AC 2011-2449: DEVELOPMENT AND USE OF CONCEPT CONTEXT MAPS TO PROMOTE STUDENT

Jessica Triplett, Arizona State University
Jacquelyn E. Kelly, Arizona State University

Jacquelyn Kelly is doctoral student in Science Education at Arizona State University. Her Master's degree is in Materials Science and Engineering and her undergraduate degree is in Physics and Chemistry. Her principle research interests are situated in engineering education and include conceptual development, engineering academic language acquisition, and the role of motivation and emotion on these things. She is also invested and passionate about K-12 education as she teaches physics, chemistry, and science foundations at New School for the Arts and Academics, an alternative arts high school.

Stephen J Krause, Arizona State University

Stephen J. Krause is Professor in the School of Materials in the Fulton School of Engineering at Arizona State University. He teaches in the areas of bridging engineering and education, capstone design, and introductory materials engineering. His research interests are evaluating conceptual knowledge, misconceptions and their repair, and conceptual change. He has co-developed a Materials Concept Inventory for assessing conceptual knowledge of students in introductory materials engineering classes. He is currently conducting research with NSF sponsored projects in the areas of: Modules to Promote Conceptual Change in an Introductory Materials Course, Tracking Student Learning Trajectories of Atomic Structure and Macroscopic Property Relationships, and Assessing the Effect of Learning Modes on Conceptual Change.

Development and Use of Concept-in-Context Maps to Promote Student Conceptual Understanding in an Introductory Materials Course

Abstract

Concept-in-Context maps are instructional tools that can be used in and out of the classroom. They are multimodal visual outlines (created using Inspiration software) that show relationships between topics and include examples of real-world engineering components (such as a bicycle tire, frame and headlight lens) to contextualize conceptual topics covered on any given map. Traditional concept maps show a visual map of boxed concepts connected to one another by lines which incorporate verbs that are used to link the concepts. In the Concept-in-Context maps we are linking a wide array of different types of information that reflect the organization of content within a topical area in an introductory materials course. As such, topics can be characterized and articulated with multiple representations that can include equations, graphs, charts, macroscopic images, microscopic images, engineering components, and historical facts. Concept-in-Context maps (CCmaps) serve many different functions for students. They can be used as: a reading guide while a student reads a chapter in the textbook; as a resource to refer to during lecture; as a study guide before an exam; and, with selected words/phrases removed, as quizzes. An overarching goal of developing and implementing Concept-in-Context maps in classroom activities is to help students mentally organize new knowledge and discover how that information relates to what students already know. In effect, CCmaps help students begin to develop their own conceptual framework for a given topical area. The maps have also been used as learning tools by removing certain words or phrases from some of the boxes in the CCmap and then creating a word selection bank. Students may then select the appropriate words/phrases from the word bank and match it up with the appropriate CCmap box. After using the CCmaps for one semester, 78% of 38 students in an introductory materials class found that the maps either supported or strongly supported their learning. To this point, 15 CCmaps have been created for topics in the Materials course, as well as Concept-in-Context fill in the blank team activity maps. In the paper methods for creating and using CCmaps will be described along with an assessment on how students use them and their impact on student understanding.

Introduction

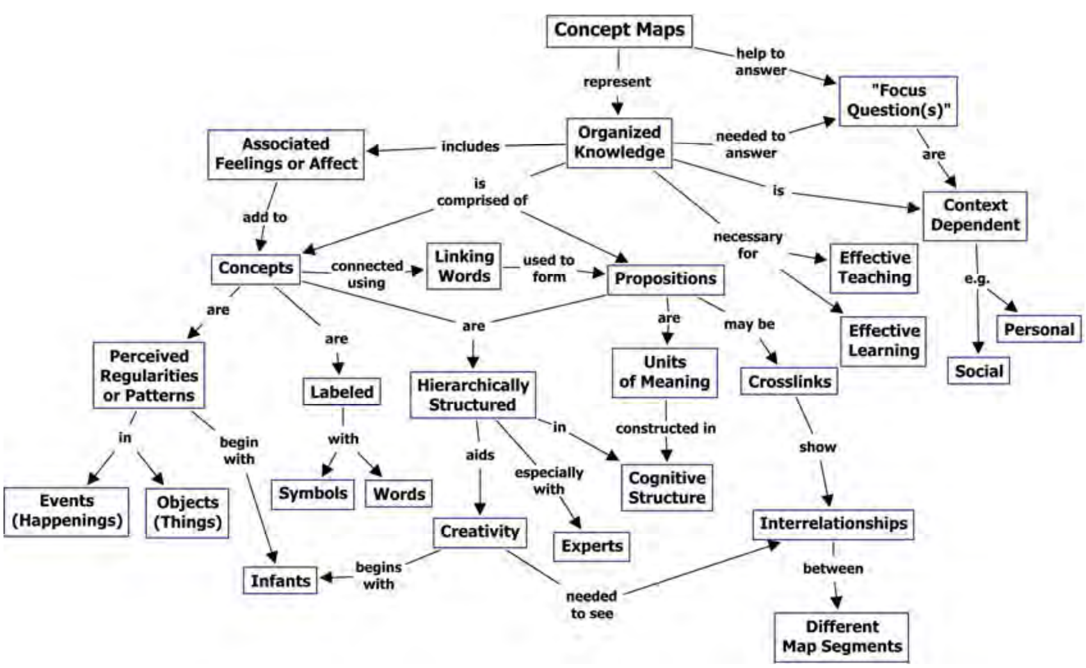
In engineering education, there is a need to better connect science concepts with engineering applications. Concept mapping is one tool by which this can be accomplished. However, concept maps have been used most extensively in science education to link hierarchical concepts. While the goal of science is to understand, explain, and predict phenomena in nature, the goal of engineering is to take the knowledge of science and math and apply it to society's needs through the creation of processes, products, and systems that benefit mankind. As such, we have developed an approach to modify traditional science-oriented concept maps and link them to application of science concepts in materials science and engineering along with their associated real world applications. We refer to these modified concept maps as *Concept-in-Context maps*. Their format utilizes some of the major principles used to construct traditional concept maps and mind maps, as well as hierarchical organization of ideas.

