AC 2010-956: "IT'S SO EASY A CAVEMAN CAN DO IT:" TEACHING INTRODUCTORY MATERIAL SCIENCE FOR INCREASED STUDENT ENGAGEMENT.

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"It's so Easy a Caveman Can Do It:" Teaching Introductory Material Science for Increased Student Engagement.

Education advocates and experts have a plethora of experiences and evidentiary research verifying the importance of student engagement in the education process. The millennial student is an expert at finding new tools and media resources to enhance their lives as they search for relevance in the activities they choose and the classes that they take. A challenge to educators is to increase the relevance of engineering core courses without spending an enormous amount of time planning changes to enhance student engagement. As educators, we are aware of topics in the core courses that are difficult for our students to learn, yet necessary for their development as engineers. Teaching styles that work with millennial students involve an instructor acting as facilitator of learning. Providing directed active engagement within the educational environment from the start of their experience will greatly assist the learning process of these students.

The modules described in this paper were created to enhance development of students' mental models and are exciting advances for those teaching in this area because of ease of implementation and adaptation for different student populations. Implementation of these activities has the potential to lower the barrier to faculty participation in active learning. The media slogan "It's so easy, a caveperson can do it" is the guiding principle behind the development of these activities. This paper will also present reflections of a diverse cross-section of teaching faculty and students for these classroom methods to highlight how these pedagogical efforts may increase student self-efficacy for their technical learning. The research question for this work is; "To what extent do student engagement activities, such as concept-context worksheets, process oriented guided inquiry learning worksheets and student test design, support student learning in an Introduction to Material Science course?" In this paper we are reporting on the implementation of teaching and learning modules for such a course. The results were overwhelmingly positive when the students were asked to rate the effect of the classroom activities on their support of student learning.

Introduction

Cognitive psychology discusses, Constructivism, a theory of cognition and learning stating that conceptual change is most likely to occur when learners are able to construct their own knowledge.[1,2] *How People Learn* identifies the cognitive processes necessary in achieving conceptual change, which occurs through modification of a student's conceptual framework. Thinking of pieces of knowledge, or concepts, we can then picture the conceptual framework that links the framework together. To explain and predict systems or phenomena, mental models, (simplified and personalized conceptual interpretations, or models, in the mind) are constructed and students decide whether specific conclusions do or do not fit these models. [3] Useful mental models allow students to understand, explain, and predict behavior of systems and phenomena, whereas defective mental models, which lead to misconceptions, do not.

Mental models can, and often do, undergo change as new stimuli are introduced. The Constructivist Model of Learning states that learning is not the transfer of material from the head of the teacher to the head of the learner in one whole piece. Instead, it is the construction of knowledge in the mind of the learner.[4] This constructed knowledge may or may not be consistent with the knowledge from the teacher, as it is dependent also on students' prior knowledge and experience.. For us faculty this means that, what we think we are teaching is not necessarily the knowledge that is being constructed by the student. Research has shown that many pedagogical strategies can enhance the effectiveness of this knowledge construction. Active learning is one such strategy that can be incorporated into curriculum. At this point in the discussion, many mainstream faculty metaphorically throw their hands up and say, "I do not have the time to change everything, including all of my teaching and testing methods." We claim that each professor does not have to re-invent the wheel. In fact, by a limited literature search many topics now have active learning templates that are easy to follow and integrate.

Two diverse student populations from two geographically distant campuses were surveyed. Faculty from two different universities, a mid-size HBCU population, University A and a large state school, University B, implemented the following three easy-to-employ active learning techniques: 1) Process Oriented class worksheets, 2) Concept-in-Context worksheets and 3) Test engagement. Each university incorporated a selection of the mentioned techniques into a specific materials science course. The University "A" faculty chose to utilize process oriented class worksheets, concept-in-context worksheets, and test engagement. These materials were used in MEEN 360, a required undergraduate course of 35 students emphasizing the fundamentals of materials science. The University "B" faculty chose to utilize concept-in-context worksheets in MSE 250, an introductory materials science and engineering course of 38 mostly chemical, mechanical, and materials engineering students. Student opinions of the support of these activities for their learning were monitored using daily reflections, periodic Blackboard surveys with essays, Likert type questions, and end-of-class reflections.

