ASEE AMERICAN SOCIETY FOR ENGINEERING EDUCATION

Paper ID #44761

Experiential Learning Utilizing Class and Lab Demos in a Material Science and Manufacturing Course

Dr. Shadi Balawi, Texas A&M University

Dr. Balawi is an Instructional Associate Professor in the Mechanical Engineering department at Texas A&M. He teaches in the areas of materials, manufacturing, and design. His interests are in the areas of Engineering Design for Disciplinary STEM Educational Research, Team Formation and Team Skill Education. Dr. Balawi earned his PhD in Aerospace Engineering from University of Cincinnati with research focus on experimental design and testing of solids for honeycomb core materials.

Matt Pharr, Texas A&M University

Matt Pharr is an Associate Professor and J. Mike Walker '66 Faculty Fellow in Mechanical Engineering at Texas A&M University with a courtesy appointment in Materials Science & Engineering. His scientific research focuses on mechanics of materials in areas including energy storage and conversion, soft materials, irradiated materials, stretchable electronics, coupled electro-chemo-mechanics, and materials for neuromorphic computing. He teaches classes primarily in mechanics of materials and materials science. He has received an NSF CAREER Award, the Kaneka Junior Faculty Award, a Texas A&M Engineering Experiment Station (TEES) Young Faculty Award, the Peggy L. & Charles Brittan '65 Outstanding Undergraduate Teaching Award, a Montague-Center for Teaching Excellence Scholar Award, and The Texas A&M Association of Former Students Distinguished Achievement Award in Teaching.

Session XXXX

Experiential Learning Utilizing Class and Lab Demos in Material Science and Manufacturing Course

Abstract

Students are typically introduced to material science concepts through PowerPoint lecture slides combined with online videos. Students are passively absorbing information and concepts from class. This approach does not provide students the opportunity to interact with introduced topics. Class demos are used to help students understand and link the effect of processing on material's microstructure and thus its mechanical properties.
Creating class-props helps in presenting various items of the material microstructure evolution and how it is linked to mechanical properties. These props will be utilized during class sessions as in-class work. The aim is to encourage students to ask their questions, examine their understanding in an inviting environment within smaller groups. This will allow all students including disadvantaged and URM ones an opportunity to learn first-hand without the anxiety feeling of asking a question in the general class setting. Basic props were built over summer 2023. These were used in demos as part of measuring initial reactions and modifying them as needed. A baseline was established using some of these demos. These props and demos showed a positive trend helping to encourage and motivate students. This paper will go over the process of developing these props for both class and lab demos that utilizes previously developed kits. A baseline material concept inventory is also introduced.

Introduction

Classroom demonstrations are a common tool used to convey concepts in challenging subjects. They are used to help reinforce and stimulate students' learning[1,2,3,4] and increase their engagement[2,5] . Engaging students in an interactive demonstration has been shown to have many benefits such as increased performance[6] ; development of independent learning skills, critical thinking, and problem-solving skills[7] . Adding demonstrations increases enjoyment and positively impact learning [4,5] . Students often exhibit a lack of understanding or have misconceptions regarding concepts that our experiments had targeted. we proposed to introduce short demonstrations/activities that can be implemented with typical lab or classroom settings to help combat misconceptions. This mode of experiential learning increases student engagement, enhance learning, and increase the retention of concepts[8]. These activities can also be used as a tool to enhance critical thinking skills.
When designing the demonstrations, we surveyed the literature for best practice guidelines[9,10,11] . Milner et al. discussed the importance of observing a demonstration correctly to result in conceptual understanding. For instance, a lack of learning/understanding can occur when experiments do not go as expected. An essential element in an effective demonstration is in allowing the students to predict the outcome[2,12]. In addition to implementing this approach, we also strived to review the underlying physics and, where possible, include a hands-on element to actively engage the students and make the demonstration more interactive. Other elements we implemented included having the demonstrations be short, attention-grabbing, and performed in small groups. Using this framework,

as depicted in Figure 1, we developed short demonstrations/activities. Students are asked to take a concept quiz based on the basic material science prerequisite course. This concept quiz is presented in Figure 2. It has questions related to basic material microstructure, crystal structure, diffusion, and basic polymer material knowledge. The results of this conceptual quiz, that is taken at the start of the course, help identify conceptual issues that would need further attention. This may be utilized on prioritizing which class activities would be developed first. The formatting is through multiple choice and True/False questions. This quiz served two purposes; first, to help students identify whether they are ready for the following course or need to review some of the concepts. The second is to help design class demonstrations/activities to correct and enhance any deficiencies for the class.

