Course Syllabus

Jump to Today Edit

> # ALL THAT GLITTERS: INVESTIGATING THE EXPRESSIVENESS OF MATERIALS
>
> *Physical information pervades the world and it is through its continuous production that matter may be said to express itself.*

Description

Materials are as varied as water, gold and whiskers. We understand their qualities without measurement or thinking. Materials are simple, ineffable facts. They are the nouns of our world. How can we talk about the differences between materials? One way is to measure and weigh them. This is the *quantitative* approach, and it has been very successful in our conquest of the world. What if you wished to describe materials without resorting to rules and balances? Could we understand materials by describing their characteristics? What will we learn by appreciating the expressive qualities of materials? Could we understand materials using the same measures we use to evaluate living things?

We will study ceramics, metals, minerals, wood, textiles, bone and plastics. We will advance by using the tools at hand. Use your eyes and ears, your fingers and smart-phones to evaluate materials. We do not wish to anthropomorphize materials: we want them to stand on their own without reference to others.

What makes materials expressive? How do materials behave differently from one another? How might we talk about the character of materials? Let's assume that materials are mass assemblies of tiny parts. The parts are so tiny that they exist in a world beyond our ability to observe. We appreciate them as the aggregated forms we know as materials. These parts have relationships with one another. Together the microscopic interactions grant character to a material. The aggregated parts and interactions describe the *expressiveness* of these materials.

We will measure and record the structural, spectral and acoustic characteristics of materials. We will describe light absorption, acoustic resonance, thermal and electrical conductivity, elasticity and hardness of each materials. We will imagine the microstructures We will make tools to refine our senses.

Requirements

You are expected to **come to class** and to participate in discussions, debates and labs.

Readings will be assigned each week and a quiz will be available on each reading.

Quizzes are optional; doing them will boost your grade and make you eligible for a high pass.

I will ask to see your sketches/descriptions. Please **buy a notebook** to keep these sketches, descriptions, debate and lab notes.

Some weeks you will bring in an example of something that goes with the week's theme. Let's call this an ***investigation***. We will begin by describing its qualities, sketching how it looks on a microscopic scale, and trying inquiries to identify the source of the quality. Three of you will present your findings each week. The three presenters will be scheduled in the third week.

Assignments Summary:

Date	Details

Date	Details	
Wed Sep 14, 2016	INTRODUCTION: Scale, the Expressiveness of Materials (https://canvas.instructure.com/calendar?event_id=1180352&include_contexts=course_1073662)	12am
	SLIDE SHOW: the scale of materials (https://canvas.instructure.com/calendar?event_id=1180353&include_contexts=course_1073662)	12am
	READ: ch1 The New Science of Strong Materials: THE QUESTIONS (https://canvas.instructure.com/courses/1073662/assignments/5274357)	due by 11:59pm
Wed Sep 21, 2016	LECTURE: AGGREGATES (https://canvas.instructure.com/calendar?event_id=1180354&include_contexts=course_1073662)	12am
	READ: Manuel Delanda (https://canvas.instructure.com/calendar?event_id=1180355&include_contexts=course_1073662)	12am
	CLASS EXERCISE: Draw/Describe the interior of a bag of Chex Mix (https://canvas.instructure.com/courses/1073662/assignments/5351225)	due by 11:59pm
Wed Sep 28, 2016	ACTIVITY: Draw the interaction between graphite and paper (https://canvas.instructure.com/calendar?event_id=1180357&include_contexts=course_1073662)	12am
	LECTURE: Hard and Soft (https://canvas.instructure.com/calendar?event_id=1180356&include_contexts=course_1073662)	12am
	CLASS EXERCISE: Draw the inside of a package of malted milk balls. (https://canvas.instructure.com/courses/1073662/assignments/5356870)	due by 11:59pm
	READ CH8 Stuff Matters: GRAPHITE (https://canvas.instructure.com/courses/1073662/assignments/5276778)	due by 11:59pm
	READ: Materials a VSI, "Soft" (https://canvas.instructure.com/courses/1073662/assignments/5321536)	due by 11:59pm
Wed Oct 5, 2016	LECTURE: Cool and Warm (https://canvas.instructure.com/calendar?event_id=1180359&include_contexts=course_1073662)	12am
	LAB: Melting ice (https://canvas.instructure.com/courses/1073662/assignments/5366921)	due by 7pm
	READ CH5 Stuff Matters: FOAM (https://canvas.instructure.com/courses/1073662/assignments/5276775)	due by 11:59pm
	READ: Materials_VSI, "Hot and Cold" (https://canvas.instructure.com/courses/1073662/assignments/5321550)	due by 11:59pm
Wed Oct 12, 2016	LAB: The Gecko's Foot (https://canvas.instructure.com/calendar?event_id=1180362&include_contexts=course_1073662)	12am
	LECTURE: Sticky, Greasy, Dry, Powdery (https://canvas.instructure.com/calendar?event_id=1180361&include_contexts=course_1073662)	12am
	READ: Human climbing with efficiently scaled gecko-inspired dry adhesives (https://canvas.instructure.com/courses/1073662/assignments/5321541)	due by 11:59pm
	LAB: What would paper look like to a flea? (https://canvas.instructure.com/courses/1073662/assignments/5274353)	due by 11:59pm