Module Usage

Type 1. Process Oriented Guided Inquiry Learning (POGIL) Modules

The POGIL method tries to engage students in the learning process by having them build conceptual understanding of a topic rather than memorizing facts or applying algorithms. According to their website, this method uses guided inquiry – a version of the Socratic method in which students use carefully designed materials that guide them to construct new learning.[5] When one goes to the POGIL website (http://www.pogil.org/) project materials are available commercially for guided inquiry classes in General Chemistry, Organic Chemistry, and Physical Chemistry.[5] The "Instructor's Guide to Process-Oriented Guided-Inquiry Learning" can be downloaded from the POGIL website.[6] In this document it is stated that:

> "Learning environments can be competitive, individualized, or cooperative. In cooperative learning, individuals, working together, construct shared understandings and knowledge. Because the ratio of students to faculty is generally large, it seems clear that the effectiveness of a university can be enhanced if it becomes a community of learners with students collaborating and learning from each other, and in fact, the literature is replete with research on different learning environments, and the benefits of students working together have been well documented. We now know that students teaching students results in effective learning and that a cooperative environment is more effective than a competitive environment. In addition, involvement in the classroom and student-student and student-instructor interactions have been identified as having the largest positive effect of numerous environmental factors on the academic achievement, personal development, and satisfaction of college students."[6]

At University "A" faculty chose to utilize both POGIL worksheets and the Concept-in-Context worksheets for the MEEN 360 course. The POGIL materials science worksheets are being developed by Dr. Elliot Douglas at the University of Florida. His materials are based upon a pedagogical approach developed for chemistry under an NSF CCLI National Dissemination grant (DUE-0231120). The currently developed worksheets cover the majority of a traditional material science course and Dr. Douglas and a team is working on a grant to develop more modules and refine and further assess the POGIL Material Science effectiveness. An example of a worksheet is shown in Figure 1. The University "A" instructor was quite satisfied with the ease of adaptation of the worksheets to the MEEN 360 course and results from student surveys shown in Tables 1 and 2 show a perceived learning increase by the students. Their open-ended responses also anecdotally verify their self- efficacy. This information suggests that students feel that POGIL worksheets support their learning. The success of these worksheets lies in the group work, but the instructor is crucial, as the students are working with the instructor and TAs are roaming the room helping and facilitating group discussion and clearing up misconceptions.

Figure 1. A portion of a POGIL Material Science worksheet created by Dr. Elliot Douglas and adapted by the University A faculty.

<u>Concepts</u>

The primary concept addressed is the idea of a guided inquiry classroom and why we do it. In order to motivate this understanding, first is a section on electronegativity. This serves both to review the material, and to allow the students to contrast the guided inquiry approach with a traditional lecture.

<u>Objectives</u>

1. Define electronegativity.
2. Predict the distribution of electrons in a bond.
3. Describe the procedures of a guided inquiry class.
4. Compare the advantages and disadvantages of a traditional lecture class and a guided inquiry class.

<u>Reading</u>

Callister 3rd Edition, Chapter 2, p. 24-33, Sections 2.5-2.8

<u>Information</u>

Electronegativity is an atomic property that describes how tightly an atom holds on to its electrons. Atoms with high electronegativity have a greater tendency to attract electrons than atoms with lower electronegativity. Figure 2.7 on page 24 of your text provides a periodic table showing the electronegativities of the elements.

<u>Group Work:</u>

1. What is the electronegativity of carbon?
2. What is the electronegativity of sodium?
3. What element has the highest electronegativity?

Table 1. University A. Survey answer results from a Blackboard anonymous survey (n=17). This exercise dealt with familiar objects (nuclear plant, blue diamond, sailboat fitting, Cu bowl) materials defects and effect on macro properties

For the Concepts in context exercise used as a classroom strategy please rate it based on how well it supports your learning. 1 means not supportive and 5 indicates very supportive.	
Answers	**Percent Answered**
Not at all Supportive	0%
Slightly Supportive	7.692%
Neutral	10.769%
Supportive	53.077%
Very supportive	38.462%
Not Applicable	0%
Unanswered	0%

Table 2. University A. survey selected answer results from a Blackboard anonymous survey (n=17).

