

## From Pennies to the Internet: Tools of the Trade

Christine Corum, Patricia Olesak  
Purdue University, West Lafayette, IN

### Abstract

The various subjects associated with a materials course can be difficult for the students to learn and the instructor to teach. Over several semesters, we have found various teaching aids, ranging from the simple to the complex, that help us better explain topics in a materials course.

Our simplest tools use the well understood topic of U.S. money for explaining the reading of a micrometer, Hume-Rothery solubility rules, diffusion, dislocations, grains and grain boundaries. A slightly more complex tool would be computer software to help explain the development of phase diagrams from cooling curves, to reading a phase diagram and making appropriate calculations. Recently, we have expanded our tools to include the Internet from which we utilize several different movie clips to help explain crystal morphology, cold working and annealing of metals, electrochemical corrosion and the amorphous structure of glass. Our range of tools also comes with a range of price tags and availability.

### Introduction

Using examples of topics discussed in a material science course are often referred to as being similar to “lifting a cloud”. Real-life, easy to understand examples can help students learn and help teachers explain various subjects. Most students need an example in order to fully understand a topic. When a good example is applied, the student is able to “put all the pieces together”. They heard the explanation of the theoretical principle involved and wrote down pertinent facts but until an example is used, they may not fully understand the theoretical principle. There are many useful, practical and helpful examples available for use by the materials’ educator. Some examples are as simple as placing coins on an overhead and projecting the images, some are more sophisticated utilizing computer software or the internet.

### US Money

The simple illustration of placing coins on an overhead and projecting images can be quite useful for explaining many topics in a material science course. The Hume-Rothery solubility rules<sup>1</sup> can be explained in this manner. Start by assuming one coin equals one atom. By stacking 25 pennies, a penny matrix can be made ( 2-D stacking of pennies; 5 pennies on a side). A penny measures 0.800 inch in diameter. The Hume-Rothery solubility rule states that the difference in size of atomic diameters of solvent and solute atoms should be less than 15%. The scenario for substituting for solvent atoms which are 0.800 inch diameter is shown below.

$$0.800 \times \pm 15\% = \begin{array}{l} / \\ 0.920 \\ \backslash \\ 0.680 \end{array}$$

If the Hume-Rothery solubility rules are to be followed, a solute atom must be within the range of 0.920-0.680 inch in diameter if the solvent atom measures 0.800 inch in diameter. A dime measures 0.755 inch in diameter, a nickel measures 0.855 inch in diameter, and a quarter measures 1.000 inch in diameter. A substitution of dimes or nickels can easily be made without much disruption to the penny matrix, since either substitution is within 15% of 0.800 in. However, a quarter substitution substantially distorts the penny matrix, since it is 25% larger than the 0.800 inch diameter pennies. These substitutions can easily be demonstrated as shown in Figure 1.

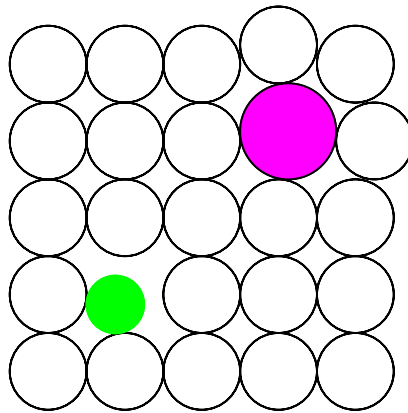


Figure 1. Hume-Rothery solubility rules

A vacancy can be demonstrated by removing a penny from the full penny matrix as shown in Figure 2. Diffusion can be illustrated when a vacancy is illustrated. By gliding a penny into the existing vacancy, a new vacancy can be created, located adjacent to the old vacancy. It can be shown how easy diffusion can occur with the presence of vacancies. The migration of specific pennies can illustrate the concept of diffusion.

An alloy with an interstitial solute atom can be illustrated by using small thumb tacks (0.310 inch diameter). The thumb tack is placed in the interstitial positions of the penny matrix as shown in Figure 2 (point side facing up so it is easy to grab).

Dislocations can be illustrated by modifying the stack of pennies. Stack the pennies so that there are five pennies across the top row, five pennies across the second row, five pennies across the third row, five pennies across the fourth row and four pennies across the fifth row. The “extra” column of pennies will illustrate the insertion of a dislocation. When the bottom penny of the “extra” column is moved to a vacant position, the migration of the dislocation can be observed as

shown in Figure 2. The dislocation can be moved from the right to the left side of the matrix using this technique.