Date	Details	
	READ: ch6 Stuff Matters: PLASTIC (https://canvas.instructure.com/courses/1073662/assignments/5274361)	due by 11:59pm
Wed Oct 19, 2016	LECTURE: Resonance (https://canvas.instructure.com/calendar?event_id=1180363&include_contexts=course_1073662)	12am
	WATCH: The Tacoma Narrows Bridge (https://canvas.instructure.com/calendar?event_id=1180364&include_contexts=course_1073662)	12am
	QUIZ: Plastics (https://canvas.instructure.com/courses/1073662/assignments/5274344)	due by 4:59pm
	QUIZ: Waves (https://canvas.instructure.com/courses/1073662/assignments/5274345)	due by 7:59pm
	LAB: Find the resonant frequency of materials (https://canvas.instructure.com/courses/1073662/assignments/5321544)	due by 11:59pm
Wed Oct 26, 2016	LECTURE: Strong (https://canvas.instructure.com/calendar?event_id=1180365&include_contexts=course_1073662)	12am
	READ: CH1 Stuff Matters: STEEL (https://canvas.instructure.com/courses/1073662/assignments/5276770)	due by 11:59pm
	READ: The New Science of Strong Materials, "Stiff and Strong" (https://canvas.instructure.com/courses/1073662/assignments/5322449)	due by 11:59pm
Wed Nov 2, 2016	LECTURE: Fluid (https://canvas.instructure.com/calendar?event_id=1180366&include_contexts=course_1073662)	12am
	LAB: Buoyancy (https://canvas.instructure.com/courses/1073662/assignments/5321553)	due by 11:59pm
Wed Nov 9, 2016	LECTURE: Elastic (https://canvas.instructure.com/calendar?event_id=1180367&include_contexts=course_1073662)	12am
	IN CLASS EXERCISE: code your plastic (https://canvas.instructure.com/courses/1073662/assignments/5274351)	due by 6pm
	READ: The New Science of Strong Materials, "Elasticity and the Theory of Strength" (https://canvas.instructure.com/courses/1073662/assignments/5322468)	due by 11:59pm
Wed Nov 16, 2016	LECTURE: Metallics (https://canvas.instructure.com/calendar?event_id=1180368&include_contexts=course_1073662)	12am
	READ: The New Science of Strong Materials, "Metallics" (https://canvas.instructure.com/courses/1073662/assignments/5321554)	due by 11:59pm
Wed Nov 23, 2016	THXGVNG (https://canvas.instructure.com/calendar?event_id=1180369&include_contexts=course_1073662)	12am
	QUIZ: The invention of color (https://canvas.instructure.com/courses/1073662/assignments/5274348)	due by 4:59pm
	WATCH: Philip Ball on the history of pigments: COLOR (https://canvas.instructure.com/courses/1073662/assignments/5274366)	due by 11:59pm

Date	Details	
Wed Nov 30, 2016	LECTURE: Heavy (https://canvas.instructure.com/calendar?event_id=1180370&include_contexts=course_1073662)	12am
	READ CH3 Stuff Matters: CONCRETE (https://canvas.instructure.com/courses/1073662/assignments/5276772)	due by 11:59pm
	READ: ch2, Concrete and Culture: NATURAL OR UNNATURAL? (https://canvas.instructure.com/courses/1073662/assignments/5274358)	due by 11:59pm
	READ: Chapter 2, Sand: The Never-Ending Story: TRIBES (https://canvas.instructure.com/courses/1073662/assignments/5274365)	due by 11:59pm
Wed Dec 7, 2016	LECTURE: Brittle (https://canvas.instructure.com/calendar?event_id=1180371&include_contexts=course_1073662)	12am
	[OPTIONAL ASSIGNMENT] Identify three artworks that followed discoveries in materials science (https://canvas.instructure.com/courses/1073662/assignments/5274355)	due by 4pm
	QUIZ: Sand: Individuals (https://canvas.instructure.com/courses/1073662/assignments/5274349)	due by 4:59pm
	READ: CH7 Stuff Matters: GLASS (https://canvas.instructure.com/courses/1073662/assignments/5276776)	due by 11:59pm
	READ: ch9 Stuff Matters: PORCELAIN (https://canvas.instructure.com/courses/1073662/assignments/5274363)	due by 11:59pm
	READ: Materials_VSI, "Ceramic" (https://canvas.instructure.com/courses/1073662/assignments/5321555)	due by 11:59pm
Wed Dec 14, 2016	LECTURE: Wooden / Fibrous (https://canvas.instructure.com/calendar?event_id=1180372&include_contexts=course_1073662)	12am
	QUIZ: Paper (https://canvas.instructure.com/courses/1073662/assignments/5274347)	due by 4pm
	ACTIVITY: code the Chocolate (https://canvas.instructure.com/courses/1073662/assignments/5274350)	due by 7:59pm
	READ ch2 Stuff Matters: PAPER (https://canvas.instructure.com/courses/1073662/assignments/5274359)	due by 11:59pm
	READ: ch6 The New Science of Strong Materials: TIMBER AND CELLULOSE (https://canvas.instructure.com/courses/1073662/assignments/5274362)	due by 11:59pm
	READ: ch11 Stuff Matters: SYNTHESIS (https://canvas.instructure.com/courses/1073662/assignments/5274356)	
	READ: ch4 Stuff Matters: CHOCOLATE (https://canvas.instructure.com/courses/1073662/assignments/5274360)	
	READ: Chapter 1 Sand: The Never-Ending Story: INDIVIDUALS (https://canvas.instructure.com/courses/1073662/assignments/5274364)	
	Roll Call Attendance (https://canvas.instructure.com/courses/1073662/assignments/5351221)	

Learning Goals, Anticipated Outcomes

Many classes on Materials start by introducing microstructures that cannot be seen by the unaided eye. In fact these images can't be seen at all: they are produced by bouncing electrons off surfaces. Example:

> introduction to Materials Science
> The student will gain a basic knowledge of metals, polymers, and ceramics along with some aspects of nanomaterials. We will cover the fundamental properties of materials along with the fundamental aspects of phase diagrams and concepts of degradation and failure.

