# Think-Pair-Share

**What it is**:
A thought-provoking question is posed to students who think about the answer then discuss it with their neighbors.

**Implementation**:
- Ask a question
- Students think about or write down their answer (usually 1-2 minutes)
- Students pair up
- Students share their thoughts with each other and discuss the answer
- Instructor can ask for responses from some, all, or no pairs

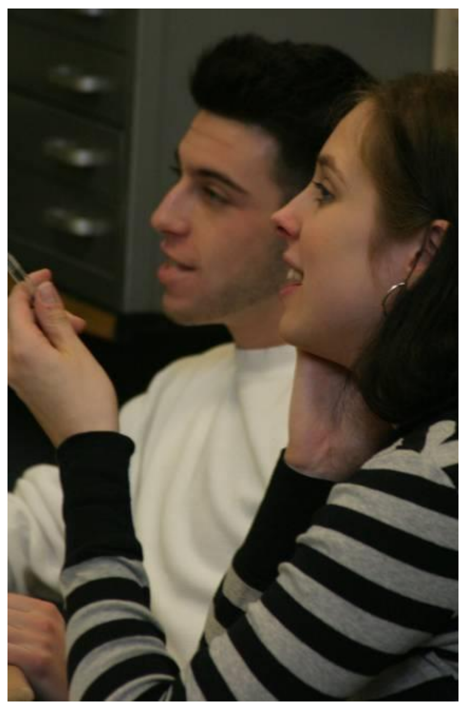
**The question**:
- Promotes student engagement
- Facilitates informal assessment

***Examples include***

- **Image Interpretation**: Interpret the geologic history of the rocks shown in this image.
- **Graph Interpretation**: From the plot of weathering depth vs. age for limestone in tombstones, estimate the mean weathering rate.
- **Open-ended question:** How do we know what the climate was like before people started keeping track?
- **More examples at:** http://serc.carleton.edu/16225

*Think individually*

*Form small groups and discuss*



*Share with larger group*

**References**
- http://serc.carleton.edu/introgeo/interactive/tpshare.html
- Lyman, F., 1987, Think-Pair-Share: An expanding teaching technique: MAA-CIE Cooperative News, 1: 1-2.
- King, 1993 , From Sage on the Stage to Guide on the Side, College Teaching, 41: 30-35

Rachel Beane, Bowdoin College

# Jigsaw

**What it is**:
Cooperative learning during which students first become experts in one aspect, then peer-teach and work together to solve a problem or complete a task.

**Implementation**:
- Instructor divides topic into team assignments
- In teams, students become experts (by completing an assignment) on one aspect
- Students recombine into new groups, with each team represented in the group
- Students in the group, first teach each other their specialties, then work together to solve a problem/complete a task.

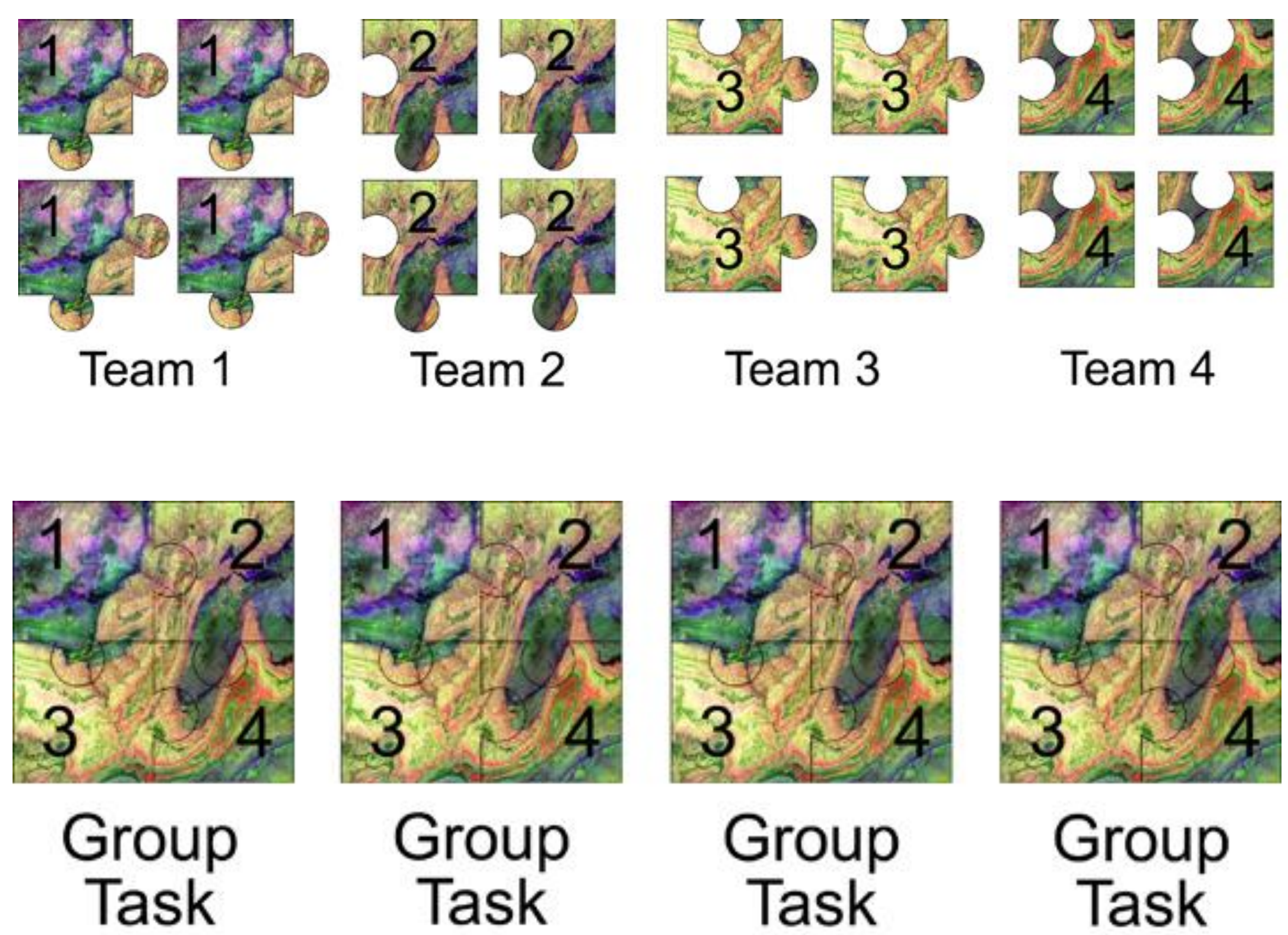
**The topic/problem should**:
- Be easy to divide
- Have related team assignments
- Not require students to be experts in everything
- Be complex enough to result in productive discussions