Please give you reflections on the class to date.
1.I like that we have in class work and not just a long one hour lecture.
2.The group work. It makes you practice by solving problems in class, and then compare results with your class mates.
3.I like the worksheets. I like having more opportunity in class to ask questions and make sure that we understand the concepts. I also like the projects in the beginning, where some of the students had to give a presentation of the sections of the chapters that they were assigned.
4.The new learning method, half teaching then half group work. It truly help me learn better.
5.I like the fact that we work with others and are very interactive...but allot of the time the worksheets don't ever get finished and it sometimes seems as if we're wasting time. Id really rather my teacher teach me the material so that I know my answers from the worksheets are correct.
6.I like the interactive learning that we do.
7.I like how the class is being more interactive in the learning process and communicate with each other on the material.
8.The things I like about class is working with our partners... I like how the learning styles is more interactive, more so of just listening to professor lecture the whole time. I also like the visuals that are provided... very helpful

Type 2. Concept-in-Context Modules

The field of materials science and engineering (MSE) strives, as a major goal of the discipline, for fulfilling the responsibility of effectively teaching learners from other disciplines about how to engineer a material's desired macroscale properties based on a knowledge and understanding of its nanoscale structure. But, achieving this goal is a significant intellectual challenge that confronts learners, specifically in developing a useful conceptual framework for effectively using MSE course knowledge in their own discipline. That is so because, in materials science, learners have difficulty constructing a useful conceptual framework which effectively links the concrete "macroworld" of everyday objects and phenomena to the abstract "nanoworld" of atoms, molecules and microstructure which actually controls a material's properties.

Students often express appreciation when topical abstract principles and content are given concrete form and substance with contextualized examples. This helps link the activities and items of their everyday lives to decontextualized academic content in their engineering classes. These linkages may also promote a better understanding of the value of the content to their future courses, graduate school, or career jobs. Concept-in-context worksheets apply the principle of contextualizing concepts into team-based activities by prompting students to pick a correct response from a selection of contextualized choices of a particular example or phenomenon. For example, four different items may have four different possibilities for: 1)most important property, 2) type of atomic bonding; 3) processing and fabrication method; and 4) lifetime failure mechanism. Students work in teams to reason through the selection process. This allows for them to activate, discuss, and construct pieces of their prior knowledge to form a complete and accurate representation of that example or phenomenon from the choices provided. In doing so, students are able to correctly categorize these pieces to construct a conception, contextualize ideas to understand applicability of concepts, and make connections between properties, processing, and structure of various materials. As students engage in this interactive process, their thinking and ideas are made apparent. Their reasoning can be mapped as they choose, revise, and settle on their choices to each question. For example, on the Concept Building Context Worksheet in Appendix 1, the student had originally chosen that a metal trash can have covalent and van der Walls forces as the core of its atomic structure. Here, it is clear that the student did not previously draw a connection between material and type of bonding. As shown, the student’s mind was changed as a result of group work. Afterwards, correctly choosing metallic bonding as the structure responsible for the metal trash can. This reorganization was apparent throughout the remainder of the worksheet as well and clearly reflects the change from the initial disconnects between the macroscopic and the atomic level to the beginning of establishing consistent model.

For students and their teams to activate prior knowledge, repair misconceptions, and construct new knowledge during the class, the organization of content and activities must be coordinated. Thus, class structure involved short mini-lectures followed by individual concept exploration, group work, and team presentation to class. Students responded positively to group work as they appeared more engaged, academically driven, and inquisitive. By working in small groups, students were forced to negotiate ideas. This allowed for students to discuss and debate their ideas and come to a group consensus. This articulation of thoughts kept students active and aided in conceptual understanding and awareness. As students feel the need to defend their choices to peers, they are required to explain ideas completely. In doing so, any logical inconsistency in conceptual frameworks and mental models are revealed. Because the group is working together to come up with a reasonable model, when a faulty model is presented, an alternative one is often suggested immediately by other group members. This process of cognitive dissonance and alternative conceptions hinted at student conceptual change during completion of the activity. Since students actively constructed their knowledge it is more likely that it will be retained and available for new situations or more advance work in the future. Student assessment from University A. and their Blackboard surveys reflects their recognition of learning self efficacy. Their open ended essay responses, Table 2, also show the improved engagement of the classroom method.

