Purdue University Energy Academy
Problem Based Learning for Energy Education
Teacher Education Packet
June 16-22, 2013

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The Purdue Energy Academy

June 16-22, 2013

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The Energy Education Aspect via Problem Based Learning (PBL)

As part of the Purdue Energy Academy (PEA), teacher participants will have the opportunity to observe the student participants, participate in problem solving, direct hands-on experiences, and prepare PBL experiences to be implemented in their classrooms.

PBL is an approach that challenges students to learn through engagement in a real problem. It is a format that simultaneously develops both problem solving strategies and disciplinary knowledge bases and skills by placing students in the active role of problem solvers. PBL is student-centered and focuses on learning. The process is aimed at using the power of authentic problem solving to engage students and enhance their learning and motivation. The PBL experience requires teachers to become co-learners, co-planners, and co-evaluators as they design, implement, and continually refine their curricula. The PBL approach is grounded in solid academic research on learning and on the best practices that promote it. Students take responsibility for their own learning, collaboration is fostered, problem solving skills are improved, and motivation for life-long learning is encouraged.

The nine steps to PBL are: 1) Explore the issues—the teacher presents an "ill-structured problem" to the students. Discuss the problem and list its significant parts. Gather information and learn new concepts, principles, or skills as you engage in the problem solving process. 2) List what you know to solve the problem. Assess the strengths and capabilities of each team member. 3) Develop and write out the problem statement in your own words. The problem statement should list what you know and what you will need to know to solve the problem. Your team should agree on the statement. The problem may be revisited often and edited as new information is discovered or old information is discarded. 4) List possible solutions and order them from strongest to weakest. Your team should choose the best one or the one you think is most likely to succeed. 5) List actions to be taken with a timeline. 6) List what the team needs to know to solve the problem. Include the research needed, possible resources, experts to consult, and assign duties and research tasks to the team members. 7) Prepare and present your solution to the problem with supporting documentation which should include the problem statement, questions, data gathered, analysis of the data, support for solutions to the problem, recommendations based on data analysis, and conclusions based upon the information and activities you have conducted. 8) Review your team's performance. What did your team learn from this experience? What content was learned, what skills were developed, what attitudes were fostered?

Assignment: Working in teams of no more than four and using the Investigation Planning Guide, develop a PBL energy experience for your students tied to your grade level, subject(s) taught, and provide for incorporating the state and/or national standards for your discipline. The experience should feature inquiry learning, hands-on, direct experiences and should include a problem at the academic level that you choose. Your team will present your product on Friday, June 21, 2013, from 3:00 to 5:00 PM. Your ten-minute presentation could use technology, be a skit, involve your colleagues, involve Energy Academy Staff, involve student participants, etc. Be creative, innovative, and surprise us!

General References:

Next Generation Science Standards (2013). http://www8.nationalacademies.org

What is Problem-Based Learning? By De Gallow, University of California Irvine. http://www.pbl.uci.edu/whatispbl.html

http://online.sfsu.edu/rpurser/revised/pages/problem.htm

Educating Students for the 21st Century, smithsonian.com

National Assessment of Educational Progress, naep.org

Problem Based Learning, pbl-online.org

The New Activities Handbook for Energy Education, By Gerald H. Krockover and Alfred De Vito, 260 pages, catalog.socialstudies.com

Problem Based Learning References:

1. www.nebhe.org/programs-overview/professional-curriculum-development/about-stempbl/stem-pbl-overview/

STEM PBL Overview:

The STEM PBL Project is developing problem-based learning (PBL) instructional resources and providing professional development activities in STEM subjects with a focus on sustainable technologies. NEBHE's previous NSF/ATE funded projects focused on optics and photonics.

The current project goal is to increase the number of job-ready STEM workers by engaging high school and college students with challenging learning materials and innovative teaching methods.

Students are prepared for the real world by working in teams to solve an authentic technological workplace problem where multiple solutions are possible. The instructor facilitates and acts as consultant as students balance technology, budget and time constraints to devise and test a solution.

What is problem-based learning (PBL)?
Problem-based learning teaches a problem-solving model employing a cycle of problem analysis, independent research, brainstorming solutions, and testing solutions.

2. www.nebhe.org/programs-overview/professional-curriculum-development/about-stempbl/stem-pbl-resources/

Teachers' Resources:

STEM PBL Challenge Implementation Guide:
Download our new **PBL Challenge Implementation Guide**
STEM PBL Standards Alignment:
Download our new **National Science, Mathematics and Technological Literacy Standards**
STEM PBL Implementation Stories:
The **Implementation Stories**, organized by Challenge, provide details on how the STEM PBL Challenges were used by field-testing participants in their classrooms.

Challenge Partners & Collaborators

The STEM PBL project has developed a series of six multimedia industry-based Challenges designed to stimulate problem-based learning in the classroom. With a focus on sustainable technologies, the Challenge topics include solar and wind power, green chemistry sustainable agriculture, and energy efficient lighting. STEM PBL Challenge partners and project collaborators can be found below.

Beyond Benign, Green Chemistry Education, Wilmington, MA
Cape Cod Cranberry Growers' Association, Sustainable Agriculture, Carver, MA
FloDesign, Wind Power, Waltham, MA
Johnson & Johnson, Green Chemistry in Personal Care Products, Skillman, NJ
RSL Fiber Systems, Energy Efficient Lighting Systems, East Hartford, CT
SPG Solar, Solar Power, Novato, CA/Tucson, AZ
Sustainability Collaborative, Professional Alliance for Universal Sustainability, International
The Tookany/Takony Frankford Watershed Partnership, Watershed

Management, Philadelphia, PA

3. http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1349&context=ijpbl&sei-redir=1&referer=http%3A%2F%2Fwww.google.com%2Furl%3Fsa%3Dt%26rct%3Dj%26q%3Dresearch%2520about%2520pbl%2520in%2520secondary%2520schools%2520in%2520the%2520stem%2520disciplines%26source%3Dweb%26cd%3D3%26ved%3D0CD4QFjAC%26url%3Dhttp%253A%252F%252Fdocs.lib.purdue.edu%252Fcgi%252Fviewcontent.cgi%253Farticle%253D1349%2526context%253Dijpbl%26ei%3DquZ2UbaCPIzdqQHJl4HgCA%26usg%3DAFQjCNGNJgSI9AonMzqIU3VzfLbJgh4I7Q%26sig2%3D8-0YfBChHWfibi2wvpGUfg%26bvm%3Dbv.45580626%2Cd.aWM#search=%22research%20about%20pbl%20secondary%20schools%20stem%20disciplines%22

The PBL approach to STEM education has some inherent advantages over traditional discipline-based teaching and learning because it:

- fosters an understanding of connections among principles, concepts, and skills across discipline specific domains (Jordan, 1989; Nikitina & Mansilla, 2003);
- arouses students' curiosity and sparks their creative imagination and critical thinking (Capon & Kuhn, 2004);
- helps students to understand and experience the process of scientific inquiry (Biggs, 2003; Hmelo-Silver, 2004; Ramsey, Radford, & Deese, 1997; Stepien, Gallagher, & Workman, 1993);
- encourages collaborative problem-solving and interdependence in group work (Biggs, 2003; Pease & Kuhn, 2008; Ward & Lee, 2002);
- expands students' knowledge of mathematical and scientific knowledge (Engel, 1991; Tchudi & Lafer, 1996; Torp & Sage, 2002);
- advances active knowledge construction and retention through self-directed study (Dodds, 1997; Stepien & Gallagher, 1993; Ward & Lee, 2002);
- fosters connections among thinking, doing, and learning (Goodnough & Cashion, 2006);
- promotes student interest, participation, and increased attendance (Lieux & Duch, 1995); and
- develops students' ability to apply their knowledge (Boud & Feletti, 1997; Torp & Sage, 2002).

Furthermore, over-reliance on standardized tests and exams to measure students'knowledge limits the effective assessment of students' critical thinking and problem-solving skills (Gordon, Rogers, Comfort, Gavula, & McGee, 2001; Maxwell, Bellisimo, & Mergendoller, 2001; Meier, Hovde, & Meier, 1996). Unfamiliarity with suitable assessment techniques and the difficulty in developing appropriate assessment tools for process-oriented, problem- based tasks further exacerbates the problem (Tchudi & Lafer, 1996). Similarly, developing "self-monitoring guidelines"

and rubrics for engaging students in self-evaluation and reflection on the problem-solving process seems to be an important impediment to the assessment of PBL units (Ertmer et al., 2007; Gallagher, Sher, Stepien, & Workman, 1995).