http://serc.carleton.edu/introgeo/jigsaws/index.html

"When efforts are structured cooperatively, there is considerable evidence that students will exert more effort to achieve, learn more, use higher-level reasoning strategies more frequently, build more complete and complex conceptual structures, and retain information learned more accurately" Johnson & Johnson, 1999, *Making Cooperative Learning Work*.

**Example: Google Earth.** Each team analyzes different locations that show similar features (e.g., barrier islands, folds, valley glaciers, volcanic cones, etc.), then combine to discuss similarities and differences of the feature.

**Example: Plate tectonics.** Teams analyze earthquake, volcano, seafloor age, and topography data maps, then combine to draw plate boundaries and interpret processes.




*Puzzle graphics by Barbara Tewksbury, with background ASTER image from NASA/GSFC/METI/ERSDAC/JAROS, and U.S./Japan ASTER Science Team*

**Rachel Beane, Bowdoin College**

# ConcepTest

**What it is:**
Multiple-choice question that focuses on one key concept of the lesson.

**Implementation:**

- Present a short lecture (5-10')
- Post a Concept Test on board/screen
- Students consider question and answer (by hands, lettered cards, clickers…)
- Students discuss reasons for their answers with neighbors
- Students answer question again
- Instructor, or student spokesperson, explains the correct response

**The question should:**

- Focus on application of a single concept (not recognize a fact or define a term)
- Be of intermediate difficulty (expect 35-70% of student to initially answer correctly)

**ConcepTests have been shown to:**

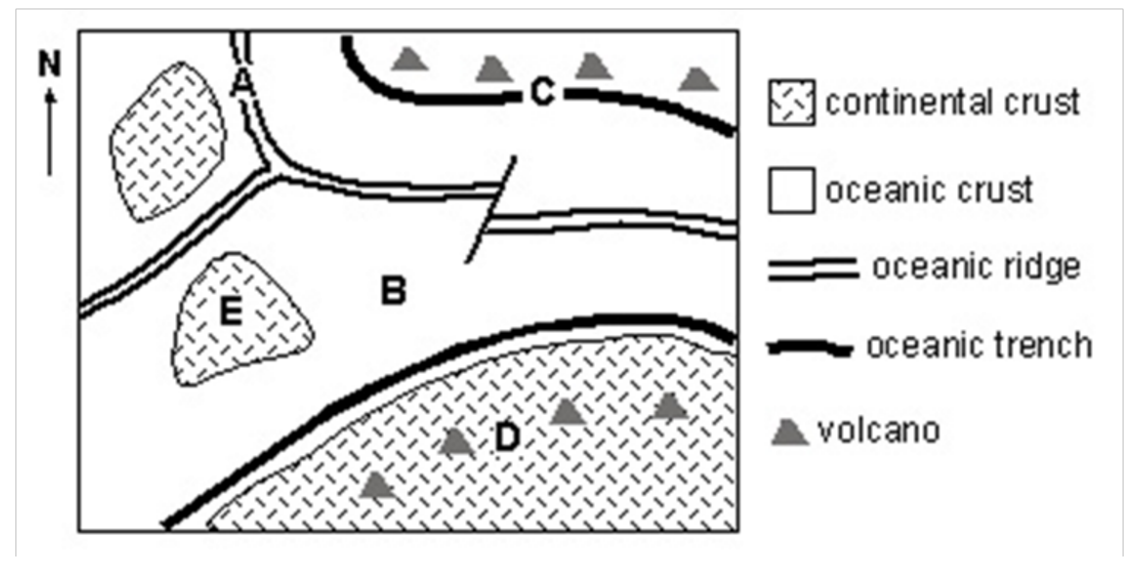
- Increase student engagement
- Communicate high expectations
- Promote interaction
- Provide prompt feedback
- Increase student course satisfaction
- Improve student attendance
- Improve student learning

## Examples

How many plates are present?