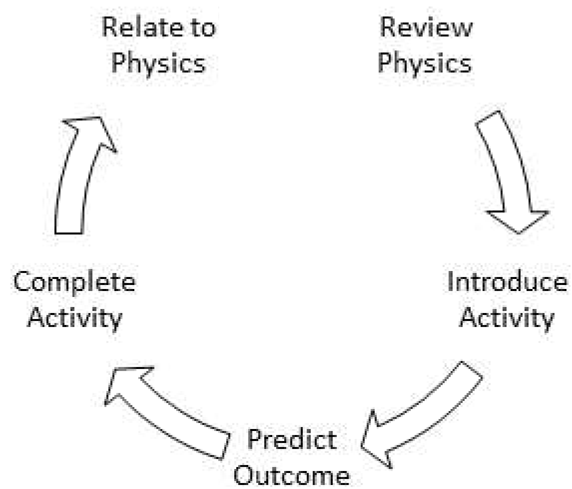

Figure 1 Proposed framework for implementation of demonstrations[13].

The following section will describe some of the recent experiential learning exercises that were developed and implemented in Fall 2023. Two lab demonstrations have been introduced and analyzed in a previous publication[13]. The current exercises can be completely done in a classroom setting, while the previous ones utilized liquid nitrogen that is more suited for a lab setting. These current activities will be followed by a quiz to check their efficacy compared to a baseline group who are not exposed to these activities. Both the baseline and study groups took the conceptual quiz to make sure that we started from a similar baseline knowledge. Findings of the next phase of the study will be communicated in future publications. Data on the student body demographics are being collected and part of it will help assess in more details the impact of such demonstrators/activities of URM students. It is worth mentioning that the recent demographic data shows more than 40% of the College of Engineering at Texas A&M students are from URM background[14].

Part A (12 pts, 1 pt. each): True or False (T / F).

1. Al (aluminum) is more ductile than aluminum oxide (Al_2O_3).
2. Metal forming is easier to perform on brittle materials (i.e., less ductile ones).
3. Springback during sheet metal forming occurs due to elastic deformation ("elastic recovery").
4. The experimentally measured strengths of metals are much lower than theoretically predicted (based on bonding alone) because of defects.
5. Reducing the grain size of a metal typically decreases its strength.
6. Thermoset plastics are readily recyclable.
7. Polymers are produced from monomers through a process called "crystallization."
8. Vacancies increase entropy, and thus a significant (i.e., non-zero) equilibrium concentration of vacancies exists in metals (e.g., at room temperature).
9. Dislocations provide a mechanism for plastic deformation, particularly in metals.
10. Slip directions are almost always along the crystallographic directions with the longest distance between like atoms (or ions).
11. BCC metals tend to have lower strength but higher ductility than FCC metals.
12. The rate of diffusion strongly depends on the concentration gradient and temperature.

Part B (18 pts, 2.25 pts. each): Multiple Choice. CHOOSE THE LETTER FOR the correct answer.

1. Identify the **incorrect** statement regarding metals and their alloys:
   A. Metals are typically good electrical conductors.
   B. Metals are typically quite ductile (e.g., compared to ceramics).
   C. Metals typically have relatively high strength (e.g., compared to polymers).
   D. Metals are typically poor thermal conductors.

2. Amorphous polymers
   A. Lack long range order.
   B. Are relatively strong compared to their crystalline counterparts.
   C. Contain multiple grains.
   D. Are more resistant to corrosion than their crystalline counterparts.