Student Evaluation of Instructional Strategies for University B from Spring 2009 are displayed in Tables 3 -5. For each strategy, the students were asked to assign a rating based on the level each activity supported their learning. A score of 1 indicates a strategy felt not to be supportive of learning. A score of 5 indicates a strategy felt to be very supportive of learning. For Table 3 the overall course at University B was surveyed. The final right-hand column is a combination of the two "supportive" columns. Notice where the team work satisfaction falls (the first two rows) as compared to lectures and traditional homework and tests, both team based items are 20-30 points higher on the scale. Table 4 displays the student support ratings on each individual and available concept-in-context worksheet activity from University B. These ratings suggest that students feel that concept-in-context worksheets are supportive to their learning.

Table 3. Instructional Strategies

Instructional Strategies	**Not at All Supportive**	**Not Supportive**	**Neutral**	**Supportive**	**Very Supportive**	**Supportive + Very Supportive**
Team based problem solving	-	3%	7%	40%	50%	90%
Team based discussions	-	3%	13%	27%	57%	84%
Team presentations of problem solutions	-	13%	27%	20%	40%	60%
Lectures	-	10%	23%	33%	33%	66%
Homework	-	13%	23%	37%	27%	64%
Tests	-	13%	23%	40%	23%	63%

Table 4. Various Concepts-in-Context Worksheet satisfaction student survey results .

	Not at All Supportive	Not Supportive	Neutral	Supportive	Very Supportive	Supportive + Very Supportive
Everyday items (window, wire, plumbing, bag, trash can, sharpen stone) Bonding type, material property & processing	-	3%	0%	43%	53%	96%
Integrated Circuit Parts (chip, adhesive, solder, lead wire, package) Atomic bonding & macro properties (Tm, E, alpha, elec. & th. cond.)	-	13%	13%	33%	40%	73%
Airplane parts (wing, arm rest, tire, window, turbine blade coating) Bonding type, material property & processing	-	3%	17%	30%	50%	80%
Material Disasters (Titanic, World Trade Center, Napoleon buttons) Unit cells crystallographic structures	-	3%	0%	23%	73%	96%
Everyday mtls. (PE chain fold planes, steel phase transf, rolled brass) Indexing crystallographic planes in unit cells	-	10%	10%	37%	43%	80%
Familiar objects (nuclear plant, blue diamond, sailboat fitting, Cu bowl) Materials defects and effect on macro properties	-	7%	27%	27%	40%	67%
Everyday objects (saxophone, Si IC chip, ski pole, file box, Ferrari gears) Unit conversions (wt% > at%, at% > atoms/cm3)	-	7%	27%	23%	43%	66%
Everyday items (window, wire, plumbing, bag, trash can, sharpen stone) Stress Strain Curves characteristic shape & properties (E, YS, TS % el)	-	3%	17%	24%	55%	79%
Disaster(Titanic, DC10 crash, chem. plant blast, Hawaii jet skin, World TC) Material failure mechanisms (creep, fatigue, nil ductility, stress corrosion)	-	3%	3%	33%	60%	93%
Everyday objects (Cu wire, saxophone, turbine blades) Single phase strengthening (alloy, grain size, cold work, anneal)	-	3%	13%	33%	50%	83%
Sweetening Coffee Phase Diagram Concepts (solubility limit, saturation, chem. comp ph frac.)	-	7%	20%	27%	47%	74%
Bicycle Parts (fender, axle, chain, gear teeth)- Fe-Fe3C diagram, effect of steel microstructure on mechanical properties	-	10%	10%	43%	37%	80%

Testing Variance and Engagement

A humorous quote has been found that conveys the problem with educational assessments:
"You can't fatten a hog by weighing it."--Anonymous Midwestern Farmer