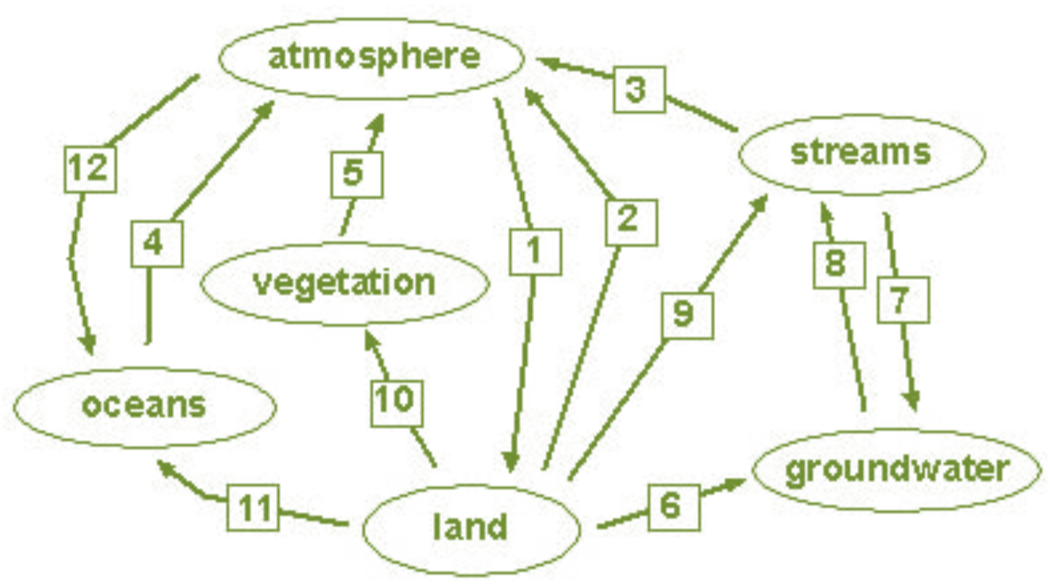
a. 3 (26%; 0%)
c. 5 (44%; 75%)
b. 4 (19%; 18%)
d. 6 (11%; 7%)

*Individual responses*
*Post-discussion responses*




McConnell, D.A., et al., 2006, Journal of Geoscience Education, v. 54, #1, p.61-68.

The following diagram illustrates the hydrologic cycle. Arrow 11 best represents what process?




a. evaporation
b. precipitation
c. transpiration
d. run-off

http://serc.carleton.edu/introgeo/conceptests/examples/hydro_cycle11.html

**More examples and information at http:serc.carleton.edu/introgeo/conceptests/index.html**

**Rachel Beane, Bowdoin College**

## References


- Beatty, I.D., Gerace, W.J., Leonard, W.J., and Dufresne, R.J., 2006, Designing effective questions for classroom response system teaching. American Journal of Physics, v. 74 (1), p. 31-39.
- Greer, L., and Heaney, P.J., 2004, Real-time analysis of student comprehension: An assessment of electronic student response technology in an introductory Earth Science course. Journal of Geoscience Education, v. 52(4), p. 345-352.
- McConnell, D.A., Steer, D.N., Owens, K.D., Knott, J.R., Van Horn, S., Borowski, W., Dick, J., Foos, A., Malone, M. McGrew, H., Greer, L, and Heaney, P. J. 2006. Using conceptests to assess and improve student conceptual understanding in introductory geoscience courses. Journal of Geoscience Education, v. 54(1), p. 61-68.
- Smith, M.K., Wood, W.B., Adams, W.K., Wieman, C., Knight, J.K., Guild, N., and Su, T.T., 2009, Why peer discussion improves student performance on in-class concept questions. Science, v. 323, p. 122-124.

# Minute Paper

**What it is**:
Questions that require short responses from students. The “Minute Paper” is sometimes called “Muddiest Point” or “Daily Check-In” depending on how it is used.

**Implementation**:
- Pose a question.
- Students respond

  *May be anonymous.*
  *May be collected on notecards.*
- Collect responses and review

  *Read with an open mind.  You may learn students are unsure about a concept you believe was explained clearly.*
- Address student responses

  *You may choose to do this at the start of the next lesson or electronically via email or a class website*

**Advantages:**
- Provides immediate feedback
- Students self-assess: they must mentally review before they can respond
- Facilitates student reflection which increases retention
- Allows all students to have a “voice” in the class

**Examples of common questions:**

- What was the most important point discussed in today’s class?
- What question do you have about today’s class/reading/discussion?
- What was the muddiest point in today’s class?
- What would you like to learn more about?