In this paper we first review from available literature the applications and effectiveness of traditional concept maps for a variety of uses. We will then discuss the Concept-in-Context maps (CCmaps) we have created to facilitate learning of the major topics covered in an introductory materials course. We have also collected preliminary data about the effectiveness of the usage of these CCmaps. In the conference session in which we are presenting our results, we will have disciplinary related activities that will demonstrate and facilitate the creation of both concept maps and also Concept-in-Context maps. One of the goals of this session is to demonstrate the relative ease of construction of these tools as well as their potential usefulness for a variety of applications across the breadth of engineering disciplines. Finally, we will discuss possible applications for CCmaps which include use as a teaching tool in the classroom, a learning tool for students, and an assessment tool for instructors.

Background

Concept maps demonstrate a way of organizing, classifying, and connecting information visually. Concept maps were developed in 1972 for a research program by Novak[1], and their initial purpose as a research tool was to better illustrate the cognitive framework of children's understanding of science (as compared to interview transcripts). The basic rules for the structure of concept maps are as follows: concepts or ideas appear in a bordered shape (ovals, rectangles, bubbles, etc…), and are connected by arrows to other concepts using linking words. In their paper, *The Theory Underlying Concept Maps and How to Construct and Use Them*[1], Novak and Cañas refer to a concept map on concept maps to illustrate their structure, which shown below in Figure 1.

Figure 1. Concept Map on Concept Maps

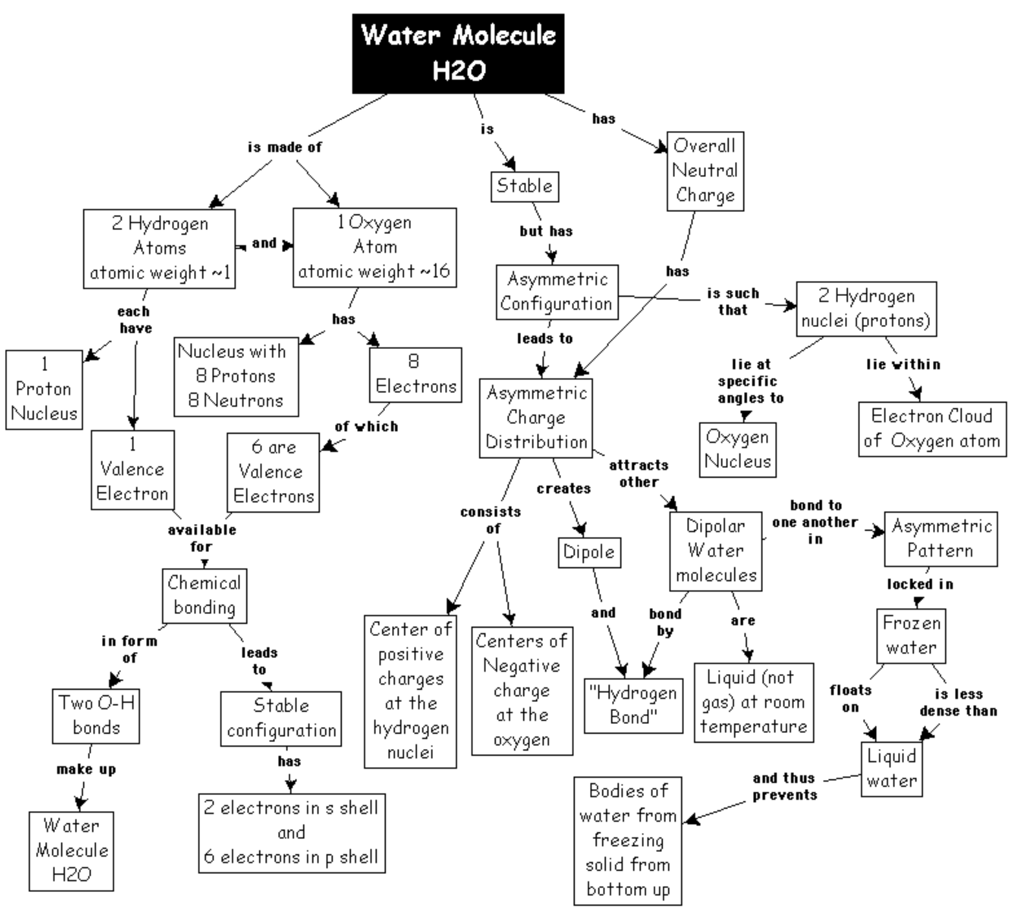


Since the development of concept maps, much research has carried out to determine their effectiveness as educational tools. A primary focus appears to be in using them as tools for student assessment. McClure, Sonak, and Suen[2] suggest that the production skills necessary to create concept maps are simple in comparison to that of traditional subjective assessment tasks, which could mean more accuracy in the assessment of student knowledge. However, Markow and Lonnig[3] compared the effectiveness of having students use concept mapping to demonstrate knowledge as opposed to writing essays. It was found that, before conducting an assessment, students must be taught how to construct concept maps in order to ensure a level of competence with the construction so that students can effectively use them to display their knowledge of a concept. Unfortunately, this process carries a time commitment some might consider prohibitive for using concept maps for assessment..

Hoz, Bowman, and Chacham[4] showed that by explicitly requiring students to make connections between concepts, concept maps could be used to evaluate learning outcomes in the classroom. Similarly, McClure, Sonak, and Suen[2] suggest that student-created concept maps may provide a means for instructors to identify student misconceptions, thereby helping instructors assess, and also tailor their teaching with those misconceptions in mind.

Concept maps can also be used as teaching tools that present natural science concepts. As an example, a concept map on the water molecule is shown in Figure 2. (http://www.coexploration.org/howsthewater/html/overviewwater.html)[5]