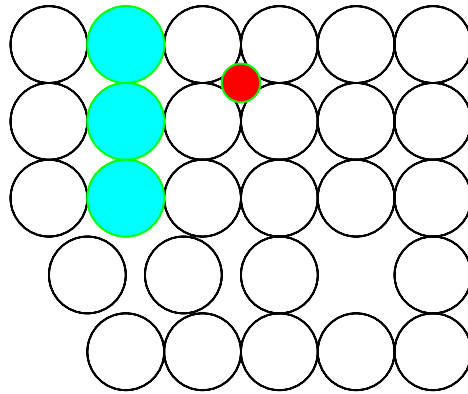


Figure 2. Vacancy, interstitial, dislocation

Grains and grain boundaries can be illustrated by using the penny matrix. Place your hand over approximately nine pennies and rotate the nine pennies towards the right (clockwise). The north/south, east/west axis are now north-east/south-west, east-south/west-north. The nine pennies are lined up with each other, yet their orientation is slightly off with the other 16 pennies. The edges of the nine pennies illustrates the grain boundary region. The slight mismatch between the nine, rotated pennies and the remaining 16 pennies illustrates a region of high energy at the boundaries.

US money can also be used as an example when reading a micrometer.<sup>2</sup> Think of the numbers on the sleeve as dollars, the vertical lines on the sleeve (in between the numbers) as quarters, and the divisions on the thimble as pennies. When the total is added up, put a decimal sign in front of the figures instead of a dollar sign.

### Software

A computer software program can be helpful in giving students an opportunity to work with phase diagrams. For a number of years, we have used a software program titled “The Use Of Phase Diagrams” in material laboratories as a supplement to phase diagram laboratories and lectures.<sup>3</sup> The program contains a number of isomorphous and eutectic binary phase diagram examples. Given a phase diagram to work with, students can practice calculations on their own and then turn to the computer program to check their work. Each diagram labels phases and marks the location of the alloy on the phase diagram when alloy composition and temperature are entered. While students may not typically struggle with identifying locations (given alloy and temperature) on a phase diagram and identifying a tie line and its end points, they tend to have difficulty determining compositions of phases and using the inverse tie line concept to calculate relative amounts of phases. Their error is obvious when they verify their calculations with the program. Results can be displayed for as many as four to seven alloy/temperature scenarios on

the screen at one time allowing students to see how phase amounts vary as composition or temperature vary as shown in Figure 3.

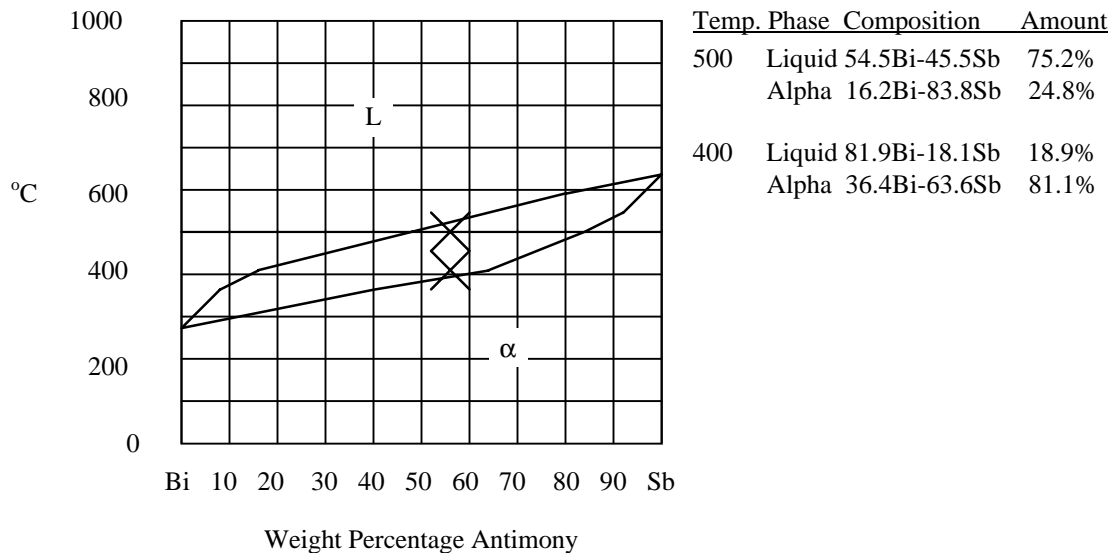


Figure 3. Screen for a 55% Sb alloy at 500 and 400 °C.

In addition to calculating relative amounts of phases, this particular program also displays results of various solidification and heat treatment processes. When directed to use the solidification menu, students see the cooling path through the phase diagram, the cooling curve for that particular alloy, and a picture of the microstructure that develops as cooling takes place. When using the heat treatment menu, students see the cooling path through the phase diagram, the Time-Temperature Transformation curve or Time-Temperature profile, and a picture of the microstructure that develops as heat treatment takes place.