**References**

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Angelo, Thomas A. and Cross, K. Patricia,1993. Classroom assessment techniques: A handbook for college teachers. 2nd edition. San Francisco: Jossey-Bass Publishers, p.148-153.

Chizmar, John F.; Ostrosky, Anthony L.,1998, The One-Minute Paper: Some Empirical Findings, *Journal of Economic Education*, 29: 3-10.

Stead, David R, 2005. A review of the one-minute paper, *Active Learning in Higher Education*, 6: 118-131.

**http://serc.carleton.edu/introgeo/interactive/oneminwrite.html**

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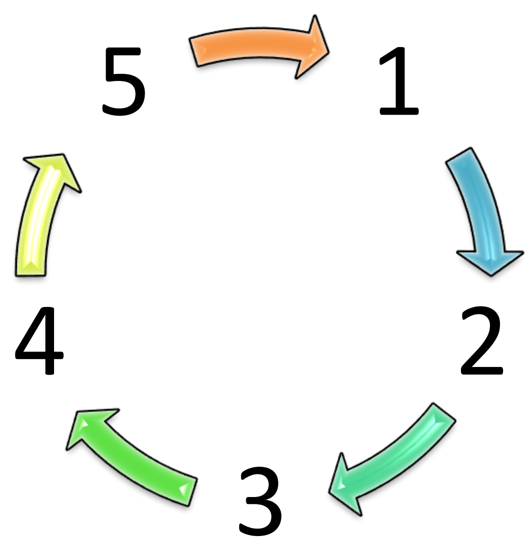



# Gallery Walk

**What it is**:
Students get out of their seats and respond in small groups to a prompt, and then respond to other student's responses as well.

**Implementation**:
- Instructor posts a series of prompts around room. Prompts should be open-ended, allowing for a variety of responses.
- Provide instructions to students and arrange students into groups
- Each group responds on paper to one of the prompts.
- Groups rotate through prompts, responding both to the prompt as well as prior groups' comments. Instructor monitors and spurs discussion when needed.
- Students report out key points. Instructor adds comments and corrects for misconceptions.

**Benefits:**
- Facilitates student interaction & collaboration
- Allows all students to voice their thoughts
- Promotes debate and consensus building
- May be used to assess students' prior knowledge or misconceptions
- Wakes up students with movement

**Example prompts:**
- Images
- Graphs
- News headlines
- Opinion statements
- Questions

**Group members may choose roles:**
- Leader
- Reporter
- Monitor
- Recorder

**Examples of Gallery Walk questions**
organized by Bloom's Hierarchy

- **Knowledge:** *List the impacts of increased ultraviolet radiation reaching the earth.*
- **Comprehension:** *What is the difference between weathering and erosion?*
- **Application:** *Use Darcy's Law to calculate groundwater flow rates in the marked locations.*
- **Analysis:** *What inference can you make about the geomorphic history of this region based on the terraces?*
- **Synthesis:** *Create a coastal zoning plan to better protect from hurricane damage.*
- **Evaluation:** *Use scientific evidence to defend or criticize the use of Yucca Mountain as a nuclear waste repository.*

**http://serc.carleton.edu/introgeo/gallerywalk/index.html**

Gallery Walk introducing REE in 30 person, non-majors course.
Photo by Kevin Travers, Bowdoin College.

**Rachel Beane, Bowdoin College**

# Worksheets (Lecture Tutorials)

**What it is**:
Short worksheets aimed at reducing misconceptions or working through difficult concepts that students complete in groups in class.

**Implementation**:
- Give a short, introductory lecture.
- Students pair up and complete a worksheet (instructors can create their own worksheets or use Lecture Tutorials in a published workbook).
- Briefly review select questions. Collecting the worksheets is optional.