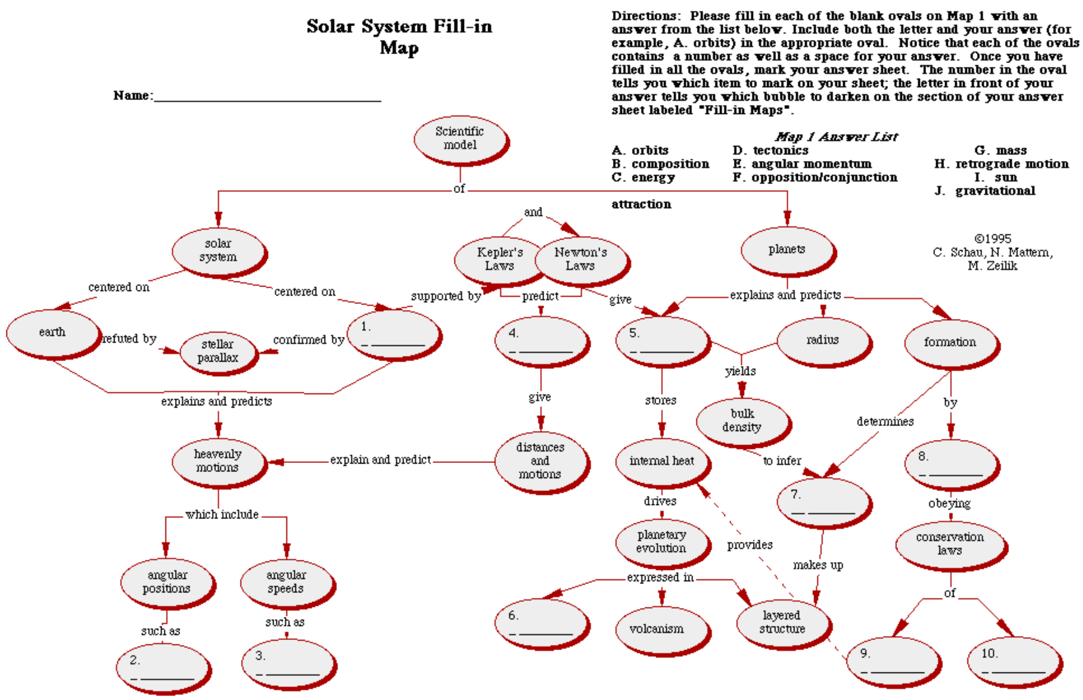
Figure 2. Concept Map on the Water Molecule.



The web-like structure of concept maps can be seen in this example, as linkages may span across the map to make all possible connections.

Concept maps may be used as fill-in-the-blank activities by removing certain concepts from the map boxes and placing them in an answer list, as shown in an example in Figure 3 below. A larger figure is also available in the appendix. (http://flag.wceruw.org/tools/conmap/solar.php)[6]

Figure 3. Concept Map quiz on the Solar System.



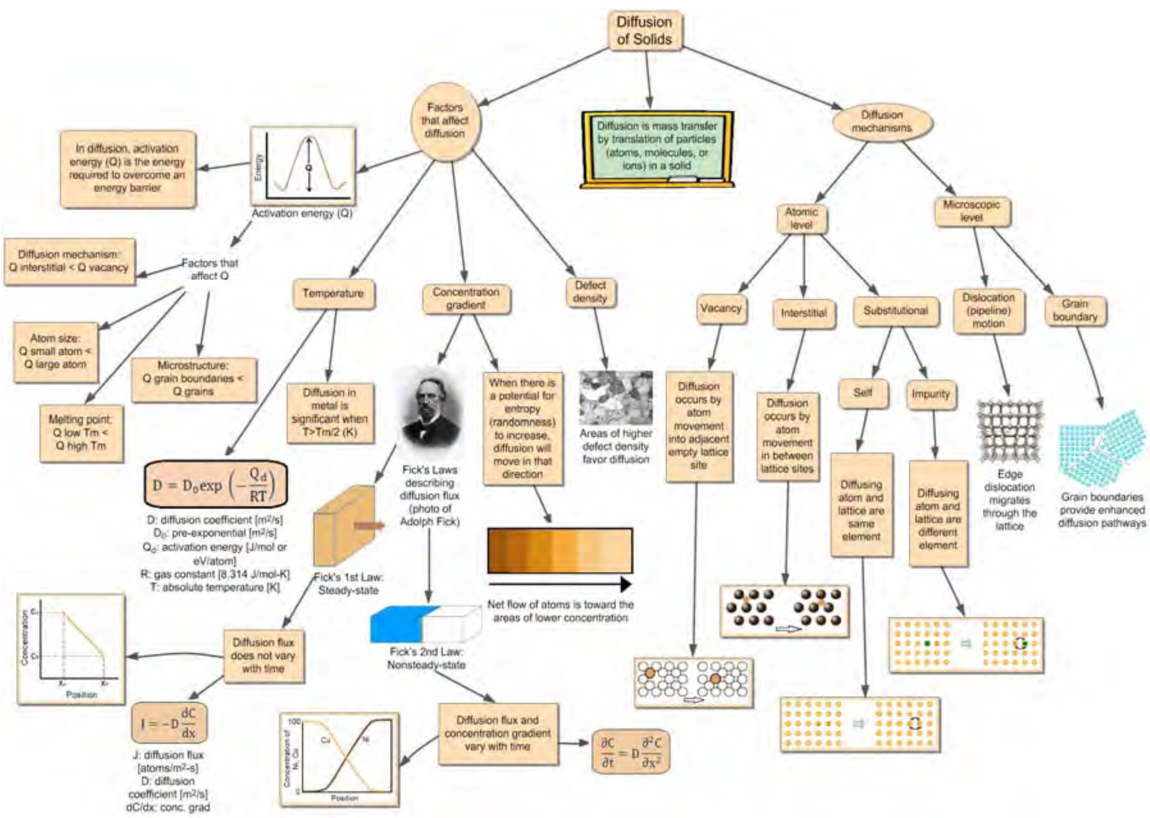
There have been more recent reports into the usage of traditional concept maps in engineering education. Borrego et. al. reported on using concept maps as interdisciplinary assessment tools, commenting on the value and ability of concept maps to link together concepts and the usefulness of using them to link interdisciplinary concepts[7].

Concept-in-Context Maps

Concept-in-Context maps (CCmaps) were developed to provide an educational tool for helping students build a conceptual framework for different topics studied in an introductory materials science. Another reason for developing CCmaps was to promote topical vocabulary skills since students encounter approximately 400 new words and terms throughout the semester. Finally, the ability of concept maps to show connections and relationships between ideas was appealing because one goal of the introductory materials course is help students connect new engineering course material to content from their natural science classes within their existing conceptual frameworks. However, certain modifications were necessary in order to tailor this new tool to the engineering classroom. Science classes teach students how to explain and predict phenomena of the natural world. Engineering classes aim to take the foundations of scientific knowledge and teach students how to apply that knowledge to engineering processes and applications to design, create, and innovate devices, systems, and products. With this goal in mind, we modified the traditional concept map to meet the needs of engineering classes by applying science concepts to a real world context.