3. Metal forming is typically done in the plastic deformation region of a metal. Microstructurally, what is the dominant mechanism during this process?
   A. Dislocation generation and movement
   B. Widespread (global) bond breaking
   E. Self-diffusion
   C. Grain boundary diffusion

4. Identify the **correct** statement related to crystal structures:
   A. Most metals have a tetragonal crystal structure.
   B. A face-centered cubic (FCC) metal is amorphous.
   C. A crystal structure can be thought of as a combination of a lattice and a basis.
   D. Most metals used in engineering applications are single crystals.

5. Which of the following **is not** considered a point defect?
   A. Vacancy
   B. Interstitial
   C. Substitutional defect
   D. Dislocation

6. Interstitial defects
   A. Are formed when an atom/ion is missing from its normal site in the crystal structure.
   B. Typically weaken a metal.
   C. Distort the surrounding lattice, thus generating localized stresses/strains.
   D. None of the above.

7. Identify the **incorrect** statement related to dislocations.
   A. Dislocations are important in the deformation behavior of polymers.
   B. Metals usually contain many dislocations.
   C. Dislocations provide a key mechanism for plastic deformation in metals.
   D. Mechanical properties of metals can be controlled by blocking the movement of dislocations.

8. Identify the **incorrect** statement related to diffusion.
   A. Diffusion of substitutional atoms typically occurs more rapidly than for diffusion of interstitial atoms.
   B. Close-packed crystal structures have higher activation energies than more open crystal structures.
   C. Cations typically diffuse faster than anions due to a cation's smaller relative size.
   D. Diffusion strongly depends on the concentration gradient.

Figure 2. Basic material science concept quiz.

Current Experiential Learning Exercises

Based on the results of current run of the conceptual quiz, students showed more conceptual issues with the following areas

- Interstitial space and ideas related to alloying of metals,
- Slip systems,

- Grain size and grain boundaries,
- Relations between temperature and grain size,
- Mechanical metal and polymer tensile testing,
- Cooling of liquid metal and its effect on grain size.

To build these experiential demonstrators we have used ball magnets and ball bearing to resemble the atoms in the material. Figure 3-left shows a case where the interstitial spaces in between large atoms can be filled with smaller atoms. Students would receive these in the class and try to load them and experience how would this change the behavior compared to ones made of the same "atomic" size. Figure 3-Right demonstrates the preferred "slip system" That demonstrates that it would be physically easier to slip in a 45-dgree angle. Students get the chance to experience these and "feel" how much force is needed compared to trying to break on a horizontal surface.

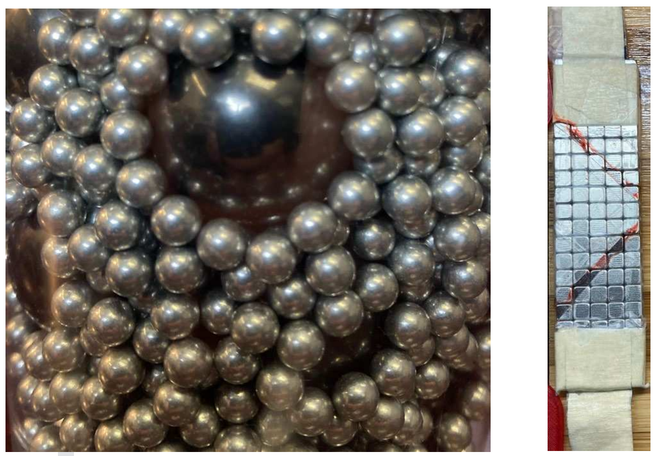

Figure 3. Atom size and interstitial spaces demonstrator.

Other demonstrators are presented in Figure 4. The one on the right is based a short YouTube video[15] that helps students understand and experience why we have point and line vacancies in the material structure. These demonstrates are provided to the students to try to make more and more of these grain possibilities and for them to observe how theses vacancies are formed while the whole structure is stable.
Figure 4-right shows the similar structure but with "alloying elements" which are made of similar size ball magnets (colored). The rational behind it is to show that alloying elements may change the interatomic forces and thus with similar motion the students may have harder time generating as wide of a range of "grain sizes" compared to "pure" metals. The horizontal bar is introduced to demonstrates the dislocation movement and how it is easily achievable in pure metals compared to alloys. The students experience that a horizontal slip due to the bars motion will cause various slip direction in various grains. Students experience and feel how these are energetically different which emphasizes why alloys are stronger than pure metals. It also helps students see and feel the impact of the alloying element quantity and its relation to strength (opposition to slip in this case).