We start with the axiom that the nature of most materials exists beyond our ability to see. Rather than map unobservable qualities into a visual medium (as is often done with electron microscopy) we will investigate observable properties including mutability, resonance/deflection, consistency, hardness, spectral emissions, absorption and fluorescence.

I have gathered 100 questions that you should be able to answer on the last day in a normal introduction to Materials Science. For the first three meetings we go over these questions and we don't try to answer them. We may discuss strategies for answering the questions and offer things to try that would narrow the possible answers. We refuse to answer them out of respect. There is no need to rush an answer, and it's certainly more fun to entertain a full range of answers.

Students usually get attached to some of the questions. The first assignment is to adopt one of the questions. The adopted question becomes the center of inquiry.

Example. Let's say that you become interested in why (most) metals feel cold to the touch. You have your experience, a few ideas, an explanation from your parents, perhaps even a chapter from your AP Chemistry textbook. We will ask you to put away the explanations and prove it to yourself using your eyes, ears, fingers, and the tools you have in your pocket to make a personal conclusion. You also have help from your colleagues and the scientific method.

You will formulate *falsifiable statements* to help design experiments. *Falsifiable statements* are lovingly explained in Karl Popper's book *The Logic of Scientific Discovery.* It's a process:

1. start with an idea about something
2. try to prove your idea wrong by describing it with falsifiable statements
3. design experiments to prove the falsifiable statements correct, disproving your theory
4. iterate until every angle has been tried
5. if the idea holds up then publish the experimental results

Back to our question: *why do most metals feel cold to the touch?* Let's say that you want to narrow your ideas before offering an theory. Here are a few falsifiable statements to help you get focused:

1. Metals are colder than other materials (measure their temperature)
2. metals conduct heat better than other materials (measure their heat conductivity)
3. metals pull the heat out of materials that are less conductive (test heat transfer between metals and skin and other materials)
4. Metals will not feel cold after they reach body temperature.
5. Other materials in contact with the body resist heat transfer.

Anyone who does these experiments will be in a good position to advance a hypothesis about why metals usually feel cool to the touch. Even more important, the student went through a process of hypothesis. experimentation, synthesis and discovery before accepting an answer.

Methods: How it works

This is an experiment in pedagogy. I don't know if it will work. We start with the ends: make a list of 100 questions that students should be able to answer after taking an introductory class in materials science. Discard the lessons that explain the qualities of materials without some form of interaction. Encourage the students to make their own investigations and draw their own conclusions.

Questions are categorized into things that are well known (and can be presented), properties that may be calculated, and speculations.

The goal is to make the class self-generating: illustrations provide the foundation for speculation, calculators provide the tools, and speculation provides hypothesis that may be tested by experiment.

What do we gain by this process?

1. The students become engaged when they are answering their own questions
2. by designing their own experiments the students capture some of the excitement of learning somethign for the first time (rather than doing a tired, well-worn experiment)
3. They actually have the chance to discover something new
4. they learn how to formulate and conduct experiments
5. we use what we have--the resources are modest (call this *For a Poor Science*)
6. using language to reveal big ideas (rather than reducing the ideas themselves)

The questions range from *Why is the sky blue?* to *What makes glass brittle?* Ask a group of 25-30 students to select five questions from the 100 and/or write their own questions about common materials (glass, metal, wood, bone, etc.) This first assignment gives the students some skin in the game as they will be investigating materials that interest them and/or materials that are relevant to their metier.

Whenever possible we avoid textbooks and learn directly from the materials. We seek to learn from craftspeople who have spent a lifetime working with materials; from industrial processes to transform materials. These

The questions are refined and qualified by type: *illustration*, *calculation* and*speculation*. These definitions define specific tasks that will help explain what Each student will be responsible for answering these questions.

An *illustration* is a 5-10 minute presentation showing a material, a process or idea. Generally this is a short film or other presentation showing interaction with a material. Example: for the section on metals the student might bring in a video showing a blacksmith forging horseshoes.
A *calculation* is a resource that we will use to explore a material, process and/or idea. Specifically I would like you to make a reactive web page that calculates for you. *Speculation* is a hypothesis, an idea or position about a material that may be rendered into a*falsifiable statement.* The student's speculations will be the basis of the experiments that we conduct in class.

Now we put the questions on the calendar. I used **Kanban boards** **(https://en.wikipedia.org/wiki/Kanban_board)** to organize the questions under materials and then to schedule them.

The questions overlap in ways that suggest collaborations. Their work produces an understanding of materials from interaction with materials. They depend on one another's work to advance their own understanding. This raises the stakes for everyone in the class. The design of the course promotes engagement and collaboration.

We also recreate relevant debates in the sciences including *Aristotle vs. Democritus on the number of elements* and *light is a wave vs. light is a particle* . These debates help the students to imagine a time before our understanding about materials was fully codified.