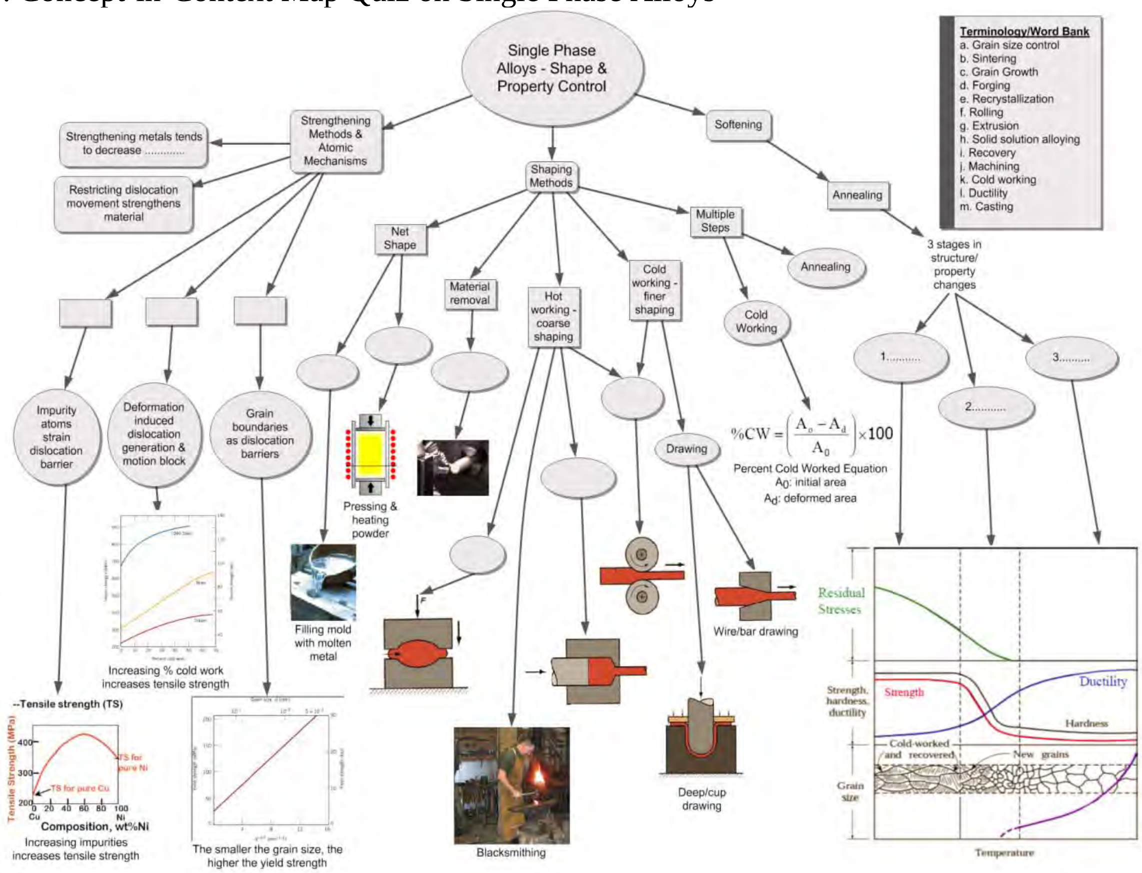
CCmaps can be described as multimodal visual outlines, class topic guides, and hierarchical subject maps. The structure of Concept-in-Context maps places less emphasis on including linking words on the lines between the boxed concepts which is the characteristic web structure of traditional concept maps. Instead, it places more emphasis on establishing the hierarchy and interrelatedness of the information on any given concept, then connecting relevant related details and visual representations for topics and sub-topics. CCmaps show linkages between abstract concepts and concrete real world manifestations (such as a bicycle tire, frame and headlight lens) of those concepts (such as atomic bonding types associated with polymers, metals, and ceramics). Any given concept on the map may be connected to related macroscopic and microscopic images, equations, graphs, charts, engineering items, and historical facts. This allows a student to see at a glance important connections displayed in a visual manner that aims to encourage understanding and retention of information while facilitating construction of a conceptual framework on a topic. A CCmap on the topic of diffusion is shown in Figure 4 below and is also available in a larger scale format in the appendix.

Figure 4. Concept-in-Context Map on Diffusion of Solids.



A completed CCmap can be used as a learning tool for students. A map for any given topic can be used as a lecture guide to help students with cognitive organization of information during a lecture and while note-taking, as a 'road map' to assist students while reading the textbook, and as a study guide for students preparing for an exam. Additionally, altering the amount of information conveyed in a CC map can turn it into a teaching tool for an activity or an assessment tool to evaluate student understanding. A quiz or classroom activity can be created by removing some of the concepts from their boxes on the map and placing those words in a word selection ban, in a similar manner as shown above in the concept map example in Figure 3. Students can be asked to use the words in the selection bank to fill in the appropriate blanks, thereby filling in and completing their own CCmap. An example of a CCmap quiz we have created is shown here in Figure 5 and is also available in the appendix in a larger scale format.

Figure 5. Concept-in-Context Map Quiz on Single Phase Alloys



This CCmap quiz has a terminology/word selection bank from which students can select terms for placement on the CCmap. Additional opportunities exist for other types of selection banks as well, such as selection banks for equations, graphs, objects, or microstructures. All of the related images on a particular CCmap may be placed into an image selection bank for students to identify and match up the correct image with the appropriate concept heading. For example, our CCmap about the Failure of Metals contains images of various microscopic fracture surfaces. Placing those images in a selection bank and asking students to match them up with their respective failure type provides for a class activity. And a more challenging quiz or activity can be created by removing concepts and having no selection bank, requiring students to fill in the concepts and details on their own by searching through class notes or the textbook, or by discussing possible selections with classmates.

Lastly, CCmaps may be used as an assessment tool by asking students to create their own map on a topic given the main concepts and respective contexts. In a similar manner as described above when using a selection bank to complete a quiz, multiple selection banks may be provided to students on a given topic, containing the graphical representations, verbal definitions, microscopic and macroscopic images, etc, providing all of the 'puzzle pieces' for students to use to assemble their own CCmaps. Instructors can then assess student knowledge and misconceptions by analyzing how students link together concepts and information.

Differences between novices and experts and the language they use in the world of science and engineering reveals their experience and expertise. Experts actually use and communicate concepts, ideas, plans and designs with multiple representations in a very visual/verbal language. They might think of atomic level representations of things in terminology which is visually symbolic, such as hard sphere models of atoms, and how they might be organized for example, to represent a crystal structure. CCmap structure, connections, and visual and written representations provide a communication tool that is consistent with expert discourse in exchanging concepts and ideas. It is a way that engineers communicate, especially in the world of design where you represent ideas and concepts with visual-schematic-parametric terminology characteristic of a discipline. Well designed CCmaps and associated activities have the potential to be a starting point in the facilitation of novice to expert development in a given topical area.