Figure 4. 2D representation of crystal structure (left) pure metals and (right) metallic alloys.

The same demonstrators presented in Figure 4 are used to explain how temperature changes the energy levels in metals and can cause a complete rearrangement of the crystal structure and even can cause huge grains to form thus “softening” the material. The temperature is introduced as “vibration” [14] by placing these on shaker tables. Students experience in real time how the grains will merge and how they would form a much lager grain. The shaker table has various frequencies that demonstrate lower to higher temperature which helps the students link how annealing temperature and time are linked (the higher the temperature the lower the time needed to completely anneal the metal).

The next set of demonstrators utilize the small kits developed by the authors[16]. These kits were developed for answering different needs but prove to be very practical to bring into a classroom and allow students to interact with them and get a first had “feel” of the various aspects of the activities. These kits are presented in Figure 5. The PUTM can be used for multiple types of tests such as tensile, three-point bending, compression and hardness test. we have been running both metal and polymer tensile tests in the classroom. These tests are manually driven, and students feel how much force is needed to complete the test since these are force driven not displacement driven kits. A pneumatic system is used to apply the loading. Samples are shown in Figure 6 that include polymers and metals. As depicted in the figure the metallic sample breaks clearly at 45-degree which resonates with the demonstrator described earlier.

The personal foundry kit is used for melting low temperature metals in the classroom. Molds are used to produce samples that can be used in the PUTM. The kit allows students to see under a document camera how the phase change happens, and the instrumented kit can show how the temperature is fixed for pure metals during the phase change from liquid to solid and solid to liquid. This provides the students with a real time generation of the solidification cooling curves. By allowing the metal to cool down on the hot plate compared to the room temperature these kits can produce different grain sizes that could be visible on the specimen surface. It also helps demonstrate the casting Shrinkage (as depicted in Figure 7) and Gas Porosity defects.

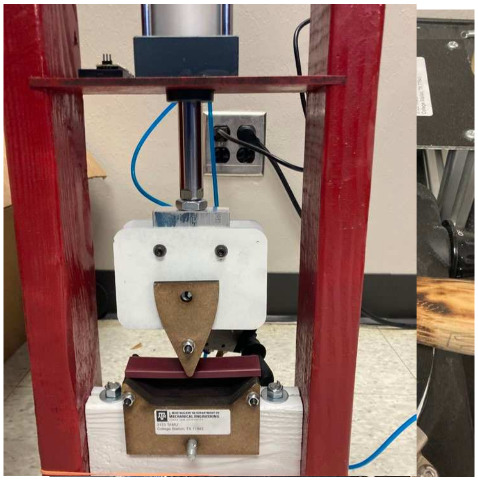

Figure 5. Small lab kits (left) personal universal testing machine (PUTM) and (right) personal foundry.

Figure 6. Various tensile samples used with the PUTM including polymer and metal samples.

Figure 7. Various personal foundry casting samples showing shrinkage defect on the top.

Summary and Conclusions

In summary, the aim of this work is to encourage students to ask their questions, examine their understanding in an inviting environment within smaller groups. This allows all students including disadvantaged and URM ones an opportunity to learn first-hand without the anxiety feeling of asking a question in the general class setting. Basic experiential learning demonstrators and props were built and used in demos and class exercises. By measuring initial reactions of the piloted setups, we are modifying and updating these demonstrators as needed. A baseline was established using some of these demos. These props and demos showed a positive trend helping to encourage and motivate students. Plans are to build augmented reality applications that will expand further the learning experience and try to encourage students learn.