Policies

Absences

As soon as the add/drop period has concluded you are allowed up to 3 absences in this class. Any more than that will earn you a grade of Incomplete (I) or No Credit (NC) depending on the whim of the instructor. This is not recommended.

Grading Policy

CalArts does not grade on the A-F scale. Rather:

CalArts grade	external GPA	description
High Pass (HP)	4	Passing with Excellence
Pass (P)	3	Passing with Quality
Low Pass (LP)	2	Passing
Incomplete (I)	--	Temporary evaluation
No Credit (NC)	0	No Credit

A grade of Incomplete (I) is a temporary evaluation. Through agreement between student and instructor, Incompletes must be made up during the following semester. Incomplete evaluations not made up within the specified period of time will convert to NC.

The No Credit (NC) grade indicates that the student's work did not meet the criteria for credit. NC evaluations may not be converted to credit bearing grades except by petition to the deans council initiated by the instructor of the class or, in the instructor's absence, the dean of the school offering the course.

The following changes to the grading policy went into effect for all students beginning Fall 2013:

- NC (no credit) grades will appear on a student's permanent academic record
- NX (insufficient attendance) grades will no longer be used
- Withdrawal Period will be extended until the 10th week of the semester

NC grades must appear on external records to ensure accurate reporting to peer institutions and for financial aid reporting. While CalArts does not use a Grade Point Average (GPA) as part of its marking system, the following formula will be used for external purposes: HP =4.00, P=3.00, LP=2.00, NC=0.00.

Students will no longer receive NX grades, but the longer withdrawal period (through the 10th week of the semester) will provide an option for students to exit a course without receiving a failing grade. To drop a course during the extended withdrawal period, a student will obtain the Course Withdrawal form from the Registrar's Office, consult with his or her mentor, obtain the course instructor's signature verifying the last date of attendance, and return the form to the Registrar's Office. The course will remain on the student's record with a "W" grade, but the grade of "W" will have no effect on the grade point average.

If a student misses more than 3 sessions of class and does not pursue the withdrawal option, a NC will be given and will appear on external records.

To read the revised Grading Policy in its entirety as well as frequently asked questions, click on the link below:

CalArts grading policy **(https://my.calarts.edu/policy/3-1-8-1-grading-policy-beginning-fall-2013)**

Change of Grade

In the interests of operating an equitable grading system, Critical Studies stringently enforces CalArts' change of grade policy. Students have one semester upon receiving an "Incomplete" grade to make up any missing coursework and/or projects. If this work has not been completed by the end of the semester, the Incomplete converts automatically to a "No Credit". After that time, changes require the approval of Deans Council. Deans Council will approve such grade changes only in the case of extreme, extenuating circumstances or in cases of administrative/faculty error.

Services for Students With Disabilities

CalArts will provide reasonable accommodations to students with disabilities who have registered with the Student Affairs office. Registration with the Office of Student Affairs is on a voluntary, self-identifying basis. Services are available only after a student has presented certified, current documentation of the disability from an appropriate medical or educational specialist, and this documentation has been reviewed and accepted as complete. Please navigate to the **Disabilities page** (http://calarts.edu/student-services/disabilities) for extensive information on services for students with disabilities.

Plagiarism

Critical Studies endeavors to teach students the essential skills and basic ethics involved in any academic enquiry. To this end, we are committed to observing the policy on plagiarism set out in the CalArts Course Catalog. This stipulates that plagiarism is the use of ideas and/or quotations (from the internet, books, films, television, newspapers, articles, the work of other students, works of art, media, etc.) without proper credit to the author/artist. Critical Studies holds to the view that plagiarism constitutes intellectual theft and is a serious breach of acceptable conduct. It is also the policy of CalArts that students who misrepresent source material as their own original work and fail to credit it have committed plagiarism and are subject to disciplinary action. In the case of Critical Studies, any student caught plagiarizing will immediately be given a no credit grade for that class. The student will not be allowed to re-write the paper, and if there is further evidence of plagiarism, Critical Studies will recommend more severe disciplinary action, including suspension or dismissal.

If you have any questions regarding plagiarism or want direction on how to credit source material, ask the member of faculty and refer to reference guides on permanent reserve in the CalArts library. The CalArts reference librarians may be able to offer additional information as well.

View Progress

+ Module

0. scale

READ: ch1 The New Science of Strong Materials: THE QUESTIONS
Sep 14

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1. aggregates

CLASS EXERCISE: Draw/Describe the interior of a bag of Chex Mix
Sep 21 | 5 pts

CLASS EXERCISE: Draw the inside of a package of malted milk balls.
Sep 28 | 5 pts

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2. hard and soft

READ CH8 Stuff Matters: GRAPHITE
Sep 28

READ: Materials a VSI, "Soft"
Sep 28

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3. cool and warm

READ CH5 Stuff Matters: FOAM
Oct 5

READ: Materials VSI, "Hot and Cold"
Oct 5

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4. sticky / greasy / dry / powdery

LAB: What would paper look like to a flea?
Oct 12 | 10 pts

READ: Human climbing with efficiently scaled gecko-inspired dry adhesives
Oct 12

5. resonant

LAB: Find the resonant frequency of materials
Oct 19

6. strong

READ: The New Science of Strong Materials, "Stiff and Strong"
Oct 26 | 0 pts

READ: CH1 Stuff Matters: STEEL
Oct 26

7. fluid

LAB: Buoyancy
Nov 2

8. elastic

READ: The New Science of Strong Materials, "Elasticity and the Theory of Strength"
Nov 9 | 0 pts