Methods

The CCmaps have been created with Inspiration which is a concept mapping software program. It has an interface is similar to a drawing or painting program, with a palettes of shapes symbols and icons which can be moved around the workspace and connected with lines that may also be used with linking verbs and phrases. The items can be dragged and dropped anywhere in the workspace. The method by which a Concept-in-Context map can be constructed is outlined below. By following these instructions, a new CCmap creator will learn about the different aspects that go into creating a CCmap. However, ease of creation as well as personalization and adaptation may arise from individual creators through experience.

<u>Concept-in-Context Map Construction Principles</u>

1. Read lecture notes, text book, etc…
2. Use an existing written outline or create an outline of the material
3. Identify the "Big Questions" for a topic
    a. What is it?
    b. What does it do (in an engineering sense)?
    c. Why should I learn about it?
    d. What are the important terms and nomenclature involved?
4. How is the topic material arranged/interconnected; what are the relationships?
5. Find expressed models of multiple representations for important ideas.
    a. Definitions

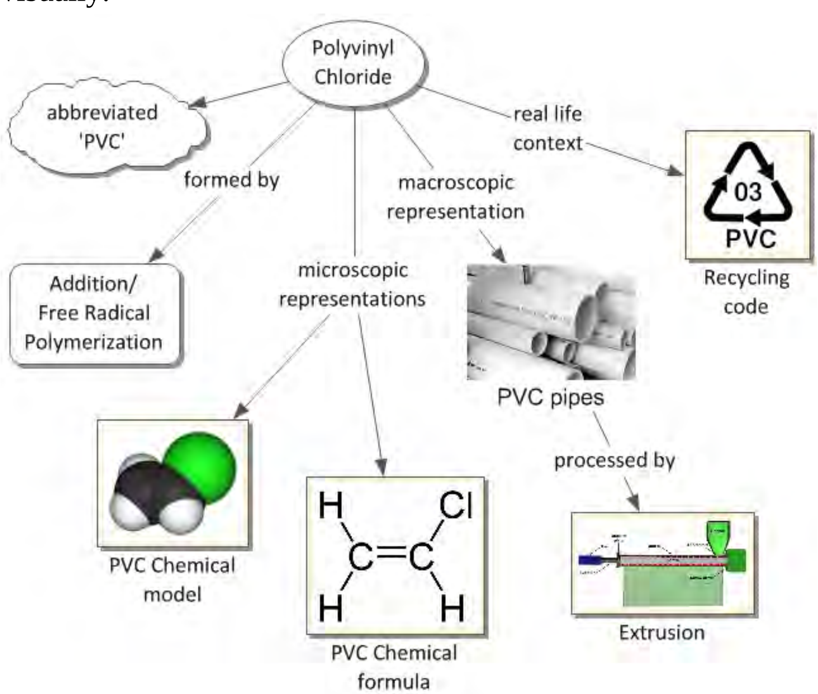
b. Charts, graphs
c. Macroscopic & microscopic images
d. Real life/everyday representations
e. Equations
f. Historical context

6. Enter the topic, sub-topics, and supporting details into concept mapping software such as Inspiration.

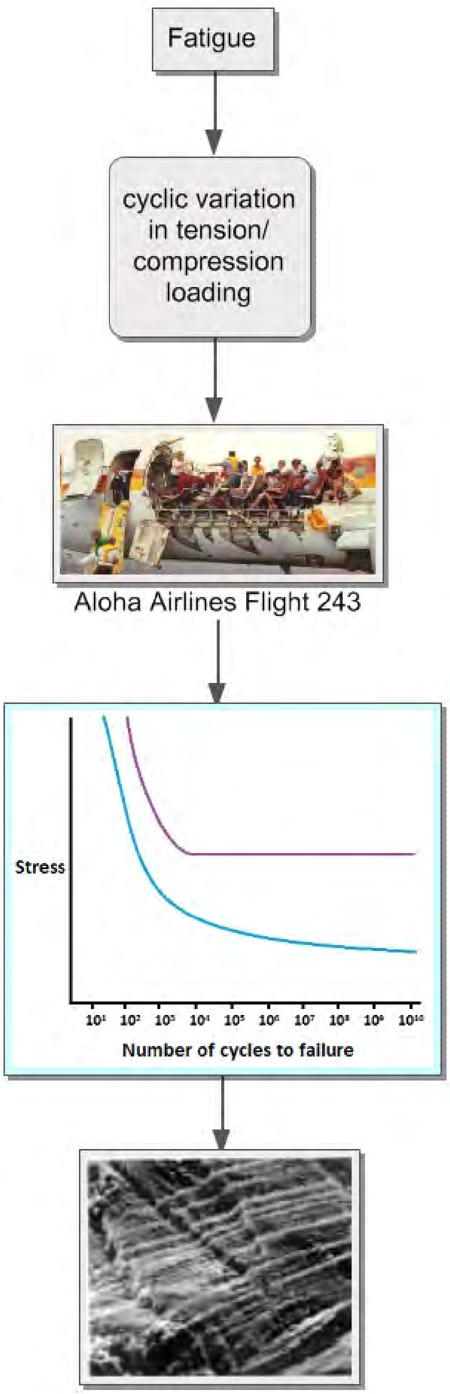
To illustrate taking an outline on an idea and transforming it into a visual framework, we will use the topic of Polyvinyl Chloride as an example.

I. Polyvinyl Choride
 A. Abbreviation
 B. Formation
 C. Microscopic representations
  1. Chemical formula
  2. Chemical model
 D. Macroscopic representation
  1. PVC pipes
   i. Processing method
 E. Real life context
  1. Recycling codes

Gather multiple visual representations of some of the outline ideas, and connect them to PVC visually.



As an additional example of how to construct a CCmap, we will examine a section of an existing CCmap that contains various expressed models of the fatigue mechanism of failure in metals.



A good starting point is to place the concept in a box or bubble.

Next, a brief definition may be included to describe the concept.

Here is a picture that illustrates the real world implications of fatigue failure. When learning about materials science and engineering, real world relevance helps students understand the purpose for learning topics.

Now we include a graph that shows the relationship between stress applied to a material and number of cycles to failure, or how many cycles (or time) before a material may experience fatigue failure.