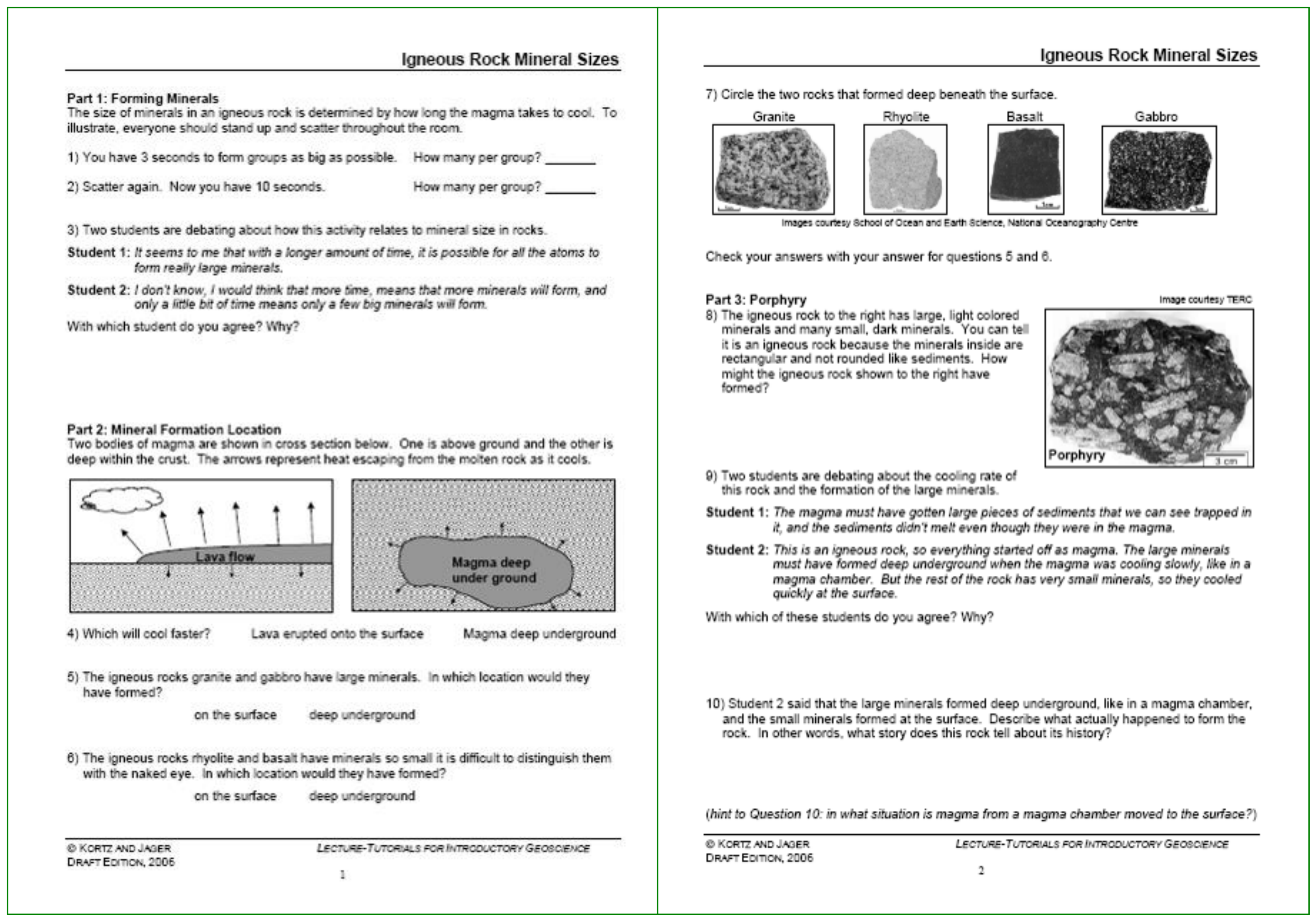
**The worksheet should**:
- Address topics with which students have difficulties.
- Require mid- to high-level thinking.

**Lecture Tutorials have been shown to:**
- Increase student learning
- Reduce misconceptions
- Promote interaction
- Provide prompt feedback
- Create a positive response in students

**Directions to create your own**:

Lecture Tutorial module:
*http://serc.carleton.edu/sp/library/lecture_tutorials/index.html*

## Example



**Igneous Rock Mineral Sizes**

**Part 1: Forming Minerals**
The size of minerals in an igneous rock is determined by how long the magma takes to cool. To illustrate, everyone should stand up and scatter throughout the room.

1) You have 3 seconds to form groups as big as possible. How many per group? _______

2) Scatter again. Now you have 10 seconds. How many per group? _______

3) Two students are debating about how this activity relates to mineral size in rocks.

**Student 1:** *It seems to me that with a longer amount of time, it is possible for all the atoms to form really large minerals.*

**Student 2:** *I don't know, I would think that more time, means that more minerals will form, and only a little bit of time means only a few big minerals will form.*

With which student do you agree? Why?

**Part 2: Mineral Formation Location**
Two bodies of magma are shown in cross section below. One is above ground and the other is deep within the crust. The arrows represent heat escaping from the molten rock as it cools.



4) Which will cool faster? Lava erupted onto the surface Magma deep underground

5) The igneous rocks granite and gabbro have large minerals. In which location would they have formed?
on the surface deep underground

6) The igneous rocks rhyolite and basalt have minerals so small it is difficult to distinguish them with the naked eye. In which location would they have formed?
on the surface deep underground

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1

**Igneous Rock Mineral Sizes**

7) Circle the two rocks that formed deep beneath the surface.



Images courtesy School of Ocean and Earth Science, National Oceanography Centre

Check your answers with your answer for questions 5 and 6.

**Part 3: Porphyry**
Image courtesy TERC

8) The igneous rock to the right has large, light colored minerals and many small, dark minerals. You can tell it is an igneous rock because the minerals inside are rectangular and not rounded like sediments. How might the igneous rock shown to the right have formed?



9) Two students are debating about the cooling rate of this rock and the formation of the large minerals.

**Student 1:** *The magma must have gotten large pieces of sediments that we can see trapped in it, and the sediments didn't melt even though they were in the magma.*

**Student 2:** *This is an igneous rock, so everything started off as magma. The large minerals must have formed deep underground when the magma was cooling slowly, like in a magma chamber. But the rest of the rock has very small minerals, so they cooled quickly at the surface.*

With which of these students do you agree? Why?