9. metallic

READ: The New Science of Strong Materials, "Metallics"
Nov 16

10. colorful

WATCH: Philip Ball on the history of pigments: COLOR
Nov 23

11. shiny

READ: CH7 Stuff Matters: GLASS
Dec 7

12. heavy

READ CH3 Stuff Matters: CONCRETE
Nov 30 | 0 pts

13. brittle

READ: ch9 Stuff Matters: PORCELAIN
Dec 7

READ: Materials_VSI, "Ceramic"
Dec 7

14. wooden / fibrous

READ: ch6 The New Science of Strong Materials: TIMBER AND CELLULOSE
Dec 14

READ ch2 Stuff Matters: PAPER

Dec 14

15. sharp / smooth

100 Questions

100 Questions

You will choose one of these questions (or a variation on one) to be the center of your inquiry. You will not be encouraged to answer this question! Instead please come up with good questions to ask and start thinking about the inquiry you would make to demonstrate the hypothese that emerge after considering the question and making some initial inquiry.

id.	category	question
1.	structure	What kind of symmetry can crystals have?
2.	structure	Can you describe the arrangement of salt crystals? What makes you think so? How will you test your theory?
3.	structure	Is glass a crystal?
4.	structure	What makes elastic stretchy--is the attraction mechanical, magnetic, chemical or something else?
5.	structure	Do sugar crystals have a regular structure?
6.	structure	How does a saw cut wood?
7.	structure	What makes glass transparent?
8.	structure	Do all crystals have symmetry? What kinds of symmetry are possible? How does symmetry inform the expressiveness of materials?
9.	structure	You are carrying a large stone (granite) in a small boat in a pool. You toss the stone into the pool. Does the level of water in the pool change? If so, did it go up or down?
10.	structure	It is possible to fill a glass above its sides. What holds the water in?
11.	mechanical properties	What makes a material rough? Why are some materials smooth?
12.	mechanical properties	Why are some materials cold to the touch? Why do some materials feel warm to the touch?
13.	mechanical properties	Why doesn't milk separate?
14.	mechanical properties	What holds paper together? Is it the same mechanism that holds felt together?
15.	mechanical properties	What holds iron together?
16.	mechanical properties	What holds salt together?
17.	mechanical properties	Can you describe the interaction between a pencil and paper on a microscopic level?
18.	mechanical properties	Does ice form crystals? What do they look like?
19.	mechanical properties	How does symmetry in crystals relate to the structures we see in salt?
20.	mechanical properties	What holds metal alloys together? Please use bronze as an example.
21.	mechanical properties	Is glass more like salt or felt? How can you tell?
22.	mechanical properties	What are the crystals you see in galvanized metal?
23.	mechanical properties	Why are some metals magnetic?
24.	mechanical properties	The Eiffel Tower is 324 meters tall. It is made of (wrought) iron and subject to temps from -24 to 40 deg C. How much can we expect the tower to expand?

25.	mechanical properties	How does a knife cut?
26.	mechanical properties	Why do some materials cut more easily in one direction than another?
27.	mechanical properties	What is the difference between ice, water and water vapor?
28.	mechanical properties	Can ice be compressed? Can water? How about water vapor?
29.	resonance	What happens when a material resonates?
30.	resonance	How do you find the resonance of a material?
31.	resonance	How does crystal packing inform resonance?
32.	resonance	Do all materials have a resonance point?
33.	resonance	Why do some materials resonate better (or longer) than others?
34.	resonance	Can you talk about the resonance we see in archival films on the Tacoma Narrows bridge failure?
35.	resonance	It was recently discovered that conversations vibrate thin films like the ones used in potato chip bags. How would you listen in on these conversations?
36.	resonance	Can you describe the different kinds of waves produced by an earthquake?
37.	resonance	Some (earthquakes) waves are more destructive then others. Can you demonstrate why?
38.	resonance	Where does a cat's purr come from?
39.	strength	How might you measure the strength of a material? List several ways.
40.	strength	What is deformation? Can you show us? How would you measure it?
41.	strength	What is elasticity? Can you show us? How would you measure it?
42.	strength	What is brittleness? Can you show us? How would you measure it?
43.	strength	What is ductility? Can you show us? How would you measure it?
44.	strength	What is plasticity? Can you show us? How would you measure it?
45.	strength	What is viscosity? Can you show us? How would you measure it?
46.	strength	Are composite materials stronger than elements?
47.	friction	What determines the friction between two surfaces?
48.	friction	Are some materials 'stickier' than others? What makes them sticky?
49.	friction	What holds bricks and mortar together?
50.	friction	How would reduce the friction between two materials?
51.	friction	Do fat tires help a car stick to the road (more then skinny tires made of the same material)?
52.	friction	You have a two blocks of salt: one the size of a sugar-cube, the other sized for a brick. Put them both on a board and raise the board. Will they slide at the same time?
53.	density	Is a total vacuum even possible in this universe?
54.	density	What is the difference between ice, water and steam from the standpoint of density?
55.	density	What is the relationship between the speed of sound and the density of a material? Can you demonstrate?
56.	density	Mix one pound of salt into ten pounds of water. How does the weight of the water change after the salt is mixed in?
57.	density	Mix one cup of salt into ten cups of water. How does the volume of water change after the salt is mixed in? Does it vary as the salt concentration increases?
58.	density	Does sound travel at different rates through different materials?
59.	density	How quickly does sound travel in water? Does this velocity vary with the temperature of the water?
60.	density	Why do Helium balloons want to go up?
61.	density	Close the cab of your car. Tie a balloon to the hand brake and accelerate. Which way will the ballon drift?
62.	density	Now brake the car with the Helium balloon. Which way does the ballon go?
63.	light	Can you compare the optical properties of crystals (fluorite for example, diamond, or salt)?
64.	light	Are rainbows material?
65.	light	What are the colors of the rainbow?