The sources of this resistance can be traced to at least three external barriers: the structure of schools, the curriculum, and the way education is organized and evaluated at the state level. The resistance based on the structure of schools came from the perception on the part of teachers that working with colleagues in other subject specific areas would be difficult if not impossible given the constraints imposed by the compartmentalized system of teaching in the scientific disciplines and the lack of adequate team preparation time (Ertmer et al., 2009; Ertmer et al., 2007; Park & Ertmer, 2008; Ward & Lee, 2002). There appeared to be a disconnect between the State's desire to create STEM academies and the study participants'current teaching environments. Although teachers are expected to integrate STEM disciplines, academic schedules in schools are not coordinated to create interdisciplinary connections across different STEM subjects.

4. www.bsd405.org/news-events/news/investing-in-innovation-stem-pbl.aspx

How is SHS preparing students for 21st century careers?

Working with mentors is also an important component of PBL, which is why eight students in Katie Piper's U.S. Government class are wearing judges' robes as classmates argue for and against the use of race in college admissions policies. The black robe-clad students form a mock Supreme Court, with mentor and practicing attorney Kate McMahan serving as Chief Justice. McMahan volunteers in Piper's classroom every Thursday through the district's VIBES program.

5. 21centuryedtech.wordpress.com/2011/10/06/connecting-pbl-and-stem-40-free-engaging-resources-to-use-in-the-classroom/

Connecting PBL and STEM... 40 Free Engaging Resources To Use In The Classroom

6. www.edtech.vt.edu/edtech/id/models/powerpoint/pbl.pdf

Basic Steps of PBL

- students divided into groups
- real problem is presented and discussed
- students identify what is known, what information is needed, and what strategies or next steps to take
    - individuals research different issues, gather resources

- resources evaluated in group
- cycle repeats until students feel the problem has been framed adequately and all issues have been addressed
- possible actions, recommendations, solutions, or hypotheses are generated
    - tutor groups conduct peer/self- assessments

6. http://wvde.state.wv.us/teach21/SecondaryRubrics.html

7. Secondary Rubrics

8.
9. **Collaboration Rubric**
10. **Critical Thinking Checklist**
11. **Digital Storytelling Rubric**
12. **Group Evaluation Rubric**
13. **Interview Rubric**
14. **Map Rubric**
15. **Modified Writing Rubric Grade 6**
16. **Oral Communication Rubric**
17. **Oral Presentation Rubric**
18. **Peer Evaluation Rubric 1**
19. **Peer Evaluation Rubric 2**
20. **PowerPoint Rubric**
21. **Presentation Rubric**
22. **Project Presentation Rubric**
23. **Teacher Observation Rubric**
24. **Video Production Rubric**
25. **WV Writing Rubric Grade 6**

26. WV Writing Rubric Grade 7
27. WV Writing Rubric Grade 8
28. WV Writing Rubric Grade 9
29. WV Writing Rubric Grade 10
30. WV Writing Rubric Grade 11

31. http://www.laney.edu/wp/environmental_control_tech/ect-nsf-initiative/ect-nsf-labs/pbl/worksheets/

PBL Worksheets

Problem Based Learning (PBL): Worksheets and Handouts

The Laney ECT team uses various PBL worksheets to provide basic PBL methodology, key PBL overview elements, and a checklist to help guide and support the instructors and students through the PBL process. The Problem Based Learning (PBL) worksheets and handouts for each section are available for download in PDF format under each description.

Problem Based Learning (PBL) Worksheets and Handouts

Problem Based Learning: Key Points Problem Based Learning: Overview Problem Based Learning: "10 Step Process" Student Checklist Problem Based Learning: Need to Know Worksheet Problem Based Learning: Performance Indicator Worksheet Problem Based Learning: Rubric Worksheet

32. http://www.vcu.edu/cte/resources/nfrg/11_07_problem_based_learning.htm

Self and Peer Evaluation: Reflecting on both one's learning and group experiences is an integral component of the PBL process. While reflection on content and process occurs throughout the PBL cycle, summative reflection on group member contributions enables students to develop their abilities to assess their own performance as well as that of their peers. Moreover, peer evaluations which

affect one's grade may provide additional incentives for students to be active participants in the collaborative problem-solving process. Typically, students are asked to rate group members' performance on specific criteria which are identified on the peer evaluation form. A student is given a summary of the comments made by group members; however, the evaluators' names may be removed.

33. http://stem.discoveryeducation.com/index.cfm?event=showBlogPost&c=35&postid=864

Part 2: Connecting PBL and STEM... 40 Free Engaging Resources To Use In The Classroom

34. http://www.nextgenscience.org/

The Next Generation of Science Standards promise to help students understand why is it that we have to know science and help them use scientific learning to develop critical thinking skills-which may be applied throughout their lives, no matter the topic. Today, students see science as simply a list of facts and ideas that they are expected to memorize. In contrast to that approach education researchers have learned, particularly in the last 15 to 20 years, that if we cover fewer ideas, but go into more depth, students come away with a much richer understanding. Unlike previous standards, where you have separation of inquiry and ideas that students should know, in the NGSS they are now together," said Joseph S. Krajcik, Professor of Science Education in the College of Education at Michigan State University and a member of the writing team.

Standards are printed on pages labeled "B and C"

35. **https://nordic.tie.org/article/37/energy-and-environmental-technology**

Released By: Business Sweden
Release Date: 03/26/2013
Sweden holds a strong position within energy and environmental technology. In many areas the national requirements are even stricter than the existing legislation, such as within the EU. At Business Sweden we see a number of

small and medium size enterprises with business potential.

RENEWABLE ENERGY
Sweden fully embraces green technologies and the
area's major business potential. A focus on energy efficiency and alternative energy resources is evident wherever you look. This is partly explained by sophisticated industrial demand and rapid technology adoption. Swedish municipalities are also important in driving developments. Several hundred biogas plants provide electricity, heat and fuel to Swedish cities, and district heating/cooling systems reach large shares of the population. The goal is to reach a 50 percent share of renewable energy by 2020.

36.

http://www.eeweek.org/resources/energycurricula.htm

School Power...Naturally *School Power...Naturally* is part of the *Power...Naturally* program developed by the New York State Energy Research and Development Authority. The website offers numerous lessons and activities on renewable energy at all grades levels, which can be downloaded as PDFs or Word documents.The lessons are correlated to New York State Curriculum Standards for Math, Science and Tecnology.

U.S. Department of Energy Energy Efficiency & Renewable Energy K-12 Lesson Plans & Activities The U.S. Department of Energy's Energy Efficiency & Renewable Energy website has a searchable database of creative lesson plans, projects and other activities for grades K-12 on energy-related topics. Each lesson plan includes a short summary that identifies how to introduce it into the curriculum, time required, materials needed and national standards that will be met. Search for lesson plans by topic and grade level.

- See more at: http://www.eeweek.org/resources/energycurricula.htm#sthash.n6W4I4IL.dpuf

36. http://nationsreportcard.gov/science_2011/sample_quest.asp

37. Water evaporates and falls back to Earth as rain or snow. What is the primary energy source that drives this cycle?

38. A. The wind

39. B. The Sun **CORRECT**

40. C. Air pressure

41. D. Ocean currents

42. Household appliances convert electricity into one or more different forms of energy. An electric fan can best be described as converting electricity into
. heat energy only
. heat energy and sound energy only
. heat energy, sound energy, and mechanical energy only **CORRECT**
heat energy, sound energy, mechanical energy, and chemical energy

43. SAMPLE QUESTION ON PRINTOUT LABELED "D"

44. When a cork is added to a glass of water, the cork floats at the top of the water instead of sinking to the bottom of the glass. Which statement helps explain why this happens?
. The cork absorbs the water, so it cannot sink.
. The water is exerting an upward force on the cork. **CORRECT**
. The water stops the force of gravity from acting on the cork.
The density of the cork is greater than that of the water.