10) Student 2 said that the large minerals formed deep underground, like in a magma chamber, and the small minerals formed at the surface. Describe what actually happened to form the rock. In other words, what story does this rock tell about its history?

(*hint to Question 10: in what situation is magma from a magma chamber moved to the surface?*)

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2


**References**

Kortz, Murray, and Smay (2008) Increasing Learning in Introductory Geoscience Courses Using Lecture Tutorials. JGE, v. 56, 280-290

Kortz and Smay (2012) Lecture Tutorials for Introductory Geoscience, 2e. W.H. Freeman.

Kortz and Smay (2014) Lecture Tutorials for Earth Science. W.H. Freeman



**Rachel Beane, Bowdoin College**

# Cooperative Exam

**What it is:** Exams for which students answer some questions independently and some in groups. These type of exams may be called cooperative, two-stage, or pyramid exams.

**Implementation:**

- Prepare an exam that has an individual component and a cooperative group component.
- Questions may be in any format: multiple choice, short answer, problem-solving… Questions in the 2nd part may build on a questions from the 1st part or ask them in a new way.
- For the 1st part of the exam (often 30-45'), students individually answer questions and turn in their responses.
- For the 2nd part of the exam (often 30-45'), in groups of 3-5, students answer the same questions, new questions, or a combination of both depending on how you choose to format the exam.

**Grading:**

- Many instructors have the individual component count as 70-80% of the total exam grade, with the cooperative portion counting for the remaining.
- Many instructors do not penalize students if they perform better on the individual portion than on the cooperative portion.

**Advantages:**

- Exam is a learning experience
- Immediate feedback from peers
- Students achieve a higher level of mastery

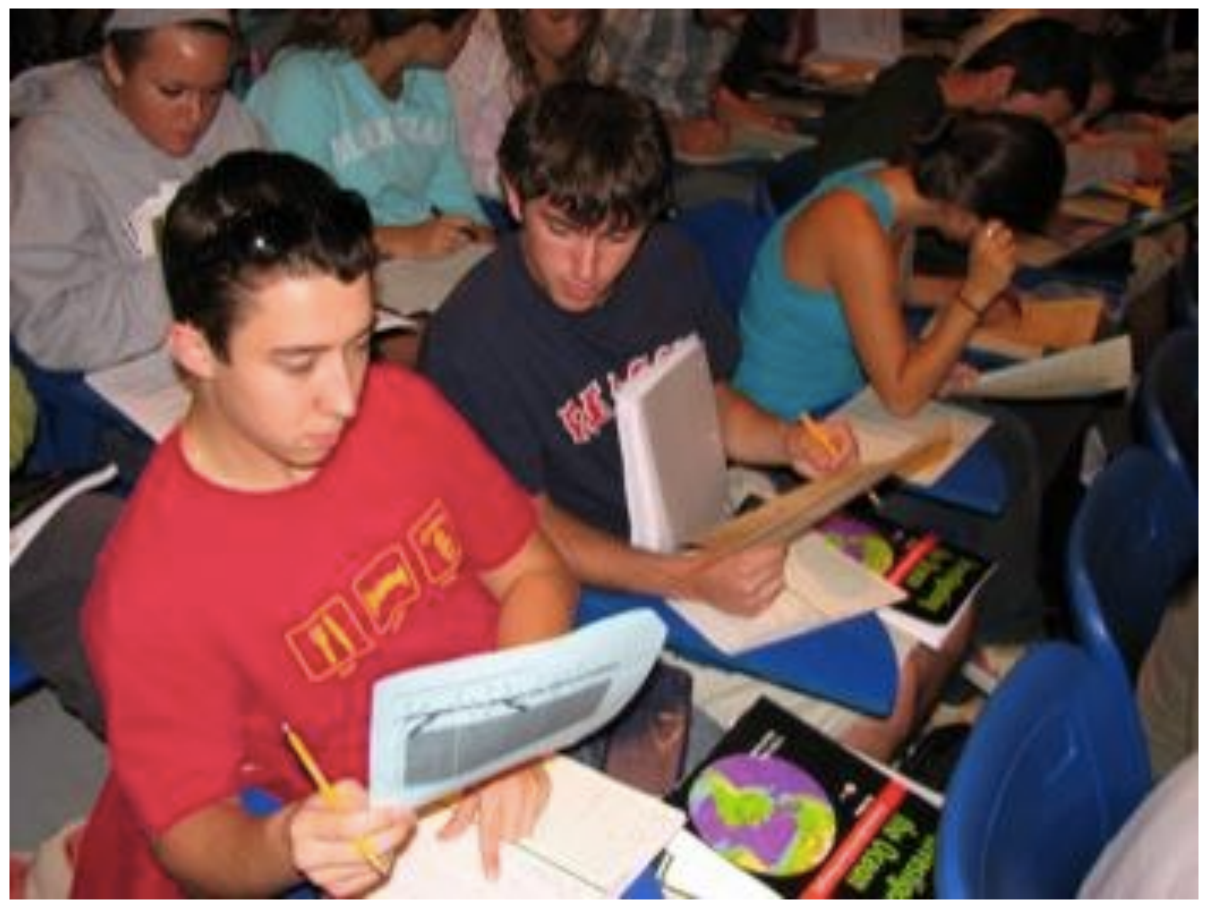

Photo by Mark Leckie

**Student comments:** (from Wieman et al., 2014)

- *I was able to instantly learn from my mistakes.*
- *It was good to compare methods and answers with others, and it allowed us to be more confident.*
- *Interesting. All had different ways of approaching the question. Very helpful to understand everyone's response and why they thought their answer was correct.*