66.	light	Do the colors of the rainbow continue beyond the visible spectrum?
67.	light	Are the colors of the rainbow evenly distributed?
68.	light	Why are there seven colors of the rainbow? Are they evenly distributed? Could you make a case for more (or less)?
69.	light	How is the shape of a rainbow related to the shape of vapor droplets?
70.	light	How do color (gel) filters work?
71.	light	How many ways can you think of to isolate pure colors from white light?
72.	light	Why is the spectrum in an oil slick different than the rainbow?
73.	light	Why is the sky blue?
74.	light	What makes the sun turn red at evening?
75.	light	Can you describe two ways to make orange light?
76.	light	Can orange light be split into red and yellow light?
77.	light	Why are the primary colors of transmissive and reflective color wheels different?
78.	light	What gives black crow feathers a blue sheen? Similarly, why might you see many colors in a pigeon's feathers?
79.	light	Are clouds material?
80.	manufacturing	Why do we define pre-history by materials (Stone age, Iron age, Bronze age, etc.)?
81.	manufacturing	What is stainless steel? What makes it stainless?
82.	manufacturing	Weathering steel (trademark COR-TEN steel) rusts to a specific depth. What keeps this steel from rusting all the way through?
83.	manufacturing	What prevents galvanized metals from rusting?
84.	manufacturing	How does Rustoleum paint keep rust from forming on iron?
85.	manufacturing	How do we make plastics?
86.	manufacturing	What is a polymer? How do polymers relate to plastics?
87.	manufacturing	What does oil (petroleum) have to do with plastic production?
88.	color	What makes the juice of the cochineal so red?
89.	color	How would you make pink with red and white pigments?
90.	color	How are stains different than paint?
91.	color	How would you make a pink stain?
92.	energy	Why do some materials conduct electricity more readily than others?
93.	energy	Can animals store (and use) electricity?
94.	energy	Can you think of alternative ways to store energy?
95.	energy	Where does the heat come from when you burn wood? Could you return the energy to the wood?
96.	energy	How would you calculate the energy stored in a lump of coal, a cup of gasoline and a cube of sugar?
97.	organics	Why is carbon so strongly associated with life on this planet? Is life possible without carbon?
98.	organics	What happens when you caramelize sugar? Could this reaction be reversed?
99.	organics	How does chemical reversibility characterize materials?
100	organics	. What makes blood red? Are there any animals that have different colored blood? What is the difference?

Readings

These are suggested readings, and they are a good start for your research and perfectly valid as assignments

1. **Science as Falsification Karl Popper, 1963 (https://www.dropbox.com/s/siwobu7fitqdrq5/KPopper_Science%20as%20Falsification.pdf?dl=0)**

2. Information and the Nature of Reality: From Physics to Metaphysics; Paul Davies and Neils Heinrick Gregerson, eds.

   1. **From matter to materialsm and (almost) back (https://www.dropbox.com/s/z1pmhlenlr5zo5p/Information-and-the-Nature-of-Reality_EMcMullin.pdf?dl=0)**; Ernan McMullin. p30-54 >*The matter concept has had an extraordinarily complex history, dating back to the earliest days of the sort of reflective thought that came to be called ‘philosophy’. History here, as elsewhere, offers a valuable means of understanding the present, so it is with history that I will be concerned – history necessarily compressed into simplified outline.*
   2. **Unsolved dilemmas: the concept of matter in the history of philosophy and in contemporary physics (https://www.dropbox.com/s/ewwe7tl4notajlv/CLAYTON_Unsolved-dilemmas-the-concept-of-matter-in-the-history-of-philosophy-and-in-contemporary-physics.pdf?dl=0)**; Philip Clayton. p55-79. >*By the end of the modern period, a particular world view had become firmly entrenched in the public understanding. Unlike most philo- sophical positions, which are sharply distinguished from scientific theories, this world view was widely seen as a direct implication of science, and even as the sine qua non for all scientific activity. For shorthand, let’s call this view “materialism.”*

3. Materials: Engineering, Science, Processing and Design; Ashby, Shercliff, Cebon

   1. **Chapter 1 Introduction: materials--history and character (https://www.dropbox.com/s/oiwuu4c5feau2z2/Materials%20Engineering_Introduction-%20materials%E2%80%94%20history%20and%20character.pdf?dl=0)**; p14-24 Ashby, Shurclif, Cebon
   2. **Chapter 2 Family trees: organizing materials and processes (https://www.dropbox.com/s/okbl9q33ax7noon/Materials%20Engineering_Family%20trees-%20organizing%20materials%20and%20processes.pdf?dl=0)**; p26-41 Ashby, Shurclif, Cebon