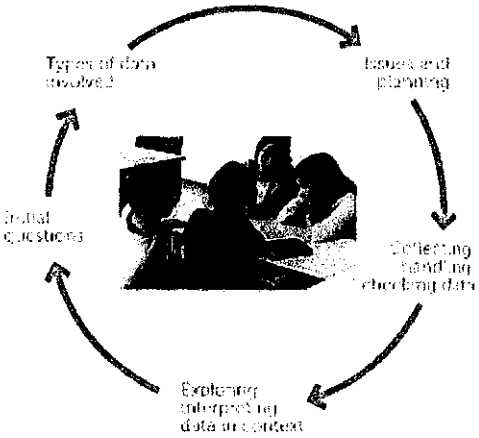
PBL Planning Guide Completion <u>Schedule With Due Dates</u>

Your

PBL

Planning

Guide



PBL Investigation Planning Guide Completion Schedule

Steps 1 and 2: Due Monday, June 17, 7:00 PM:

Group Name and email addresses:

Group Members and assignment for each member:

Energy Problem to be Investigated:

State what you know about the energy problem:

State what you need to know about the energy problem:

Steps 3, 4, 5 and 6: Due Tuesday, June 18, 7:00 PM:

Write an energy problem statement to investigate that your entire group agrees upon.

List possible solutions and order them from strongest to weakest.

Decide which solution is most likely to succeed.

Prepare a timeline and list actions to be taken.

List what your team needs to know to solve the problem, research needed, possible resources, experts to consult, students and teachers to consult and assign duties for research tasks.

Step 7: Due Thursday, June 20, 7:00 PM

Prepare your team's ten-minute presentation.

Step 8: Due Friday, June 21, 3:00 PM:

Present your team's ten-minute presentation to the Energy Academy student and teacher participants

Review your team's performance. What content was learned, what skills were developed, and what attitudes were fostered?

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What Is Your Teaching Profile?
?

Multiple Intelligences Survey

Teaching Style Inventory

Inquiry Analysis Tool

Multiple Intelligences Survey

http://surfaquarium.com/MI/inventory.htm

Part I

Complete each section by placing a "1" next to each statement you feel accurately describes you. If you do not identify with a statement, leave the space provided blank. Then total the column in each section.

Section 1

_____ I enjoy categorizing things by common traits
_____ Ecological issues are important to me
_____ Classification helps me make sense of new data
_____ I enjoy working in a garden
_____ I believe preserving our National Parks is important
_____ Putting things in hierarchies makes sense to me
_____ Animals are important in my life
_____ My home has a recycling system in place
_____ I enjoy studying biology, botany and/or zoology
_____ I pick up on subtle differences in meaning

_____ TOTAL for Section 1

Section 2

_____ I easily pick up on patterns
_____ I focus in on noise and sounds
_____ Moving to a beat is easy for me
_____ I enjoy making music
_____ I respond to the cadence of poetry
_____ I remember things by putting them in a rhyme
_____ Concentration is difficult for me if there is background noise
_____ Listening to sounds in nature can be very relaxing
_____ Musicals are more engagingto me than dramatic plays
_____ Remembering song lyrics is easy for me

_____ TOTAL for Section 2

Section 3

_____ I am known for being neat and orderly
_____ Step-by-step directions are a big help
_____ Problem solving comes easily to me
_____ I get easily frustrated with disorganized people
_____ I can complete calculations quickly in my head
_____ Logic puzzles are fun
_____ I can't begin an assignment until I have all my "ducks in a row"
_____ Structure is a good thing
_____ I enjoy troubleshooting something that isn't working properly
_____ Things have to make sense to me or I am dissatisfied

_____ TOTAL for Section 3

Section 4

_____ It is important to see my role in the "big picture" of things
_____ I enjoy discussing questions about life
_____ Religion is important to me
_____ I enjoy viewing art work
_____ Relaxation and meditation exercises are rewarding to me
_____ I like traveling to visit inspiring places
_____ I enjoy reading philosophers
_____ Learning new things is easier when I see their real world application
_____ I wonder if there are other forms of intelligent life in the universe
_____ It is important for me to feel connected to people, ideas and beliefs

_____ TOTAL for Section 4

Section 5

_____ I learn best interacting with others
_____ I enjoy informal chat and serious discussion
_____ The more the merrier
_____ I often serve as a leader among peers and colleagues
_____ I value relationships more than ideas or accomplishments
_____ Study groups are very productive for me
_____ I am a "team player"
_____ Friends are important to me
_____ I belong to more than three clubs or organizations
_____ I dislike working alone

_____ TOTAL for Section 5

Section 6

_____ I learn by doing
_____ I enjoy making things with my hands
_____ Sports are a part of my life
_____ I use gestures and non-verbal cues when I communicate
_____ Demonstrating is better than explaining
_____ I love to dance
_____ I like working with tools
_____ Inactivity can make me more tired than being very busy
_____ Hands-on activities are fun
_____ I live an active lifestyle

_____ TOTAL for Section 6

Section 7

_____ Foreign languages interest me
_____ I enjoy reading books, magazines and web sites
_____ I keep a journal
_____ Word puzzles like crosswords or jumbles are enjoyable
_____ Taking notes helps me remember and understand
_____ I faithfully contact friends through letters and/or e-mail
_____ It is easy for me to explain my ideas to others
_____ I write for pleasure
_____ Puns, anagrams and spoonerisms are fun
_____ I enjoy public speaking and participating in debates

_____ TOTAL for Section 7

Section 8

_____ My attitude effects how I learn
_____ I like to be involved in causes that help others
_____ I am keenly aware of my moral beliefs
_____ I learn best when I have an emotional attachment to the subject
_____ Fairness is important to me
_____ Social justice issues interest me
_____ Working alone can be just as productive as working in a group
_____ I need to know why I should do something before I agree to do it
_____ When I believe in something I give more effort towards it
_____ I am willing to protest or sign a petition to right a wrong

_____ TOTAL for Section 8

3D

Section 9

_____ I can visualize ideas in my mind
_____ Rearranging a room and redecorating are fun for me
_____ I enjoy creating my own works of art
_____ I remember better using graphic organizers
_____ I enjoy all kinds of entertainment media
_____ Charts, graphs and tables help me interpret data
_____ A music video can make me more interested in a song
_____ I can recall things as mental pictures
_____ I am good at reading maps and blueprints
_____ Three dimensional puzzles are fun

_____ TOTAL for Section 9

Part II

Now carry forward your total from each section and multiply by 10 below:

Section	Total Forward	Multiply	Score
1		X10	
2		X10	
3		X10	
4		X10	
5		X10	
6		X10	
7		X10	
8		X10	
9		X10	

3E

Part III

Now plot your scores on the bar graph provided:

100									
90									
80									
70									
60									
50									
40									
30									
20									
10									
0	Sec 1	Sec 2	Sec 3	Sec 4	Sec 5	Sec 6	Sec 7	Sec 8	Sec 9

Part IV

Now determine your intelligence profile!

Key:

Section 1 – This reflects your Naturalist strength
Section 2 – This suggests your Musical strength
Section 3 – This indicates your Logical strength
Section 4 – This illustrates your Existential strength
Section 5 – This shows your Interpersonal strength
Section 6 – This tells your Kinesthetic strength
Section 7 – This indicates your Verbal strength
Section 8 – This reflects your Intrapersonal strength
Section 9 – This suggests your Visual strength

Remember:

- Everyone has all the intelligences!
- You can strengthen an intelligence!
- This inventory is meant as a snapshot in time – it can change!
- M.I. is meant to empower, not label people!

TEACHING STYLE INVENTORY

Anthony F. Gregory and Helen B. Ward

This inventory is designed to assess your methods of teaching. As you take the inventory, consider each item in relation to one of your subject areas and determine which rating applies. Use a semester for your time reference in considering the percentages. Encircle the appropriate rating response.

The aim of the inventory is to describe your teaching style preferences, not evaluate them.