On first read we may all agree but, does not the act of weighing a hog allow the farmer to detect when there are problems with the fattening process. Likewise student assessment can be a diagnostic tool to ensure students are progressing adequately towards achieving the desired learning goals. All too often assessment becomes solely a grade-assignment or ranking tool. And all too often the learning process deteriorates for students into striving to do well on the tests (assessments) so they will have a good grade, rather than focusing on the learning goals of the course.[7] In many cases preparation for the test determines the span of their learning. Ultimately to improve student performance we must recognize that essential intellectual abilities are falling through the cracks of conventional testing. The burden is on the instructor to make the tests sufficiently comprehensive and challenging to push each student to learn to the greatest extent of which he or she is capable. This step is often understated and trivialized. But just as tests can motivate students to learn at a deep level, they can also lead to student demoralization and hostility (both of which correlate with poor performance) if they are perceived by the students as being unfair.[8] Widely recognized throughout Psychology is the understanding of different type learners. Some students—sensing learners on the Myers-Briggs Type Indicator and the Felder-Silverman Learning Styles Model, work systematically and slowly, they read and reread problem statements, and often take a relatively long time to formulate their problem-solving strategies, and check their calculations. These are all good characteristics for becoming a successful engineers or experimental scientists but will frequently lead to their running out of time on long tests. On the flip side are the intuitive learners, they may answer faster and by luck achieve a better grade but if the "sensing" students had been given adequate time their tests would have demonstrated their superior mastery of the subject. How many times have your students argued they needed more time?! They may have studied hard and been well prepared for the test and then gotten a low grade because they lacked sufficient time to demonstrate their understanding. Any student who fails a one-hour test that she could have succeeded on if two hours had been allowed, deserves the higher grade. Remember that if a group of students is given adequate time those who deserve the grade will achieve the grade and those who are underprepared will never be able to guess their way to success.

How many of us have tried to "challenge the students" on their in class tests, they call them surprises. Is a one hour test the best time to throw a curve at the students and expect their best? Do engineers in the field have split-second surprises pitched to them and on their own without any resources except their own knowledge in their head to answer them? These authors argue not! Why do we insist on doing this in their course assessments, what is our goal? Remember one of the objectives of tests is to motivate and help students learn what the instructor wants them to learn and to enable the instructor to assess the extent to which they have succeeded in doing so. Felder states that "There is neither empirical evidence nor logic to support the argument that long and tricky tests assess students' potential to be successful engineers or help students become better problem solvers." "This does not mean that we should construct easy tests, which do not motivate students to learn at a deep level. It is rather to set the bar high but to teach in a manner such that all students who have the ability to meet the challenge can do so." [9,10]

At University A, in a testing study, 3 distinct types of tests were administered. First, a traditional in-class one hour exam was given. There were mixed type questions of varying levels as described in the Webb's Depth of Knowledge (DOK) chart, Figure 1, which is a simplified form of the Bloom's taxonomy.[11] The average over two semesters for a similar test was a score of 69 out of 100, with a near normal distribution. The instructor hoped that this low average would motivate the students to work harder. But the opposite occurred and student reflections showed that student self confidence was damaged and morale sank.

Is this what was intended? Based on discussion in a prior faculty engineering education workshop, a different test method was tried. The next test was a completely open-ended assessment. A detailed chapter title was given with a blank page for each student to share their knowledge from the chapter. A rubric was created and used to grade their mastery of the concepts. This better suited some students but others needed the structure of formal test questions and problems. Student reflection was not positive and the instructor deemed a re-test was needed. The retest occurred just before a school break. The instructor gave students the opportunity for extended test engagement by asking students to complete a take-home test to add to their grade. The take home was designed such that it could not lower their score, just improve the score. The reasoning behind this was two-fold. One, it helped the students grades. And, secondly, it caused the students to bring home their books and invest more time (extended engagement) into topics they had already studied but now in an open-book format.

