu$ and $800°C$, what phase(s) are present, what is the composition(s) of the phase(s) and the mass fraction(s) of the phase(s)
   (d) At $30at\%Ag$ and $600°C$, what phase(s) are present, what is the composition(s) of the phase(s) and the mass fraction(s) of the phase(s)

Phase Diagrams: Active Learning Activity 2

1. Given the Hf-V binary phase diagram, do the following:
   (a) Locate the temperatures and compositions of all the eutectic, eutectoid, peritectic and congruent phase transformations.
   (b) Label the phases present in each of the different two phase regions
   (c) Write the reactions for all of these transformations (whether they are shown on the given diagram or not) for either heating or cooling. Indicate heating/cooling direction.
      Eutectic, Eutectoid, Peritectic, Congruent

2. For the Fe-C binary phase diagram, for a given the composition of 0.5 or $1.5wt\%C$
   (a) Specify if this alloy is hypoeutectoid or hypereutectoid
   (b) Name the proeutectoid phase
   (c) Compute the mass fractions of proeutectoid phase and pearlite
   (d) Draw a schematic diagram of the microstructure just below the eutectoid temperature

6.4 Phase Transformations

Reading Quizzes and Active Learning Activities were designed based on reading and learning objectives of Chapter 11 of Callister et al.[1]

Reading Quiz 1

1. The total free energy associated with solidification is associated with the nucleation of a particle of solid in the liquid. Schematically explain how to determine the critical radius of nucleation from the volume free energy and surface free energy terms of the equation.

Logarithm of heating time, t
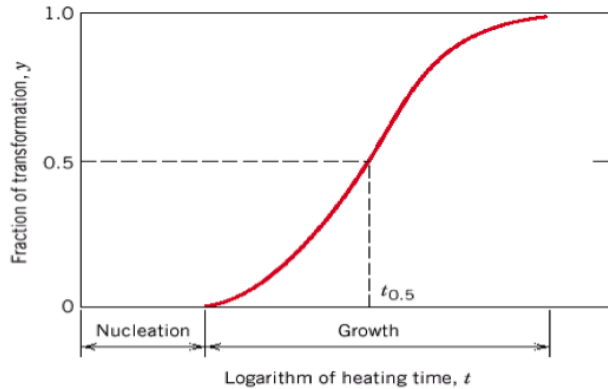
2. Label the nucleation and growth regimes in the following diagram that shows a diffusional transformation. What equation describes this behavior?

3. Rank the following steel phases from hardest to softest: bainite, pearlite, martensite, tempered-martensite

Reading Quiz 2

1. What and how is the microstructure changing during martensite tempering?

2. What is occurring when a precipitation hardened material becomes overaged.

3. How does specific volume change if a material transitions from liquid to glass versus a material that transitions from liquid to crystalline?

Phase Transformations: Active Learning Activity 1

1. Sketch a simple isomorphous phase diagram
   (a) Label the different phase regions
   (b) Label the liquidus and solidus lines

2. Sketch a simple eutectic phase diagram
   (a) Label the different phase regions
   (b) Label the liquidus, solvus, and solidus lines

3. Given the Ag-Cu binary phase diagram.
   (a) What are the components of this system? Label each of the unlabeled phase regions
   (b) Indicate the point on the diagram for: $30at\%Ag$ and $1000°C$, what phase(s) are present, what is the composition(s) of the phase(s) and the mass fraction(s) of the phase(s)
   (c) Indicate the point on the diagram for: $20at\%Cu$ and $800°C$, what phase(s) are present, what is the composition(s) of the phase(s) and the mass fraction(s) of the phase(s)
   (d) At $30at\%Ag$ and $600°C$, what phase(s) are present, what is the composition(s) of the phase(s) and the mass fraction(s) of the phase(s)

4. Briefly describe the microstructure for each of the following microconstituents that are found in steel alloys:

(a) fine pearlite

(b) coarse pearlite

(c) spheroidite

(d) bainite

(e) martensite

(f) tempered martensite

5. Cite the general mechanical characteristics for each of the following microconstituents
    (a) fine pearlite
    (b) coarse pearlite
    (c) spheroidite
    (d) bainite
    (e) martensite
    (f) tempered martensite

6. Using the isothermal transformation diagram for an iron–carbon alloy of eutectoid composition, specify the nature of the final microstructure (in terms of microconstituents present and approximate percentages of each) of a small specimen that has been subjected to the following time–temperature treatments. In each case assume that the specimen begins at $760°C (1400°F)$ and that it has been held at this temperature long enough to have achieved a complete and homogeneous austenitic structure.
    (a) Cool rapidly to $700°C (1290°F)$, hold for $10^4 s$, then quench to room temperature.
    (b) Reheat the specimen in part (a) to $700C (1290F)$ for $20h$.
    (c) Rapidly cool to $600°C (1110°F)$, hold for $4s$, rapidly cool to $450°C (840°F)$, hold for $10s$, then quench to room temperature.
    (d) Cool rapidly to $400°C (750°F)$, hold for $2s$, then quench to room temperature.
    (e) Cool rapidly to $400°C (750°F)$, hold for $20s$, then quench to room temperature.
    (f) Cool rapidly to $400°C (750°F)$, hold for $200s$, then quench to room temperature.
    (g) Rapidly cool to $575°C (1065°F)$, hold for $20s$, rapidly cool to 350°C (660°F), hold for $100s$, then quench to room temperature.
    (h) Rapidly cool to $250°C (480°F)$, hold for $100s$, then quench to room temperature in water. Reheat to $315°C (600°F)$ for $1h$ and slowly cool to room temperature.

Phase Transformations: Active Learning Activity 2

1. Using a phase diagram, describe and explain the two heat treatments that are used to precipitation harden a metal alloy.

2. Make a schematic plot of room-temperature strength (or hardness) versus the logarithm of time for a precipitation heat treatment at constant temperature. Explain the shape of this curve in terms of the mechanism of precipitation hardening for aluminum alloys.

3. Copper-rich copper–beryllium alloys are precipitation hardenable. After consulting the portion of the phase diagram in the text, do the following:
   (a) Specify the range of compositions over which these alloys may be precipitation hardened.
   (b) Briefly describe the heat-treatment procedures (in terms of temperatures) that would be used to precipitation harden an alloy having a composition of your choosing yet lying within the range given for part (a).

4. List four characteristics or structural components of a polymer that affect both it's melting and glass transition temperatures.

5. For each of the following pairs of polymers, plot and label schematic specific volume– versus–temperature curves on the same graph [i.e., make separate plots for parts (a) to (c)].
   (a) Spherulitic polypropylene of 25% crystallinity and having a weight-average molecular weight of $75,000g/mol$; spherulitic polystyrene of 25% crystallinity and having a weight-average molecular weight of $100,000g/mol$
   (b) Graft poly(styrene-butadiene) copolymer with 10% of available sites crosslinked; random poly(styrene-butadiene) copolymer with 15% of available sites crosslinked
   (c) Polyethylene having a density of $0.985g/cm^3$ and a degree of polymerization of 2500; polyethylene having a density of 0.915 g/cm^3 and a degree of polymerization of 2000