Subject selected:_____

Statement	Encircle Response			
I. USE THE FOLLOWING IN MY CLASS:	Usually	Often	Occasion-ally	Rarely/ Never
1. Activity books or lab manuals	(51-100%)	(26-50%)	(6-25%)	(0-5%)
3. Instructional technology	U	Of	Oc	R/N
2. Video tapes and/or DVD's	U	Of	Oc	R/N
1. Lectures accompanied with overhead transparencies, drawings, or models; demonstration teaching	U	Of	Oc	R/N
4. Games or simulations	U	Of	Oc	R/N
3. Audio tapes and/or iPods	U	Of	Oc	R/N
2. Group discussions among students	U	Of	Oc	R/N
4. Independent study projects	U	Of	Oc	R/N
2. Lecture w/ discussion of material	U	Of	Oc	R/N
3. Extensive textbook reading assignments	U	Of	Oc	R/N
1. Hands-on materials (paint, frogs, plastic or wood models, apparatus, etc.)	U	Of	Oc	R/N

Statement	Encircle Response			
I. USE THE FOLLOWING IN MY CLASS:	Usually	Often	Occasion-ally	Rarely/ Never
4. Occasional reading assignments	(51-100%)	(26-50%)	(6-25%)	(0-5%)
2. Television	U	Of	Oc	R/N
1. Field trips	U	Of	Oc	R/N
4. Brief mini-lectures to introduce	U	Of	Oc	R/N
2. Short reading assignments which are springboards for class activities	U	Of	Oc	R/N
1. Programmed instruction or computer-assisted instruction	U	Of	Oc	R/N
3. PowerPoint®	U	Of	Oc	R/N
4. Problem solving activities	U	Of	Oc	R/N
3. Lecture with few or no visual aids	U	Of	Oc	R/N
TO SUCCEED IN MY CLASS, STUDENTS MUST:				
2. Listen to, learn from, and respond to their fellow students	U	Of	Oc	R/N
4. Frame hypotheses; develop alterna-tive solutions and test them	U	Of	Oc	R/N
1. Follow step-by-step directions exactly	U	Of	Oc	R/N
3. Be able and willing to read large amounts of material	U	Of	Oc	R/N
4. Be able to solve problems with limited information or data provided	U	Of	Oc	R/N

Statement	Encircle Response			
I. TO SUCCEED IN MY CLASS, STUDENTS MUST:	Usually	Often	Occasion-ally	Rarely/ Never
1. Use various drill techniques to practice what they have learned	(51-100%)	(26-50%)	(6-25%)	(0-5%)
3. Be able to conceptualize ideas and convey them either orally or in writing	U	Of	Oc	R/N
2. Be aware of color, sounds, and moods in their environment	U	Of	Oc	R/N
1. Show all steps they use in their work	U	Of	Oc	R/N
4. Experiment with ideas and materials through application	U	Of	Oc	R/N
2. Observe body language; listen for intonation, and reflect upon these in connection with the messages being given	U	Of	Oc	R/N
3. Be able to concentrate on an idea without being distracted by environmental activities or inner feelings	U	Of	Oc	R/N
3. Take notes, draw charts, and make outlines	U	Of	Oc	R/N
1. Respond to questions whose correct answers are available directly from textual materials	U	Of	Oc	R/N
4. Plan projects they will work on by themselves	U	Of	Oc	R/N
2. Be able to gather ideas from discussion groups or rap sessions	U	Of	Oc	R/N

SCORE SHEET FOR TEACHING STYLE INVENTORY

Find all statements numbered 1 (there are 9 items numbered 1) PTS.

How many of them did you indicate as Usually? _____ x 4 = _____
How many of them did you indicate as Often? _____ x 2 = _____
How many of them did you indicate as Occasionally? _____ x 1 = _____
How many of them did you indicate as Rarely/Never? _____ x 0 = _____

Total number of points for #1 _____

Find all statements numbered 2 (there are 9 items numbered 2) PTS.

How many of them did you indicate as Usually? _____ x 4 = _____
How many of them did you indicate as Often? _____ x 2 = _____
How many of them did you indicate as Occasionally? _____ x 1 = _____
How many of them did you indicate as Rarely/Never? _____ x 0 = _____

Total number of points for #2 _____

Find all statements numbered 3 (there are 9 items numbered 3) PTS.

How many of them did you indicate as Usually? _____ x 4 = _____
How many of them did you indicate as Often? _____ x 2 = _____
How many of them did you indicate as Occasionally? _____ x 1 = _____
How many of them did you indicate as Rarely/Never? _____ x 0 = _____

Total number of points for #3 _____

Find all statements numbered 4 (there are 9 items numbered 4) PTS.

How many of them did you indicate as Usually? _____ x 4 = _____
How many of them did you indicate as Often? _____ x 2 = _____
How many of them did you indicate as Occasionally? _____ x 1 = _____
How many of them did you indicate as Rarely/Never? _____ x 0 = _____

Total number of points for #4 _____

BOX SCORE

Statement #1-Concrete Experience- No. of points _____
Statement #2-Reflective Observation- No. of points _____
Statement #3-Abstract Conceptualization No. of points _____
Statement #4- Active Experimentation No. of points _____

TEACHING TECHNIQUES

For CE Use:

1. Activity books or lab manuals
2. Lectures accompanied with overhead transparencies, drawings, or models; demonstration teaching
3. Hands-on materials (paints, frogs, plastic or wood models, apparatus, etc.)
4. Field trips
5. Programmed instruction or computer-assisted instruction

And Expect Students To:

1. Follow step-by-step directions exactly
2. Use various drill techniques to practice what they have learned
3. Give correct answers available

For RO Use:

1. Video tapes and/or DVD's
2. Group discussions among students
3. Lecture with discussion of material presented
4. Television
5. Short reading assignments which are springboards for class activities

And Expect Students To:

1. Listen to, learn from, and respond to their fellow students
2. Be aware of color, sounds, and mood in their environment
3. Observe body language, listen for intonation and reflect upon them in connection with the message being given

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For AC Use:

1. Instructional technology
2. Audio tapes and/or iPods
3. Extensive textbook reading and assignments
4. PowerPoint
5. Lecture

And Expect Students To:

1. Be able and willing to read large amounts of material
2. Be able to conceptualize ideas and convey them either orally or in writing
3. Be able to concentrate on an idea without being distracted by environmental activities or inner feelings

For AE Use:

1. Games or simulations
2. Independent study projects
3. Optional reading assignments
4. Brief mini-lectures
5. Problem solving activities

And Expect Students To:

1. Frame hypotheses, develop alternative solutions and test them
2. Be able to solve problems with limited information or data provided
3. Experiment with ideas and materials through application

TEACHING APPROACHES

I. MULTIPLE-APPROACH TECHNIQUE (used to meet the range of learner's preferences)

STEP ONE: Identify the Objective

STEP TWO: Offer teaching technique options for CE, RO, AC, AND AE

II. SINGLE-APPROACH TECHNIQUE (used to stretch styles)

STEP ONE: Identify the Objective

STEP TWO: Select a particular teaching technique

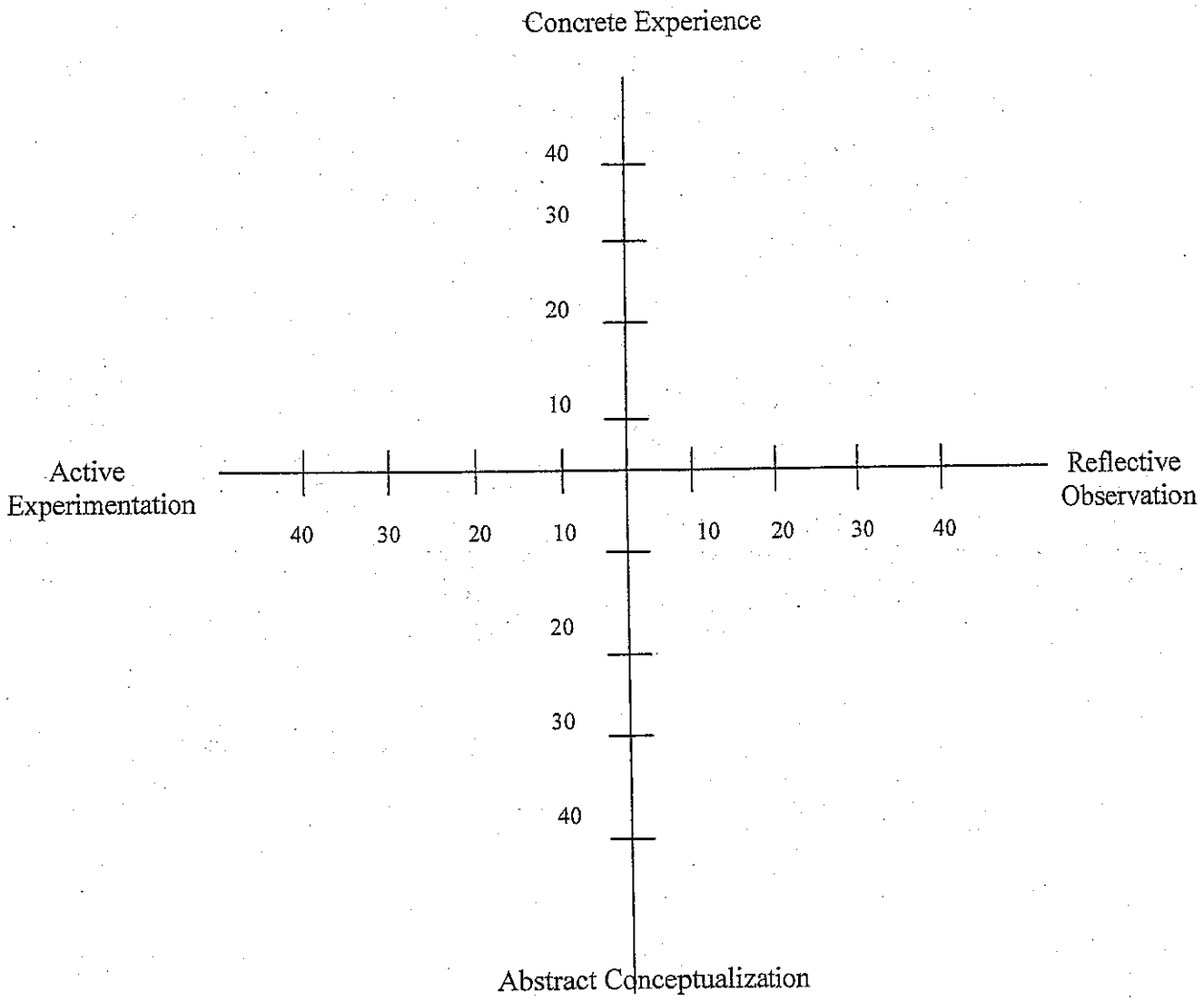
STEP THREE: Help students develop their abilities to learn via the selected technique