And lastly, here is an image of how fatigue failure looks on the material fracture surface. The striations on this microscopic image of fatigue failure illustrates what the material looks like as a crack slowly propagates with each cycle as it is undergoing tension and compression cycles.

The complete Failure of Metals CCmap is in the appendix. Additionally, as a part of the workshop that will be conducted on CCmaps, there will be an audience participation activity on how to construct CCmaps.

Results and Discussion

We are reporting on preliminary data from the most recent and current semesters, including focus group discussions and student surveys. The analysis of all data will be presented during the conference.

Students of the Fall 2010 MSE 250 Introductory Materials class took a student evaluation at the end of the semester. When asked to rate the supportiveness of CCmaps to student learning on a scale of 1 to 5, 78% of students gave positive responses of 4 or 5 indicating that they found the CCmaps supportive or very supportive of their learning. Of the responses, 49% of students rated the CCmaps as 4, supportive, and 29% of students rated the maps as 5, very supportive.

CCmaps have only been fully implemented during the Fall 2010 – Spring 2011 academic year and were only briefly tested at the end of the previous academic year. One measure of the impact of the use of CCmaps on a daily basis in classes can be demonstrated from student hourly test scores. Data are presented for the first test, which included material on atomic bonding, crystal structures, and atomic bonding, for the 2009-2010 and 2010-2011 academic year (AY). For the 2009-2010 AY, the first test top-quartile, median, and bottom quartile scores for 81 students were 89, 79, and 71. For the 2010-2011 AY, test #1 top-quartile, median, and bottom quartile scores for 88 students were 92, 89, and 82. These preliminary results indicate second and third quartile students appear to benefit moderately with median and lower quartile scores that are about 10 points higher for classes where CCmaps are used. Additional data from Materials Concept Inventory scores for both academic years will be presented at the conference which will provide a valid and reliable set of results on the impact of CCmaps on change in conceptual understanding for full semester assessment.

A survey on CCmaps was also given to a focus group of 5 students. When asked to describe Concept-in-Context maps in their own words, students identified them as “a visual organization of concepts,” and said that they “show relationships and relevant images,” and “visual aids used to link different ideas and topics… and give a visual representation of these concepts/topics.” These quotes show how the CCmaps can serve as a learning tool. When asked how the students used the CCmaps, responses indicated a trend that that they had been useful as exam study guides. Students were then asked if they thought the CCmaps influenced their performance on exams, and they responded that they made it easier to obtain their desired grades.

When students were asked if the CCmaps influenced their understanding of course content, responses included “they clarified how the different ideas were related,” “they illustrate which concepts build upon each other, which helps me remember the concepts,” “helped to hold together and organize my thoughts and conceptual understanding,” and “the Concept-in-Context maps helped me to understand how the topics fit into my existing knowledge.” These quotes support the idea that CCmaps help students build conceptual frameworks for the material they are learning.

When asked to comment on the value of the CCmaps, students on average rated them a 4 out of 5 on a Likert scale ranging from 1, no value, to 5, high value. This is a reflection of student’s opinions of the value and usefulness of CCmaps for supporting their learning.

When asked “if [the CCmaps] weren’t available, would it make any difference to you?”, a trend in student responses indicated students would make their own version of CCmaps if they weren’t available through the class. This suggests that CCmaps may be constructed not only by instructors and subject matter experts, but students as well.

Positive responses were received from students when they were asked if they would find it helpful to see CCmaps used in other classes. The average response was 4.5, on a Likert scale ranging from 1, not helpful, to 5, very helpful. Students were also asked if they saw value in using visual representation to connect ideas like in CCmaps to help them learn. One student answered “Yes, because I am a visual learner, I would remember the picture to help connect the concepts.” Overall, the formative and summative qualitative and quantitative data appear show that CCmaps have had a positive impact on student learning. More extensive data and analysis will reveal if this suggestion is true or not and to what extent and will be presented at the conference.

Summary & Conclusions

Implications of this use of this tool from prior work in science and current work in engineering demonstrates excellent potential for facilitating more effective and more efficient student learning in terms of a variety of ways. It is suggested that broader usage for instructional teaching, learning, and assessment would enrich the student experience and promote more effective learning.

The multiple representations of concepts in the CCMaps reveal the ways in which various aspects of a concept can be related and connected. It was shown with the example of the concepts of materials failures and disasters, low temperature brittle failure of steels might be reflected in images of the Titanic, a microscopic fracture surface, and a graph which plots fracture toughness as a function of temperature. CCMaps can thus show the framework of related concepts in a subject area and use "expert-like" visual-verbal-graphical expressions to represent them in ways that experts might in their own visual and verbal communication. They are tools that have excellent potential for achieving more effective teaching and learning.

Acknowledgement

The authors acknowledge the support of this work from NSF IEECI Grant #0836041 and from NSF CCLI Grant #0737146.

References

1. Novak, J. D. & A. J. Cañas, The Theory Underlying Concept Maps and How to Construct Them, Technical Report IHMC CmapTools 2006-01 Rev 01-2008, Florida Institute for Human and Machine Cognition, 2008", available at: http://cmap.ihmc.us/Publications/ResearchPapers/TheoryUnderlyingConceptMaps.pdf

2. McClure, J.R., Sonak, B., & Suen, H.K. (1999). Concept map assessment of classroom learning: Reliability, validity, and logical practicality. Journal of Research in Science Teaching, 36, 475-492.

3. Markow, P.G. & Lonning, R.A. (1998). Usefulness of concept maps in college chemistry laboratories: Students' perceptions and effects on achievement. Journal of Research in Science Teaching, 35, 1015-1029.

4. Hoz, R., Bowman, D., & Chacham, T. (1997). Psychometric and edumentric validity of dimensions of geomorphological knowledge which are tapped by concept mapping. Journal of Research in Science Teaching, 34(9), 925-947.

5. Lowes, Leslie, & Nolan, Tom. Why Water? Retrieved on January 6, 2011 from http://www.coexploration.org/howsthewater/html/overviewwater.html

6. Zeilik, Michael. University of New Mexico Department of Physics & Astronomy, Institute for Astrophysics. Retrieved on January 6, 2011 from http://flag.wceruw.org/tools/conmap/solar.php

7. Borrego, M., Newswander, C. B., McNair, L.D., McGinnis, S., & Paretti, M.C. (year). Using Concept Maps to Assess Interdisciplinary Integration of Green Engineering Knowledge. Advances in Engineering Education, Winter 2009 Volume 1 Issue 3.