4. Materials Science and Engineering : An Introduction; Callister, William, Rethwisch, David

   1. **Chapter 3 The Structure of Crystalline Solids (https://www.dropbox.com/s/p34ufzjbhvn9hww/Materials%20Science%20and%20Engineering_The%20Structure%20of%20Crystalline%20Solids.pdf?dl=0)**; Callister. p79-132.
   2. **Chapter 6 Mechanical Properties of Metals (https://www.dropbox.com/s/1j0xl78vydjqxj9/Materials%20Science%20and%20Engineering_Mechanical%20Properties%20of%20Metals.pdf?dl=0)**; Callister. p196-243; 2014.
   3. **Chapter 14 Polymer Structures (https://www.dropbox.com/s/e5j3d0g57p02vis/Materials%20Science%20and%20Engineering_Polymer%20Structures.pdf?dl=0)**; Callister. p573-607; 2014.
   4. **Chapter 5.15 Plastics (https://www.dropbox.com/s/89ll6htu4srnjv7/Materials%20Science%20and%20Engineering_Plastics.pdf?dl=0)**; Callister. p633-635; 2014.
   5. **Chapter 18 Electrical Properties (https://www.dropbox.com/s/c0gdhkgoo50fiwp/Materials%20Science%20and%20Engineering_Electrical%20Properties.pdf?dl=0)**; Callister. p753-812; 2014.
   6. **Chapter 19 Thermal Properties (https://www.dropbox.com/s/ftbvqr5lpcdkpv9/Materials%20Science%20and%20Engineering_Thermal%20Properties.pdf?dl=0)**; Callister. p813-830; 2014.
   7. **Chapter 20 Magnetic Properties (https://www.dropbox.com/s/d83d7ktgejrp50v/Materials%20Science%20and%20Engineering_Magnetic%20Properties.pdf?dl=0)**; Callister. p831-865; 2014.
   8. **Chapter 21 Optical Properties (https://www.dropbox.com/s/dvo5rk3fc47hmb5/Materials%20Science%20and%20Engineering_Optical%20Properties.pdf?dl=0)**; Callister. p866-895; 2014.

5. **MATTER MATTERS (https://www.dropbox.com/s/b580edckyzlkhyi/DeLanda-Manuel-Matter-Matters.pdf?dl=0)** by Manuel DeLanda;

6. **On the six-cornered snowflake (https://www.dropbox.com/s/lsni2psywe8yn6c/Kepler_on-the-six-cornered-snowflake.pdf?dl=0)**; Kepler, 1611

> *Kepler writes that he had noticed a snowflake on the lapel of his coat as he crossed the Charles Bridge in Prague, and so*

> *came to ponder on its remarkable geometry. This charming, witty work seeded the notion from which all of crystallography blossomed: that the geometric shapes of crystals can be explained in terms of the packing of their constituent particles.*

7. The Chemical History of a Candle; Michael Faraday; 1861
   1. **Lecture 1: A Candle: The Flame - Its Sources - Structure - Mobility - Brightness** **(https://www.dropbox.com/s/dcn6sewifnjwlg9/The%20Chemical%20History%20of%20a%20Candle_1.pdf?dl=0)**
   2. **Lecture 2: Brightness of the Flame - Air necessary for Combustion - Production of Water** **(https://www.dropbox.com/s/082n6rsq8bko01l/The%20Chemical%20History%20of%20a%20Candle_2.pdf?dl=0)**
   3. **Lecture 3: Products: Water from the Combustion - Nature of Water - A Compound - Hydrogen** **(https://www.dropbox.com/s/iw1kcuj9ty9rbl6/The%20Chemical%20History%20of%20a%20Candle_3.pdf?dl=0)**
   4. **Lecture 4: Hydrogen in the Candle - Burns into Water - The Other Part of Water - Oxygen** **(https://www.dropbox.com/s/9gwfqzk9wltr7te/The%20Chemical%20History%20of%20a%20Candle_4.pdf?dl=0)**
   5. **Lecture 5: Oxygen present in the Air - Nature of the Atmosphere - Its Properties - Other Products from the Candle - Carbonic Acid - Its Properties** **(https://www.dropbox.com/s/c1cf8xqwmxtzlja/The%20Chemical%20History%20of%20a%20Candle_5.pdf?dl=0)**
   6. **Lecture 6: Carbon or Charcoal - Coal Gas Respiration and its Analogy to the Burning of a Candle - Conclusion** **(https://www.dropbox.com/s/g8r5swmzdhftpvr/The%20Chemical%20History%20of%20a%20Candle_6.pdf?dl=0)**
8. Stuff Matters: Exploring the Marvelous Materials That Shape Our Man-Made World; Mark Miodownik (May 27, 2014)
   1. **Chocolate** **(https://www.dropbox.com/s/qhpoawco88j9h7z/Stuff%20Matters_CHOCOLATE.pdf?dl=0)**
   2. **Concrete** **(https://www.dropbox.com/s/sbmp91p5okym8kx/Stuff%20Matters_CONCRETE.pdf?dl=0)**
   3. **Foam** **(https://www.dropbox.com/s/a2n7xn7654whyp4/Stuff%20Matters_FOAM.pdf?dl=0)**
   4. **Glass** **(https://www.dropbox.com/s/3262j6lnmu8tggu/Stuff%20Matters_GLASS.pdf?dl=0)**
   5. **Graphite** **(https://www.dropbox.com/s/47j93a6p84v8eeq/Stuff%20Matters_GRAPHITE.pdf?dl=0)**
   6. **Implants** **(https://www.dropbox.com/s/be6ew17akjrclt7/Stuff%20Matters_IMPLANTS.pdf?dl=0)**
   7. **Paper** **(https://www.dropbox.com/s/e1du095jszo1ljz/Stuff%20Matters_PAPER.pdf?dl=0)**
   8. **Porcelain** **(https://www.dropbox.com/s/fv89jtkphfh4gj7/Stuff%20Matters_PORCELAIN.pdf?dl=0)**
   9. **Steel** **(https://www.dropbox.com/s/955ow5ytkhp1pis/Stuff%20Matters_STEEL.pdf?dl=0)**
9. The Ten Most Beautiful Experiments, by George Johnson
   1. **Galvani: Animal Electricity** **(https://www.dropbox.com/s/od5xlok321hg4j0/Galvani_animalelectricity.pdf?dl=0)**
   2. **Lavoisier: Burning Diamonds** **(https://www.dropbox.com/s/xx4qipoue220998/Lavoisier_heat.pdf?dl=0)**
   3. **Faraday: Electromagnets** **(https://www.dropbox.com/s/lzxshg3lk14yl1w/Faraday_hidden.pdf?dl=0)**
   4. **Michelson: Does movement through space effect light?** **(https://www.dropbox.com/s/pxi1kn9hqjkuv51/Michelson_space.pdf?dl=0)**
   5. **Newton: What Color Is** **(https://www.dropbox.com/s/hl2iie0cwof5oma/Newton_color.pdf?dl=0)**