III. VARIETY APPROACH TECHNIQUE (used when learner's preferences are unknown) or not attended to

STEP ONE: Identify the objective

STEP TWO: Utilize different techniques from the various categories (CE, RO, AC, and AE) throughout a period or day

TEACHING STYLE PROFILE



Appendix A

Inquiry Analysis Tool

Teacher: _____ Level: _____ School: _____ Date: _____

Activity: _____ Grade: _____

Component	5	4	3	2	1
Teacher as a Guide	*Often guides students by listening, observing, and questioning. *Responses are primarily goal-oriented, emerge from students' responses or work, and are used to guide students' investigation.	*Frequently guides students by listening, observing, and questioning. *Responses frequently emerge from students' responses or work and are used to guide the investigation. Goal-oriented statements may occur.	*Occasionally guides students by listening, observing, and questioning. *Responses primarily teacher directed, often clarify or direct students' ideas. Goal-oriented and guiding statements may occur.	*Teacher-student interaction is primarily teacher initiated. *Responses are primarily about the correctness of students' ideas, knowledge or comprehension questions, or directive statements. Goal-oriented and guiding statements may occur.	*Teacher-student interaction is predominately low-level questioning and/or directive statements.
Assessment	*Integrated throughout the lesson. *Takes on multiple forms. *Elicits students' prior knowledge. *Provides summative, formative, educative, and evaluative feedback.	*Different forms occur frequently throughout the lesson. *Provides information that may be summative, formative, educative, or evaluative.	*Occurs periodically throughout the lesson. *Primarily captures students' understanding, students' abilities, and/or students' knowledge.	*Occasional, occurs in one or limited forms, and/or primarily represents students' knowledge.	*Primarily one form that has an emphasis at the conclusion of the lesson. *Prior knowledge not considered.
Cooperative Learning	*Integrated throughout the lesson. *Students work in groups with roles (defined or undefined). *There is positive interdependence, individual accountability, interpersonal and small group skills, and group processing throughout.	*Frequently integrated into the lesson. *A majority of cooperative learning elements are consistently evident. OR *All aspects of cooperative learning are utilized frequently.	*Partially integrated into the lesson. *Some elements of cooperative learning are present. OR *Aspects of cooperative learning are utilized periodically.	*Occasionally integrated into the lesson. *A few elements of cooperative learning are apparent or utilized by the teacher.	*Throughout a majority of the lesson students are working independently or working independently in groups.

More ---------- Orientation toward inquiry ----------Less

M = Materials: texts, manuals, written plans, worksheets, etc. A = Action observed in experience I = Interview

Inquiry Analysis Tool

Component	5	4	3	2	1
Scientifically oriented questions	*Student groups generate and refine investigatible questions. *Questions address a concept. *Identified questions directly relate to the experience. *Selected question is new knowledge and of interest to the student group.	*Student groups generate an investigatible question. *Most questions are refined. *Questions address a concept. *Most questions relate to the experience. *Selected question is new knowledge and of interest to the student group.	*Student groups identify an investigatible question: teacher or group suggestions. *Few questions are refined, address a concept, and/or relate to the experience. *Selected question may or may not be new knowledge or of interest to the student group.	*Most student groups identify an investigatible question from teacher suggestions. *Some questions are refined, address a concept, and/or relate to the experience. *Selected question may or may not be new knowledge or of interest to the student group.	*Questions are provided by the teacher, materials or other source. *Questions pertain to skill acquisition or print research.
Designing and Conducting a Scientific Investigation	*Students developed investigation aligns with selected question. *Procedures are developed by the students, are thorough yet subject to revision. *Appropriate tools and techniques are specified by the students for thorough data collection.	*Student developed investigations frequently aligns with selected questions. *Procedures are developed by students and most are thorough or comprehensive. *Appropriate tools and techniques are specified by the students or teacher for collecting most of the data.	*Student conducts suggested investigation. *Most procedures align with the identified question. *Most procedures and data collection schemes are complete. *Tools and techniques are specified for the data collection. *The data collection scheme collects most of the data that is relevant to the investigation.	*Student conducts suggested investigation. *Most investigation procedures align with the identified question. *Tools and techniques are specified for the data collection. *Procedures and data collection schemes are preliminary and/or are unrevised.	*Student is given an investigative plan to conduct. *Procedures and data collection schemes are complete as a result of teacher direction. *Without teacher intervention the data collection schemes are incomplete.
Evidence as a priority	*Students determine what constitutes evidence. *Students are attentive to collecting accurate evidence.	*Students determine what constitutes evidence. *Students are attentive to collecting evidence.	*Most students determine what constitutes evidence. *Most students attentive to collecting evidence.	*Some students determine what constitutes evidence. *Some students attentive to collecting evidence.	*Teacher indicates acceptable evidence.

More ---------- Orientation toward inquiry ---------- Less

M = Materials: texts, manuals, written plans, worksheets, etc. A = Action observed in experience I = Interview

Inquiry Analysis Tool

Component	5	4	3	2	1
Analyzing data	*Students examine data in different ways. *Students create appropriate graphical representations.	*Most students examine data in different ways. *Most students create appropriate graphical representations.	*Most students examine data in different ways. *Graphical representations may or may not be appropriate.	*Student is given data and asked how to analyze. *Most students make basic analyses. *Graphical representations may or may not be accurate.	*Student is given data and told how to analyze.
Formulating explanations	*Students develop explanations from data. *Students think critically and logically about the relationship of evidence and explanation. *Students independently examine other resources and form links to explanations.	*Most students independently develop explanations from data. *Most students think critically and logically about the relationship of evidence and explanation. *Most students independently examine other resources and form links to explanation.	*Some students independently develop explanations from the data. *Some students think critically and logically about the relationship of evidence and explanation. *Some students independently examine resources and form links to explanation.	*Some students may or may not be aware of the relationship between evidence and explanation. *Possible relationships are provided.	*Relationships are provided.
Justifying explanations	*Students form a reasonable and logical argument to support explanations. *Students use evidence to support explanation.	*Most students form a reasonable and logical argument to support explanations. *Most students use evidence to support explanation.	*Some students form a reasonable and logical argument to support explanations. *Some students use evidence to support explanation.	*Student is guided in forming an argument to support explanations.	*Student is provided an argument to support explanations.