**References**


Cohen, D. and Henle, J., 1995. The Pyramid Exam,. In *Undergraduate Mathematics Trends, MAA.*

Wieman, C., Rieger, G., Heiner, C., 2014. Physics Exams that Promote Collaborative Learning. *The Physics Teacher,* 52: 51-53.

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Zipp, J., 2007. Learning by Exams: The Impact of Two-Stage Cooperative Tests. *Teaching Sociology*, 35: 62-76.


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# Collaborative Documents

**What it is**:
Activities that encourage students to work together in or out of the classroom by using on-line collaborative tools. Many possibilities – 3 examples are shown here. May be combined with an on-line peer review tool (*e.g.* iPeer or PRAZE).

## *Class Review*

**Implementation:**
Provide a review sheet online through Google Docs or a similar tool. Invite students to share the document and study together virtually

Minerals we need to know formula for highlighted in yellow
Elements in these mineral highlighted in orange

Hey guys, I made a mineral formula quiz on sporcle for this exam:
http://www.sporcle.com/games/acheronta/geol340-review
Let me know if there are any problems with it. :) -Adele

**Sulfides**
What are the major minerals in ocean crust?
plagioclase feldspar, augite, orthopyroxene, olivine
How do we learn about the composition and mineralogy of ocean crust?
dredging and drilling
What is MORB?
mid ocean ridge basalt
What is an ophiolite?
section of ocean crust that is uplifted and exposed above sea level
What are the basic parts of an ophiolite?
chert-pillow lavas-sheeted dikes-gabbro-ultramafic rocks
top------------------------------------------------------------ >bottom
What is a hydrothermal vent?
where water seeps into the crust and get heated and dissolves metals and stuff. then rises and when it meets ocean water it precipitates to form a vent
How does it form?
water goes into pore spaces in rocks->water heats up-> water dissolves metals, sulfur->water rises->reacts with cold sea water and mineral precipitate from water (sulfides causes them to be black plumes)
Why do sulfides precipitate on hydrothermal vents?
the hot sulfur-metal rich water coming into contact with the cold sea water causes the metals and sulfur to combine and precipitate in the water
Where do the sulfur and metals that make up sulfide minerals in these vents come from?
the basaltic rock the water seeps into
What is the nature of chemical bonds in sulfides?
chemical bonding in the sulfides is less ionic than oxides, sulfur is significantly less electronegative than oxygen. Bonding is covalent or metallic depending on energy orbitals.
Know the mineral formulae for the seven sulfide minerals you have learned in this class:
*Pyrite($FeS_2$), Galena(PbS), Sphalerite((Zn,Fe)S), Pyrrhotite($Fe_{(1-x)}S$), Chalcopyrite($CuFeS_2$), Molybdenite($MoS_2$), Cinnabar(HgS)*
What are distinctive characteristics of each? What are common characteristics?Where are each of these minerals found?
SEE CHART

| mineral | formula | distinctive characteristic | common characteristic | where they are found |
|---|---|---|---|---|
| pyrite | $FeS_2$ | striated faces, cubic habit, H=6.5 | biomineral, isometric | hydrothermal deposits, |

## *Presentations*

**Implementation:** Ask students to create a presentation using one of the many on-line presentations apps available. Provide a rubric showing how they will be evaluated. Students work together in small groups to prepare a presentation, and present it to the class.

## *Wiki Page or Web Page*

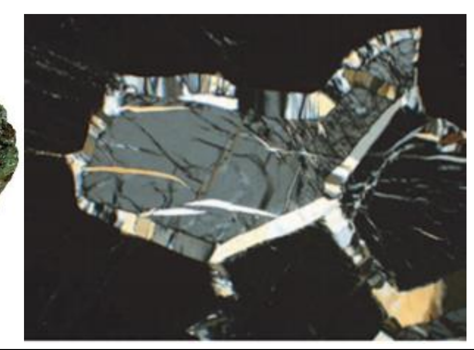
**Implementation**:
- Give an assignment with specific instructions and grading rubric. Students work in small groups over course of week.
- Students research and create a wiki or web page that describes topic, includes images, and cites sources.
- Evaluate their creations!