References

1. N. Fang, "In-Class Instructor Demonstrations Improve Students' Conceptual Understanding of Undergraduate Engineering Dynamics." Global Journal of Engineering Education 22, no. 1 (2020): 64-69.
2. C. Crouch, A.P. Fagen, J.P. Callan, and E. Mazur. "Classroom Demonstrations: Learning Tools or Entertainment?". American Journal of Physics 72, no. 6 (2004): 835-38. https://doi.org/10.1119/1.1707018.
3. B.P. Self, and J.M. Widmann. "Demo or Hands-On? A Crossover Study on the Most Effective Implementation Strategy for Inquir--Based Learning Activities." ASEE Conferences, Columbus, Ohio, 2017.
4. J. Morgan, L. R. Barroso, and N. Simpson, "Active demonstrations for enhancing learning," 2007: IEEE, doi: 10.1109/fie.2007.4418057.
5. C. Milne, and T. Otieno. "Understanding Engagement: Science Demonstrations and Emotional Energy." Science Education 91, no. 4 (2007): 523-53. https://doi.org/10.1002/sce.20203. https://dx.doi.org/10.1002/sce.20203.
6. S. Freeman, L.E. Sarah, M. McDonough, K.S. Michelle, N. Okoroafor, H. Jordt, and P.W. Mary. "Active Learning Increases Student Performance in Science, Engineering, and Mathematics." Proceedings of the National Academy of Sciences 111, no. 23 (2014): 8410-15. https://doi.org/10.1073/pnas.1319030111 .
7. A. Sivan, R. W. Leung, C. Woon, and D. Kember. "An Implementation of Active Learning and Its Effect on the Quality of Student Learning." Innovations in Education and Training International 37, no. 4 (2000): 381-89. https://doi.org/10.1080/135580000750052991 .
8. J. Theobald Elli et al., "Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering, and math," Proceedings of the National Academy of Sciences, vol. 117, no. 12, pp. 6476-6483, 2020, doi: 10.1073/pnas.1916903117.
9. T. O'Brien, "The science and art of science demonstrations," Journal of Chemical Education, vol. 68, no. 11, p. 933, 1991, doi: 10.1021/ed068p933.
10. L. S. Meyer, D. Panee, S. Schmidt, and F. Nozawa, "Using Demonstrations to Promote Student Comprehension in Chemistry," Journal of Chemical Education, vol. 80, no. 4, p. 431, 2003, doi: 10.1021/ed080p431.
11. W. M. Roth, C. J. McRobbie, K. B. Lucas, and S. Boutonné, "Why May Students Fail to Learn from Demonstrations? A Social Practice Perspective on Learning in Physics," Journal of Research in Science Teaching, vol. 34, no. 5, pp. 509-533, 1997.A. Amador-Perez and R. A. Rodriguez-Solis, "Analysis of a CPW-fed annular slot ring antenna using DOE," in Proc. IEEE Antennas Propag. Soc. Int. Symp., Jul. 2006, pp. 4301–4304.
12. K. Miller, N. Lasry, K. Chu, and E. Mazur, "Role of physics lecture demonstrations in conceptual learning," Physical Review Special Topics - Physics Education Research, vol. 9, no. 2, 2013, doi: 10.1103/physrevstper.9.020113. Grayson, L.P., 1980, ―A Brief History of Engineering Education in the United States", IEEE Transactions on Aerospace Systems, Vol. 16, No. 3, pp. 373-391.
13. A. A Youssef,.S. Balawi, M. Pharr, (2023, June), Mini-Lab Activities to Stimulate Students' Conceptual Learning Paper presented at 2023 ASEE Annual Conference & Exposition, Baltimore , Maryland. https://peer.asee.org/43925
14. URL: https://www.collegefactual.com/colleges/texas-a-and-m-university-college-station/academic-life/academic-majors/engineering/ , last accessed 26 Feb 2024.

15. URL: https://youtu.be/xuL2yT-B2TM , last accessed 30 Dec 2023.
16. S. Balawi, N. Thomas, and A.R. Srinivasa, (2023, October) "An Inexpensive Alternative to Materials Lab Turnkey Expensive Systems: A Less is More Story!," in 2023 IEEE Frontiers in Education Conference (FIE), College Station, TX, USA, 2023 pp. 1-4. doi: 10.1109/FIE58773.2023.10343041