More ---------- Orientation toward inquiry ----------Less

M = Materials: texts, manuals, written plans, worksheets, etc. A = Action observed in experience I = Interview

Inquiry Analysis Tool

Component	5	4	3	2	1
Communication	*Students communicate the process of their investigation. *Students explain their method of analysis. *Students logically discuss their argument. *Students identify limitations of their investigation. *Students generate new questions for further investigation from their analysis. *Students respond to questions or comments. *Students generate questions.	*Most students communicate the process of their investigation. *Most students explain their method of analysis. *Most students discuss their analysis and conclusions. *Most students identify limitations of their investigation. *Most students generate new related questions. *Most students respond to questions/comments. *Most students generate questions.	*Most students communicate the process of the investigation. *Basic analysis is presented. *Basic limitations are presented. *Responses to questions and comments are simplistic. *Few students generate related questions. *Some students generate questions.	*Most students communicate about the basic and fundamental processes used in the investigation. *Limitations may or may not be identified. *Responses to questions and comments may or may not occur.	*Most students present limited information about the process of their investigation.
Mathematics	*Students use math to ask questions *Students use math to gather, organize, and present data *Students use math to structure convincing explanations	*Most students use math to ask questions *Most students use math to gather, organize, and present data *Most students use math to structure explanations	*Some students use math to ask questions *Some students use math to gather, organize, and present data *Some students use math to structure explanations	*Few students use math to ask questions *Few students use math to gather, organize, and present data *Few students use math to structure explanations	*Math was not used

More ---------- Orientation toward inquiry ----------Les

M = Materials: texts, manuals, written plans, worksheets, etc. A = Action observed in experience I = Interview

Obser

Krockover, Gerald H

From: JERRY-P-BECKER-USA-L List [JERRY-P-BECKER-USA-L@LISTSERV.SIU.EDU] on behalf of Jerry Becker [jbecker@SIU.EDU]
Sent: Friday, April 26, 2013 4:38 PM
To: JERRY-P-BECKER-USA-L@LISTSERV.SIU.EDU
Subject: 8 Characteristics Of A Great Teacher

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From TeachThought.com, Friday, April 26, 2013. See http://www.teachthought.com/teaching/8-characteristics-of-a-great-teacher/

****

8 Characteristics Of A Great Teacher

What makes a teacher strong?

What differentiates the best from the rest? There's no shortage of bodies (some dramatically misguided) attempting to solve this riddle. The answers are nebulous at best. Below is a list of traits, some of which may be familiar but many of which will never show up on any sort of performance review. Check them out and see what you think.

1. They Demonstrate Confidence

Confidence while teaching can mean any number of things, it can range from having confidence in your knowledge of the material being learned to having confidence that your teaching acumen is second to none. Though these two (and many other) "confidences" are important the most critical confidence a teacher can have is much more general, and tougher to describe than that.

It's the confidence that you know you're in the right spot doing what you want to be doing and that no matter what transpires, having that time to spend with those young learners is going to be beneficial both for them and for yourself. It's clear to students when teachers exude this feeling. Working in schools is difficult and stressful, and also immensely rewarding. But if you're not confident that you're in the right place when you're teachingŠyou're probably not.

2. They Have Life Experience

Having some life experience outside the classroom and outside the realm of education is invaluable for putting learning into context and keeping school activities in perspective. Teachers who have travelled, worked in other fields, played high level sports or enjoyed any number of other life experiences bring to the profession outlooks other than "teacher". From understanding the critical importance of collaboration and teamwork, to being able to answer that ageless senior math question "when are we going to use this?", educators who have spent significant time and energy on alternate pursuits come to the profession with a deep understanding of where school fits into the bigger picture of life.

3. They Understand Each Student's Motivation

Just as each student has a different set of interests, every student will have a correspondingly different set of motivators. Many (or most) students will be able to reconcile their own outlook and ambitions with what's happening in the class and take motivation from that relationship. Unfortunately some students will rely simply on external motivators, but worse, we've all run into students who really can't find a relationship between what makes them tick and what's happening in the classroom around them.

These students run the risk of disengaging altogether. This is where the master teacher knows each of her

students and helps them to contextualize the work they're doing to allow the student to make a connection with something in his realm of interest. Teachers who can't help students make this connection need to rethink what's going on. After all, what IS the point of work in which a student finds no interest and for which he can make no connection?
woodleywonderworks54

4. They're People, Not Heroes.

Yes, all teachers are heroes. Now let's move beyond the platitude to what this really means. Some teachers still have trouble showing any sort of vulnerability of fallibility. These teachers will expend immense amounts of energy hiding the fact they're frustrated at something, that they're upset or perhaps even angry. Why? Other teachers get tied into logical knots to avoid admitting "I have no idea what the answer to your question is." But teachers who genuinely connect with students are the ones who aren't afraid to show emotions in class, who can admit that they aren't in fact the repository of all knowledge.

Of course nobody want to be a wallowing, blubbering mess in class, but what better way to teach empathy than to give the students someone to empathize with when we're having a bad day? What better way to foster collaboration and to teach that it's okay not to know something than to say "I don't know, let's find that out!"?

5. They're Technologically Capable

Let's not belabour this point, after all, plenty of ink (or pixels as the case may be!) has already been spilled on this topic. As time passes, the statement "But I'm not very good with _____."(fill in the blank with any number of technological devices) is sounding ever more like "But I'm not very good with a telephone."

The only time the sentiment above is acceptable is if it's followed immediately by "Šbut I'm very willing to learn!" After all, we wouldn't accept such weak rationalizations from students regarding their work. In 2013, as a profession, we lose credibility every time we allow excuses like this to go unchallenged. Enough said.

6. They Model Risk Taking

We encourage our students to be risk takers, we'd all like to be risk takers, but let's be honest, the nature of the beast is that many teachers are not naturally risk takers. This point goes hand in hand with showing vulnerability, the teacher who's willing to go out on a limb, to try something new, to be "wacky" in the name of pedagogy earns the respect of students, even if the snickers seem to say something different.

No matter the success or failure of the risk taken, the experience will certainly be memorable for the kids in that class, and isn't that what we're aiming for? After all, as the old adage goes, there's no such thing as bad publicity.

7. They Focus On Important Stuff

Whether it's worrying about who's late to class, collecting every little piece of work in order to "gather marks" or spending too much time lecturing to the class in order to "cover the material", there's no shortage of ways to distract teachers from what's important. Strong teachers know that things like chronic tardiness or skipping class are usually symptoms of larger issues and as such, spending precious time and energy trying to "fix" the issue almost never works. That's what administrators and counselors are for.

They also understand that efficient and effective assessment means eliminating busy work while giving targeted, meaningful feedback and that engaging the students, connecting the material to their interests and passions, is the surest way to maximize learning. There's plenty of minutiae and enough CYA (Cover YourŠ) in education to easily get sidetracked, strong teachers keep their focus on what's important.

8. They Don't Worry Too Much About What Administrators Think

This trait is tied in with many of the others listed above. Strong teachers do their job without worrying too much

about "what the principal will think". They'll take risks, their classes may be noisy, or messy, or both. Their activities may end up breaking something (usually the rules) in order to spark excitement or engagement.

They understand that learning is not a neat and tidy activity and that adhering too closely to rules and routines can drain from students the natural curiosity, spontaneity and passion that they bring to school. Worrying about what the boss may think can be draining and restrictive in any job, teaching is no exception.

In fact, the best teachers live by the code "It's easier to get forgiveness than permission."

PHOTO SIDEBAR:

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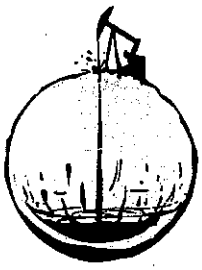
Sample PBL Energy Lesson Plan

Carbon Footprint: Climate Change



There is a lot in the media about global warming, carbon foot prints, and climate change. It's time for our world to "Go Green!" but what does is all mean? How does it all connect?

Simple truth, our world's climate is changing. Like in a green house solar energy comes in but gets trapped inside. What is trapping it you may ask? (Good question!) Greenhouse gases, mainly our friend CO2. CO2 (carbon dioxide) is released into our atmosphere in many ways. Ror example, when you exhale, and when we burn fuels to create the electricity we need to power our iPods, televisions, vehicles and so on. CO2 is not an evil villain; it's a necessary factor in life. It's what plants require and in exchange we get the oxygen we need to live. In a perfect world, the exchange of CO2 would be an equal balancing act, yet in reality our way of life exceeds our planets ability to use it. As we continue to add excess CO2 emissions, it goes up into the atmosphere forming a thicker layer as time goes on.