**The assignment should**:
- Allow students to investigate and learn information that is outside the prescribed coursework that interests them

**Pyrope**

**Mineral formula:** $Mg_3Al_2Si_3O_{12}$
**Crystal system:** Isometric
**Crystal Habit:** Dodecahedral; often found as granular
**Hardness on Mohs scale:** 7 - 7.5
**Specific gravity:** 3.56 gm/cc
**Color:** deep red
**Luster:** vitreous
**Streak:** white
**Fracture:** conchoidal
(Sources: 1, 2)





| | | |
|---|---|---|
| Small pyrope crystal, showing characteristic 'blood red' color and dodecahedral habit. Scale: crystal is 2.5mm (Mindat). | Pyrope in the metamorphic rock Eclogite. The accompanying green mineral is pyroxene. Image size: 13cm (Sandatlas) | A coesite and quartz inclusion in pyrope garnet. Characteristic radial fractures in the pyrope are visible. It was the unlikely presence of nearly pure pyrope that encouraged Chopin to check for coesite. Picture width: 1.3mm (Elements). |

**Interesting Fact:**
In 1984, geologist Christian Chopin published a paper describing his sampling of metamorphic coesite and pure pyrope in the Western Alps. His seemingly minor find went on to change the way scientists understood plate tectonics. Previously, diagrams showing the tectonic movement of continental plates had restricted such movement to the normal thickness of the continental crust. Pyrope has a high-pressure stability field, and pyrope-rich garnet had previously only been found in rocks with origins in the mantle. Chopin's findings showed that crustal rocks had penetrated much deeper into the earth than previously believed, traveling down at least 100km. The discovery of this rare pyrope and its inclusions ultimately brought around a new theory of continental tectonics (Elements, European Journal of Mineralogy).

Chopin's original article: Coesite and pure pyrope in high-grade blueschists of the Western Alps: a first record and some consequences.

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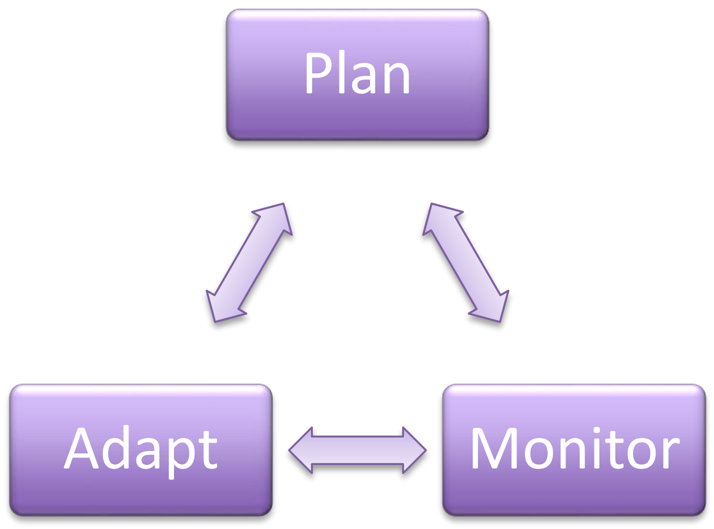
http://serc.carleton.edu/NAGTWorkshops/undergraduate_research/collaborate.html




# Wrapper

**What it is:** a self-monitoring activity that surrounds another assignment or activity.

**3 steps to teach metacognition:** (Lovett, 2008)
1. Teach students  their ability to learn can change.
2. Teach planning and goal-setting.
3. Provide opportunities for students to monitor and adapt their learning.

**Wrapper benefits:**
- Students monitor their learning.
- Students get immediate self-feedback.
- Responses to wrapper may provide start to in-class discussion.
- Big impact for a short activity.

## Lecture Wrapper
(from Lovett, 2008)

- ❖ Start of lecture: provide tips on active listening
- ❖ End of lecture: students list 3 key points of lecture. Instructor collects lists, and reveals 3 most important points for immediate feedback.
- ❖ Study: After 3 successive lecture wrappers, student responses increasingly matched the instructor's: 45%, 68%, 75%.

## Research Project Wrapper
(from R. Beane)

- ✧ What did you learn about research and the topic through this project?
- ✧ What did you learn about your own research habits and preferences?
- ✧ When were you excited and/or frustrated during the project?
- ✧ If you did a similar project in the future, would you approach the project the same or differently?

## Exam Wrapper
(modified from Ambrose et al., 2010)

1. Approximately how much time did you spend preparing for this exam?

2. What percentage of your time was doing the following:
   a. Reading textbook sections for the first time
   b. Rereading textbook sections
   c. Practicing problems
   d. Reviewing notes
   e. Reviewing class materials
   f. Other (specify)

3. After reviewing your graded exam, estimate the percentage of points lost due to the following:
   a. Lack of understanding the concept
   b. Not knowing how to approach the question/problem
   c. Carelessness
   d. Other

4. Based on your responses above, how do you plan to prepare differently for the next exam?

## Reading Reflection
(from K. Wirth)

- ✧ What is the main point of this reading?
- ✧ What did you find surprising?  Why?
- ✧ What did you find confusing?  Why?

## References


- Ambrose, Bridges, DiPietro, Lovett, Norman, and Mayer, 2010. How learning works: Seven Research Based Principles for Smart Teaching. Jossey-Bass: 336 pp.
- Lovett, 2008. Teaching Metacognition: Presentation to the Educause Learning Initiative Annual Meeting, 29 January 2008.
- Wirth and Perkins, 2008. Learning to learn.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http://serc.carleton.edu/NAGTWorkshops/metacognition/index.html