Other Materials, by Subject

1. FRICTION
   1. **Walter Lewin lecture on Friction** **(http://ocw.mit.edu/courses/physics/8-01-physics-i-classical-mechanics-fall-1999/video-lectures/lecture-8/)**
2. WOOD
   1. **Understanding Wood Ch1:The Nature of Wood** **(https://www.dropbox.com/s/i852ic8ce20wr5k/UnderstandingWood_ch1.pdf?dl=0)**
   2. **Understanding Wood Ch9: Machining and Bending Wood** **(https://www.dropbox.com/s/g0aqap2oyz48cwi/UnderstandingWood_ch9.pdf?dl=0)**
3. BUOYANCY
   1. **W Lewin on Buoyancy & Bernoulli's Equation** **(http://ocw.mit.edu/high-school/physics/demonstrations-on-video/fluid-mechanics/buoyancy-bernoullis-equation/)**
4. CONDUCTIVITY: ELECTRICITY, HEAT, SOUND, LIGHT
   1. **rainbows** **(http://ocw.mit.edu/courses/physics/8-03sc-physics-iii-vibrations-and-waves-fall-2012/unit-iv-applications/lecture-22/)**

5. RESONANCE

1. [Tacoma Narrows Bridge (https://www.youtube.com/watch?v=j-zczJXSxnw)]

   [(https://www.youtube.com/watch?v=j-zczJXSxnw)]
2. [Upright Bass string displacement captured by scanning camera (https://vimeo.com/4041788)]
3. [Interactive Wolfram demo: Transverse Standing Waves (http://demonstrations.wolfram.com/TransverseStandingWaves/)]
4. MIT Physics III: Vibrations and Waves N.B. This is not an easy-going class, but you may find it useful. *In addition to the traditional topics of mechanical vibrations and waves, coupled oscillators, and electro-magnetic radiation, students will also learn about musical instruments, red sunsets, glories, coronae, rainbows, haloes, X-ray binaries, neutron stars, black holes and big-bang cosmology.*
   1. [Lecture 2: Beats, Damped Free Oscillations, Quality Q (http://ocw.mit.edu/courses/physics/8-03-physics-iii-vibrations-and-waves-fall-2004/video-lectures/lecture-2/)] *Topics covered: Beats - Damped Free Oscillations (Under- Over- and Critically Damped) - Quality Q. Instructor/speaker: Prof. Walter Lewin*
   2. [Lecture 3. Forced Oscillations with Damping, Destructive Resonance (http://ocw.mit.edu/courses/physics/8-03-physics-iii-vibrations-and-waves-fall-2004/video-lectures/lecture-3/)]
   3. [Lecture 8: Traveling Waves, Sound Waves and Energy in Waves (http://ocw.mit.edu/courses/physics/8-03-physics-iii-vibrations-and-waves-fall-2004/video-lectures/lecture-8/)] *Topics covered: Traveling Waves - Boundary Conditions - Standing Waves - Sound (Longitudinal Waves) - Energy in Waves.*
   4. [Lecture 9: Chladni plates (http://ocw.mit.edu/courses/physics/8-03sc-physics-iii-vibrations-and-waves-fall-2012/unit-ii-waves/lecture-9/)] *Topics covered: Musical Instruments - Sound Cavities - Normal Modes*
   5. [lecture 11: Fourier Analysis, Time Evolution of Pulses on Strings (http://ocw.mit.edu/courses/physics/8-03-physics-iii-vibrations-and-waves-fall-2004/video-lectures/lecture-11/)] *Topics covered: Fourier Analysis - Time Evolution of Pulses on Strings.*
   6. [Lecture 13: Electromagnetic Waves, Polarization (http://ocw.mit.edu/courses/physics/8-03-physics-iii-vibrations-and-waves-fall-2004/video-lectures/lecture-13/)] *Topics covered: Electromagnetic Waves - Plane Wave Solutions to Maxwell's Equations - Polarization - Malus' Law*
   7.