In turn we leave our own carbon footprint on our world through our use of our lap tops, cars, cell phones and other gadgets. The global warming we hear about is the increased temperature near the Earth's surface. This global dilemma will cause a chain reaction of events in our world, although the exact repercussions are unknown.

1. What are things that would make your home more energy efficient?

2. Do you think an engineering school like Purdue would be energy efficient? Why or why not?

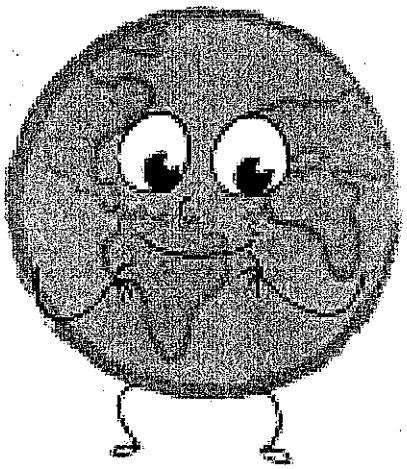
3. In your group go to a given building on campus, what are ways to identify energy efficiency?

4. What building did you investigate? What year was it built?

5. What investigations did you conduct?

6. What were your findings?

7. What changes could be made to become more energy efficient?



Carbon Footprint: One Step at a Time

Standards:

SS.3.3.7 Use a variety of information resources to identify local environmental issues and examine the ways that people have tried to solve these problems.

SC.3.5 STANDARD: Students apply mathematics in scientific contexts.

SC.6.2 STANDARD: Students use computers and other tools to collect information, calculate, and analyze data.

Objectives:

Students will be able to calculate their carbon footprints by using given sites. Students will collect information from a variety of resources and be able to decipher the validity and accuracy of information (Affective/Cognitive). Students will use the internet to aid in research of the concepts and draw connections between them (Cognitive). Students will be able to investigate a building on campus and identify ways to make the building more energy efficient (Psychomotor).

Activity:

- Students will complete three carbon footprint calculations prior to class using designated sites and complete the carbon foot print hand out.
- Students will begin to explore the concepts of climate change, global warming, and carbon footprints.
- Students will explore different areas of campus and identify ways to make buildings more energy efficient.
- Students will complete the Campus Crusade Lab Activity handout and orally present their findings with the rest of the class.

Inquiry:

1. Learner sharpens or clarifies question provided by teacher, materials, and other sources.

2. Learner is directed to collect certain data.
3. Learner formulates explanations after summarizing evidence.
4. Learner is directed toward areas and sources of scientific knowledge.
5. Leaner forms reasonable and logical argument to communicate explanations.

Assessment: One Step at a Time Observation and Question sheet

Carbon Footprint Assignment

1. Carbon Footprint Homework
2. Energy Efficiency Lab

Carbon Footprint Calculations

Go to three of the listed sites and complete your Carbon Foot print

www.BP.com/EnergyLab

www.carboncounter.org

www.carbonfootprint.com www.climatecrisis.net/takeaction/carboncalculator

http://www.nature.org/initiatives/climatechange/calculator

http://www.epa.gov/climatechange/emissions/ind_calculator.html

1. What is a carbon footprint?

2. What differences did you notice among the sites?

3. What companies or organizations made these sites?

4. Were your scores different? Why do you think that is?

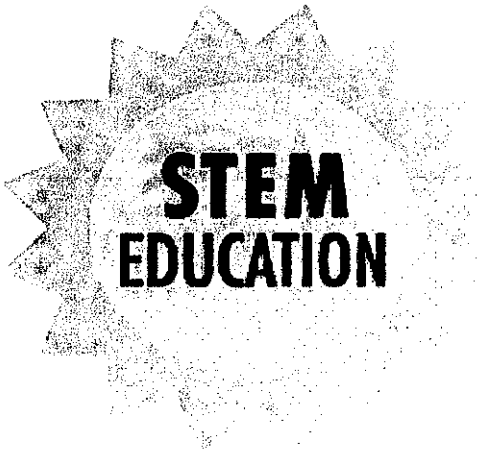
5. What can you do to improve your carbon footprint?

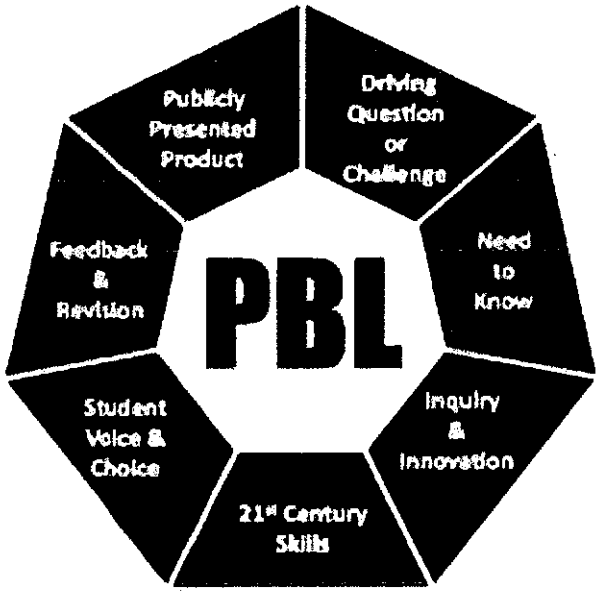
Carbon Footprint

Rubric Components	Point Scale				Student's Score
	5 Excellent	3 Good	1 Fair	0 Poor/ Nonexistent	
Carbon Footprint Calculation Handout	Completed three carbon foot print calculations and handout. Answers expressed logical conclusions based off of their observations and rationale. Used supporting details to backup their conclusions.	Completed three carbon foot prints and handout. Answers lacked detail and support.	Incomplete handout and/or observation notes.	Assignment not turned in on time.	
Carbon Footprint Activity Lab	Completed lab handout that identifies flaws in energy efficiency and ways to resolve it. Findings are logical and supported with detailed explanations.	Completed lab handout identifies flaws in energy efficiency and ways to resolve it. Lacks supporting evidence and detailed explanations.	Incomplete lab activity that fails to provide supportive explanations.	Assignment not turned in on time.	
Effort and Participation	Instructor and learner both felt that learner contributed a great deal to the inquiry investigation by taking part in group discussion and decision making.	Instructor and learner felt that the learner put forth and effort in the groups investigation.	Instructor did not observe participation by the learner. The learner felt they contributed to the investigation.	No participation in the investigation as either observed by the instructor or by notification of the learners group members.	

Total_____

PBL And STEM Resources





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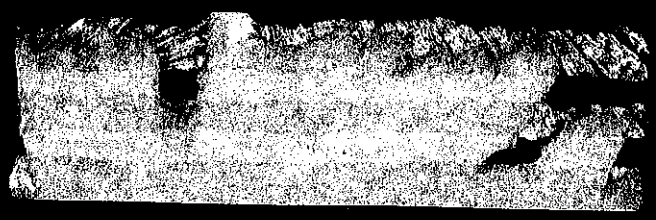
Science

Grand Challenges in Science Education



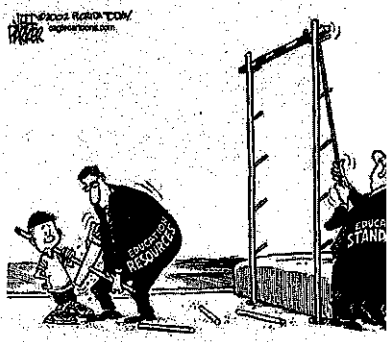
AAAS

Bruce Alberts is Editor-in-Chief of *Science*.

Prioritizing Science Education

THIS SPECIAL ISSUE OF *SCIENCE* EXPLORES "GRAND CHALLENGES IN SCIENCE EDUCATION," A CRITICAL set of the problems and exciting opportunities now facing science education on a global level. The 20 Challenges, addressed by a team of education experts, range from "Enable students to build on their own enduring, science-related interests" to "Shift incentives to encourage education research on the real problems of practice as they exist in school settings." Here I propose three additional Grand Challenges. These focus on harnessing the wisdom of teachers, helping the business community promote new directions in precollege science education, and—last but not least—catalyzing major changes in the way we teach college-level science.