Appendix

Figure 3. Concept Map quiz on the Solar System

Figure 4. Concept-in-Context Map on Diffusion of Solids.

Figure 5. Concept-in-Context Map Quiz on Single Phase Alloys

Concept-in-Context Map on Material Failures

Figure 3. Concept Map Quiz on the Solar System

Solar System Fill-in Map

Name:_______________________________

Directions: Please fill in each of the blank ovals on Map 1 with an answer from the list below. Include both the letter and your answer (for example, A. orbits) in the appropriate oval. Notice that each of the ovals contains a number as well as a space for your answer. Once you have filled in all the ovals, mark your answer sheet. The number in the oval tells you which item to mark on your sheet; the letter in front of your answer tells you which bubble to darken on the section of your answer sheet labeled "Fill-in Maps".

Map 1 Answer List

A. orbits
B. composition
C. energy
D. tectonics
E. angular momentum
F. opposition/conjunction
G. mass
H. retrograde motion
I. sun
J. gravitational attraction

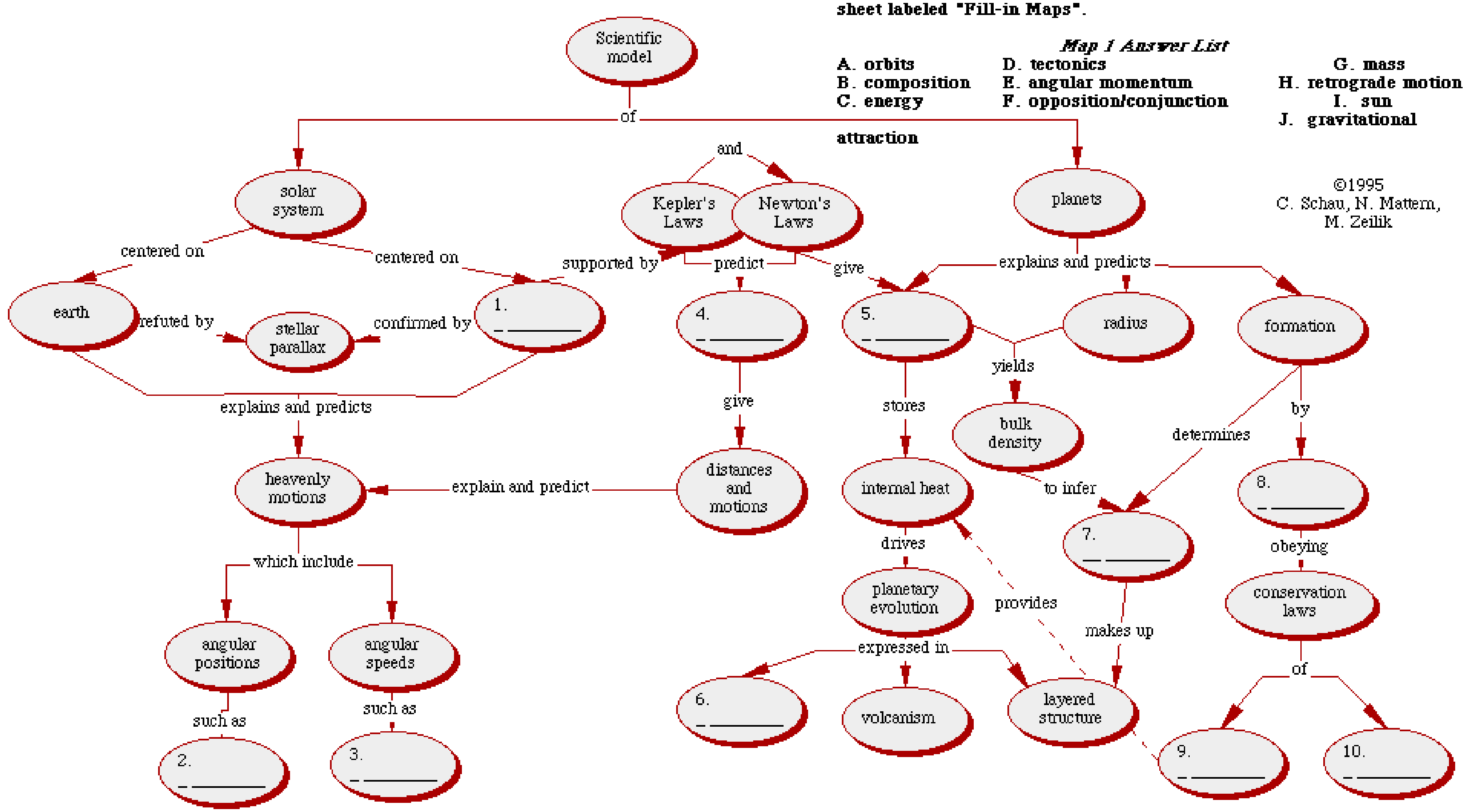


Figure 4. Concept-in-Context Map on Diffusion of Solids.