Using this software helps in several ways. For one, the software draws “real time” figures, where the instructor is limited to “snapshots.” The program continuously gives a visual display of each process selected. Students can view this display repeatedly until they are comfortable with the picture that develops in their mind. Secondly, while students may not feel confident about working with phase diagrams, using the computer as a tool gives them the opportunity to work with something they are familiar with (the computer) to help understand something they are not familiar with.

### Multimedia

The newest tool has been provided via the internet.<sup>4</sup> As reported in ASEE’s Prism, Professor John Russ established a Web site entitled “Visualizations in Materials Science.”<sup>5</sup> This is an excellent visual tool and is useful for providing students with an opportunity for self-study. This material is also available on CD-ROM.<sup>6</sup> Among the many components of this multimedia tool are animations of molecular structures and actual film clips of lab experiments. For example, a rotating view of a body centered cubic lattice is displayed with atoms repeatedly shrinking and expanding to fill the lattice allowing students to see how the center atom touches all eight

surrounding atoms. Students, taking an introductory course in materials, that visited the web site stated that it helped them to visualize the concepts discussed in class and also helped to stimulate their interest in the course. In his narrative, Professor Russ reports an increase of nearly one letter grade for students in classes (Materials 201 at North Carolina State University) where this multimedia tool was used.<sup>7</sup> Using a laptop computer with CD-ROM capability allows the instructor to bring visual aids into the classroom in absence of computer labs. In an appropriate multimedia equipped classroom, this material can be displayed to the entire class.

### **Cost Issues of Tools**

It would certainly please our group if all tools were made available to us, with no additional cost, to pick and choose from to suit the needs of our students and our teaching styles. But, since that scenario is unrealistic, some discussion of cost, availability, and suitability is appropriate at this time. For some of the simpler tools, such as the money example used in the beginning, there is little or no cost involved. Likewise, these tools are readily available and easy to move from your office to your classroom. Students can also use their desk chairs in the classroom to make grains and grain boundaries in much the same ways coins can be used. This “tool” is of no cost to the instructor but is useless if chairs are permanently mounted or if class is held in a stepped auditorium.

For more complex tools, such as computer software and multimedia, cost becomes a greater factor. For example, the phase diagram software package (DOS based) described above was purchased in 1989 for about \$100. We are interested in replacing that version with a newer one using better graphics and colored displays. Software prices increase if additional copies are needed for entire computer labs or for computing networks.

The multimedia, CD-ROM version discussed is designed to be used in conjunction with a text. The cost to the student would be the normal text expense plus just over \$40 for the CD-ROM.<sup>8</sup> Also, availability becomes a large issue. For students to have the opportunity to review the multimedia package, they must have appropriate computer systems available. Likewise, if it is used as a lecture supplement, instructors must have appropriate media equipped classrooms. Our experience has been that even having the equipment is not enough. Since equipment has reliability problems, this unfortunately means that lecture may have to continue without the intended “visual aid.” Classroom environment, such as seating and lighting, has also made this tool difficult to use. Russ points out similar experiences with implementing multimedia in his course.<sup>7</sup> At our institution, computer labs with Internet access are available to all students. For this reason, we have encouraged students to access “Visualizations in Materials Science” via the Internet. This has eliminated some cost and equipment issues, however, some computers are not yet equipped with appropriate “viewing” software so some laboratory computers can not be used to view the animated illustrations or video clips.

## Conclusion

We have identified three of our most helpful tools in teaching a materials course. These tools range widely in complexity and cost. As complexity and cost increase so do problems with equipment and availability. Feedback from our students, and the learning improvements discussed by Professor Russ indicate that even more expensive, multimedia approaches may well be worth the cost. In any case, it is up to each instructor to select the tools that best fit their teaching technique and the needs of the students.

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8. For more information contact PWS Publishing Company, 20 Park Plaza, Boston, MA 02116 (*e-mail*: info@pws.com, *Internet*: <http://www.pws.com/pws.html>)

CHRISTINE L. CORUM Assistant Professor of Mechanical Engineering Technology at Purdue University, where she teaches courses in materials and quality. She received a B.S. in Metallurgical Engineering from the University of Missouri-Rolla and an M.S. in Industrial Engineering from Purdue University. She has six years of industrial experience in metallurgy and quality and is a member of ASQC, ASM, ASEE and SWE.

PATRICIA J. OLESAK Assistant Professor of Mechanical Engineering Technology at Purdue University, where she has taught courses in quality and materials science. She received a B.S. in Metallurgical Engineering from Michigan Technological University and an M.S. in Material Science Engineering from Purdue University. She has twelve years of industrial experience in the metallurgical and quality areas. She is a CQE and belongs to ASQC, ASEE and TMS.