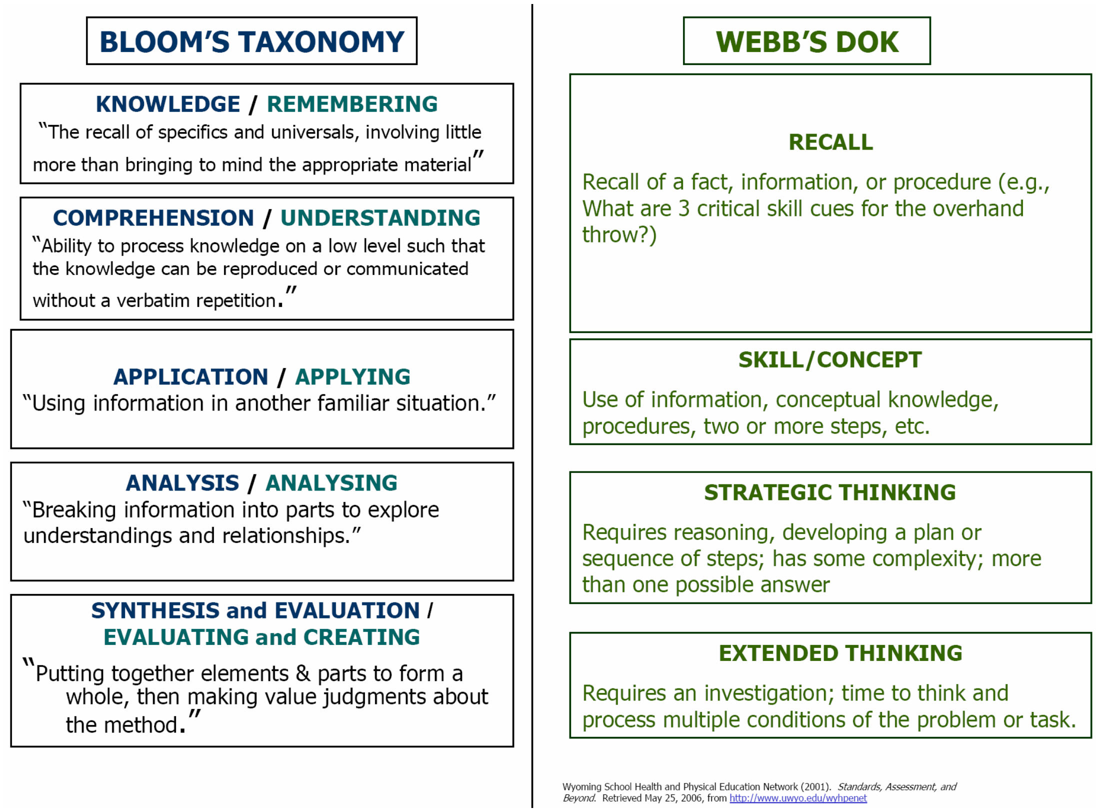
Continuous improvement occurred and the search for the perfect test continued. The third test was a combination of the first two. Students were given the chance to free respond their chapter knowledge and there were structured problems. A late semester student survey question asked:

"I would prefer tests with…"

all multiple choice answers with no partial credit	7.143%
all multiple choice answers with partial credit	21.429%
all free response questions	28.571%
a combination of question types	42.857%

These results show that most of the students appreciate a varied test format. In addition, anecdotal student comments verified their preference for a varied format, although there was not a significant difference in test averages which were within 3 points out of 100. We must remember however the scores do not tell the whole story and if the students feel they are a larger part of their own learning process their overall self-efficacy will improve.

Figure 2. Webb's Depth of Knowledge comparison with Bloom's Taxonomy.



Summary

To what extent do student engagement activities such as concept-context worksheets, process oriented guided inquiry learning worksheets and student test design support student learning in an Introduction to Material Science course? The research question for this work was to discover the extent that student engagement activities such as concept-context worksheets, process oriented guided inquiry learning worksheets and test variance support student learning in an Introduction to Material Science course. These techniques worked well for both the smaller HBCU population, University A and the large state school, University B. Student opinions were monitored using daily reflections, periodic Blackboard surveys with essays, Likert type questions and end-of-class reflections. Student evaluations and surveys showed that student perceived learning was increased by the techniques. Students also felt that they were a greater part of the process, not just passive observers. The results were overwhelmingly positive when the students were asked to rate the effect of the classroom activities on their support of student learning. More importantly the techniques were found to be quite easy to adapt and required minimal preparation before teaching, in fact the day-to-day teaching was fun! Gone were the days of putting one self to sleep at the board and on top of all of this, they were so easy a "caveperson" could do it!