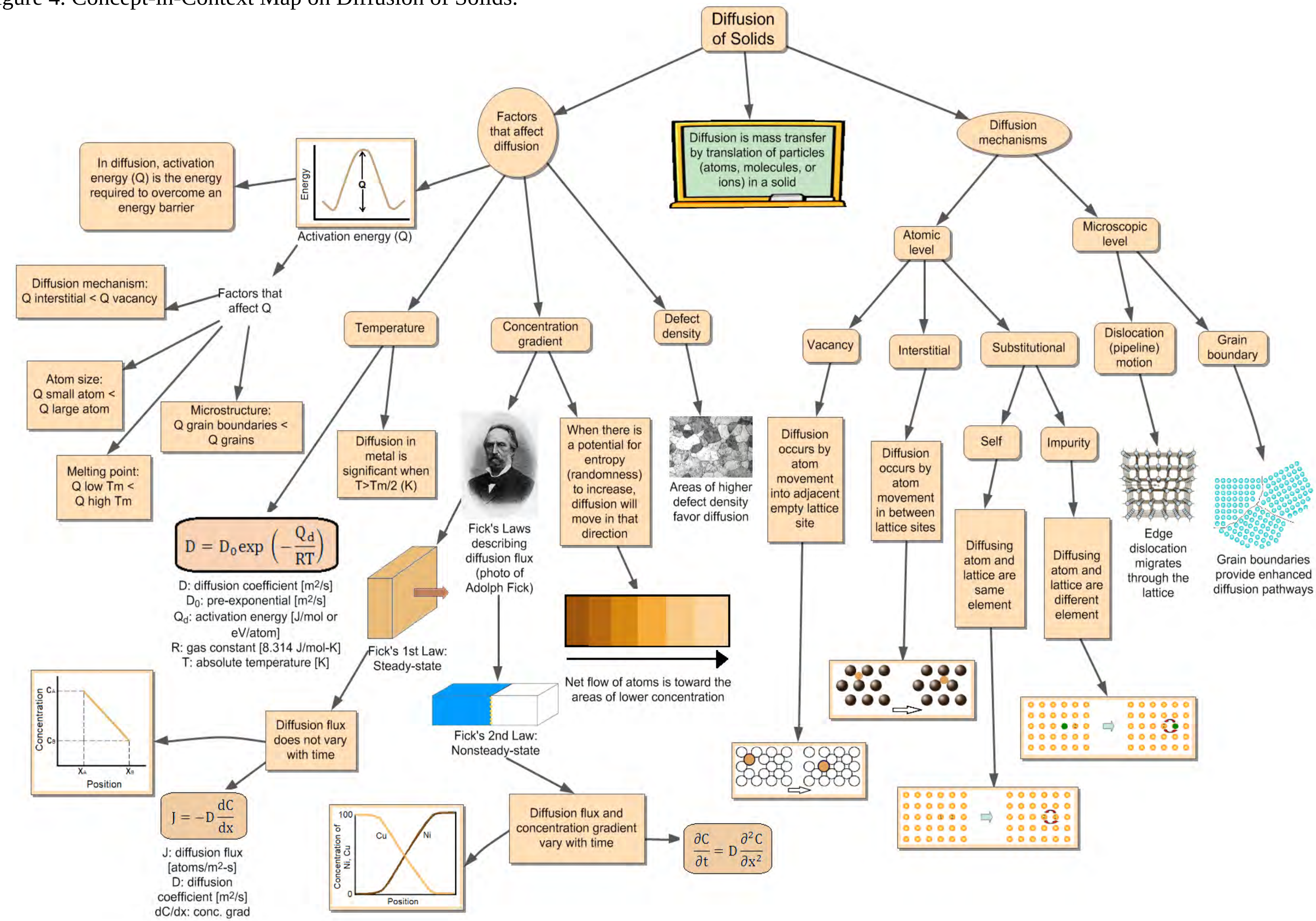
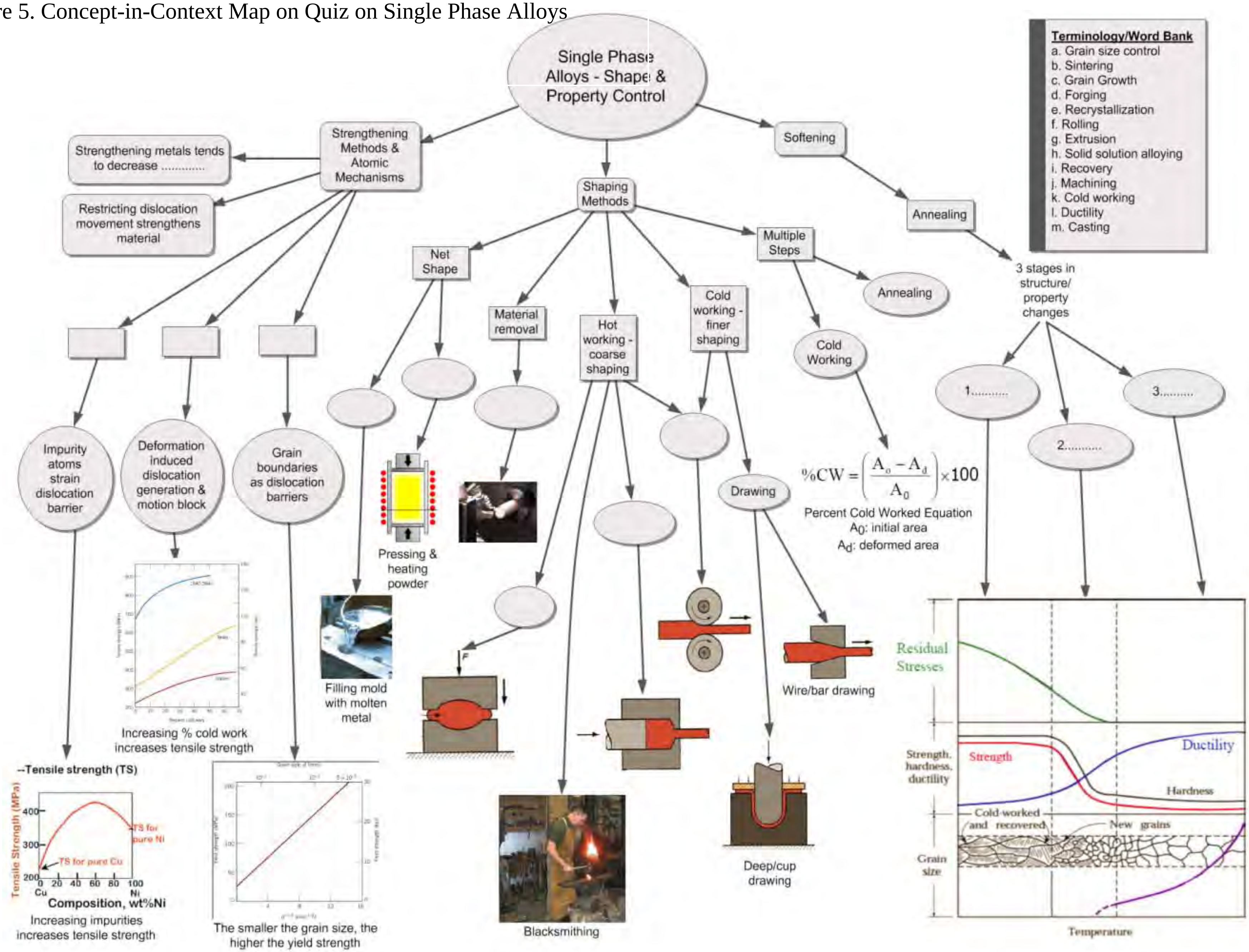


Figure 5. Concept-in-Context Map on Quiz on Single Phase Alloys



Concept-in-Context Map on Material Failures