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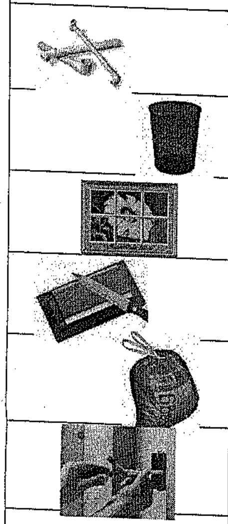
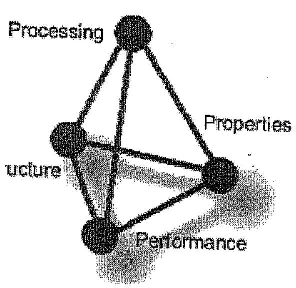
Appendix 1 – Concept Building Context Worksheet and Homework

Materials Science of Household Components

GROUPWORK



	Object	Important Properties	Material	(Structure) Atomic Bonding	Processing Method
	PLUMBING PIPE	II	2.	~~A.~~ (E)	b.
	TRASH CAN	VI.	5.	~~C~~ (C)	~~X~~ (d)
	WINDOW PANE	I.	6.	~~B~~ (A)	~~X~~ (F)
	KNIFE SHARPENER	IV.	4.	B kinda (A)	e.
	GARBAGE BAG	III.	3.	~~D~~ (E)	~~X.~~ (a)
	ELECTRICAL WIRING	V.	1.	C.	~~b.~~ (c)
SS sink	YOUR OWN HOUSEHOLD ITEM	II	5.	C.	d.



PROPERTIES	MATERIAL	BONDING	PROCESSING
I. transparent ✓	1. copper - Cu ✓	A. covalent ✓	a. film blowing
II. water resistant & tough ✓	2. polyvinylchloride (PVC) ✓	B. ionic	b. extrusion squeeze like toothpaste
III. very flexible ✓	3. polyethylene (PE) ✓	C. metallic ✓	c. drawing goes through to make smaller
IV very hard ✓	4. silicon carbide – SiC ✓	D. van der Waals	d. sheet forming
V. good electrical conductor ✓	5. steel – Fe + .2%C ✓	E. covalent & van der Waals	e. sintering pressure and heat diffusion
VI. stiff & impact resistant ✓	6. SiO2 – silicon dioxide ✓		f. float on molten tin

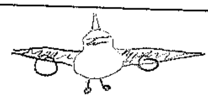
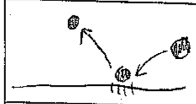
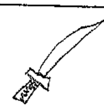
MSE 250 Homework #1

1. For an area of interest in your own discipline (write it down) suggest a futuristic device (2020 – 2030) that depends on advances in materials science or technology or processing (e.g. manipulating atoms or depositing 1 nm thick lines, flexible LED T-shirt, etc.).

2. Draw a simple sketch of the important features in the atomic bonding of a metal (Cu), a ceramic (NaCl) and a polymer (polyehtylene).

3a. Fill in the table shown below, first for the 3 given components and then you choose your own for the last 3.
3b. For each of the 6 components, write a sentence or two about your reasoning of the relationships between a component's important properties, material selected, and its relation to the properties, processing, atomic bonding and recyclability.

Materials Science of Everyday Things

Sketch Component	Object	Important Properties	Material	(Structure) Atomic Bonding	Processing Method	Recyclability 1(bad) – 5(good)
	1. AIRPLANE WING	Stiff and impact resistant	Steel (Aluminum)	mostly metallic	Sheet Forming	2.
	2. AUTO TIRE	impact resistant, durable,	Natural rubber or (polymer)	covalent and van der waals	Sheet forming or sintering	4. (Shredded for roads)
compact disc 	3. RECORDING MEDIA	Stiff yet somewhat flexible	polycarbonate plastic	covalent and van der waals	injection molding	2 or 5 (CDRW)
	Bouncy Ball 4. Polymer Object	resilliant and flexible	type of rubber	covalent and van der waals	injection molding	2.
	Knife 5. Metal Object	Sharp, super strong	steel	metallic	sintering to harden	2.
	pottery 6. Ceramic Object	water resistant, stiff	porcelain	covalent	float on molten tin	1.