From my many close contacts with outstanding U.S. teachers, I have come to deeply appreciate their wisdom. They uniquely understand today's 5- to 18-year-old students and have many valuable suggestions for improving education systems. I am also painfully aware of the many past failures that have been caused by not giving the best teachers a strong voice in the public policies that profoundly affect their profession. In the 1980s, the Japanese taught the world that building a better automobile requires listening to workers on the assembly line. More generally, experience shows that actively soliciting advice from those most intimately involved is essential for wise decision-making at higher levels. Regrettably, education is one of the few parts of U.S. society that fails to exploit this fact. Hence, my initial Grand Challenge: "Build education systems that incorporate the advice of outstanding full-time classroom teachers when formulating education policy." A start has been made,* but much more remains to be done (see the Perspective by B. Berry on p. 309).



To be competitive in the global economy, businesses need to be able to hire workers who can "think for a living." More specifically, studies reveal that the private sector seeks employees who can apply a capacity for abstract, conceptual thinking to "complex real-world problems—including problems that involve the use of scientific and technical knowledge—that are nonstandard, full of ambiguities, and have more than one right answer." These employees must also have "the capacity to function effectively in an environment in which communication skills are vital—in work groups."† Achieving the revolution in U.S. science education that is called for in the *Next Generation Science Standards* released last week‡ would go a long way toward creating the type of high-school graduates that the private sector needs (see the Perspective by R. Stephens and M. Richey on p. 313). Business leadership in the United States often fails to advocate for wise education policies, despite its potential for influence. Hence, my second Grand Challenge: "Harness the influence of business organizations to strongly support the revolution in science education specified in the *Next Generation Science Standards*."

Several years ago on this page, I pointed out that, "Rather than learning how to think scientifically, students are generally being told about science and asked to remember facts. This disturbing situation must be corrected if science education is to have any hope of taking its proper place as an essential part of the education of students everywhere. Scientists may tend to blame others for the problem, but—strange as it may seem—we have done more than anyone else to create it."§ College science courses are taught by scientists, and they define "science education," modeling for teachers and adults what should be done at lower levels. Most college faculty have not yet faced up to the urgent need to improve on the standard one-size-fits-all lecture format (see News story by J. Mervis on p. 292). Thus, my final Grand Challenge: "Incorporate active science inquiry into all introductory college science classes."

The aim is nothing less than a more rational world.

– Bruce Alberts

10.1126/science.1239041

*http://sites.nationalacademies.org/DBASSE/TAC; www.ccst.us/ccstinfo/caltac.php. †R. Marshall, M. Tucker, *Thinking for a Living: Education and the Wealth Of Nations* (Basic Books, New York, 1993). ‡www.nextgenscience.org/next-generation-science-standards. §B. Alberts, *Science* **323**,437 (2009).

CREDITS: (TOP) TOM KOCHEL; (RIGHT) JOE PARKER/FLORIDA TODAY

SCIENCE EDUCATION

Opportunities and Challenges in Next Generation Standards

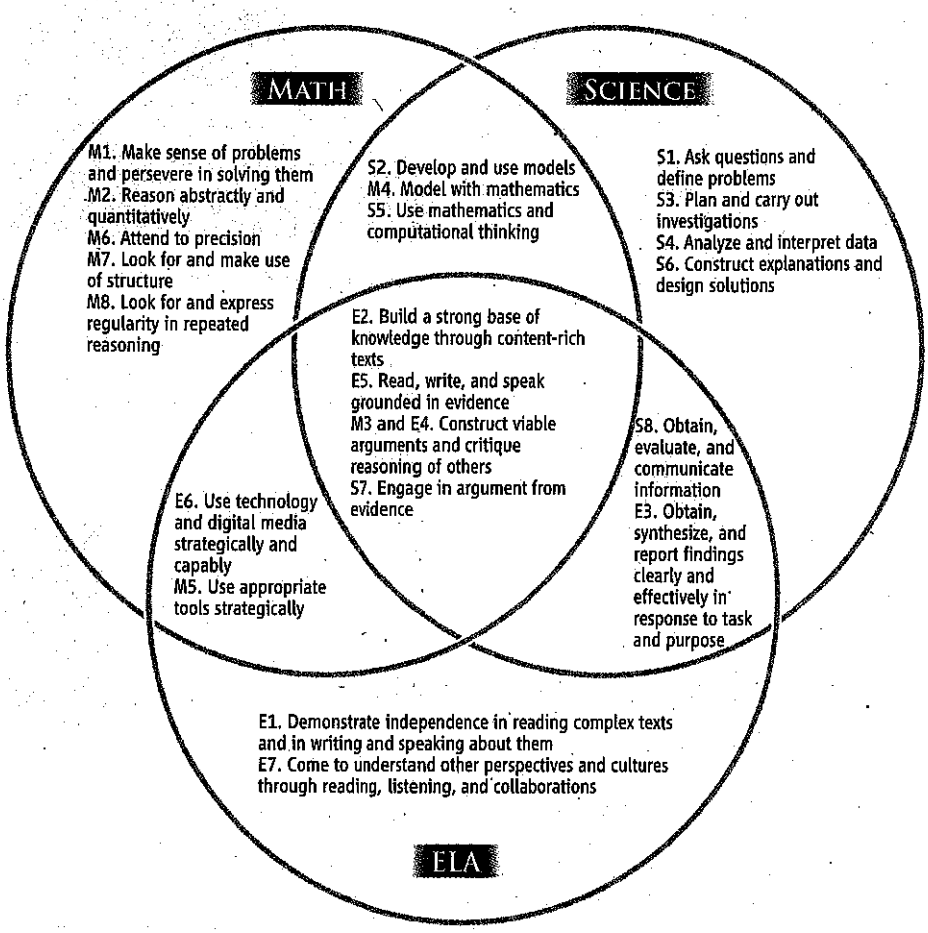
Goals for literacy, math, and science education may increase citizens' capacity to argue from evidence.

E. K. Stage,[1*] H. Asturias,[1] T. Cheuk,[2] P. A. Daro,[3] S. B. Hampton[3]

Imagine that politicians and the people they represent understood how human activity impacts Earth, including climate. And imagine that they had learned how to evaluate claims, argue from evidence, and understand models. These understandings and practices are prominent in the U.S. National Research Council (NRC) framework to guide the next iteration of standards for U.S. elementary and secondary school students (*1*). We discuss how aspects such as authorship, coordination among subject areas, and broader goals of college and career readiness give reason to believe that this effort will be more successful than previous attempts to use standards to improve science education (*2*).

Concurrent development in English Language Arts (ELA) ("literacy") and Mathematics, under the Common Core State Standards (CCSS) (*3*, *4*), has provided the opportunity to build on the strengths of these literacy and math documents from a science education perspective. Closely following the CCSS, the Next Generation Science Standards (NGSS) are being developed by Achieve, a nonprofit organization, working directly with 26 lead states (*5*). This structure acknowledges that the standards will be adopted and implemented at the state level.

Past educational standards were developed by professional organizations on behalf of scientists and educators and in different subject areas independently, yielding more material than any K–12 school system (kindergarten to high school) could teach well (*6*, *7*). Now there is a call for "fewer, clearer, and higher" standards (*8*).



Relations and convergences in literacy (*3*), math (*4*), and science and engineering (*1*) practices. Adapted from (*12*).

Building on Literacy and Math

The CCSS focus not only on what it will take to become a successful student in higher education but also a successful employee. Broadening the scope in this way, skills and abilities that support civic participation are explicit in the standards. Reading standards give earlier and more extensive treatment of informational text than in the past. This is echoed in the writing standards; "The ability to write logical arguments based on substantive claims, sound reasoning, and relevant evidence is a cornerstone" (*9*). Writing standards include in-depth research with an emphasis on analysis and presentation. Standards for speaking and listening include "Integrate multiple sources of information presented in diverse formats and media (e.g., visually, quantitatively, orally) in order to make informed decisions and solve problems, evaluating the credibility and accuracy of each source and noting any discrepancies among the data" (*3*).

We see a similar emphasis on reasoning and problem-solving in the math standards. Comparisons with high-performing countries find that spending more time on fewer topics gets better results. Thus, the math standards emphasize focus and coherence rather than covering topics in a curriculum that is a "mile wide and an inch deep" (*10*). Greater depth in each topic comes from students' development of mathematical expertise defined by eight standards for mathematical practice.

The math standards take an overdue step toward greater synergy with science by introducing modeling in secondary grades. The math standards define modeling as "the process of choosing and using appropriate mathematics and statistics to analyze empirical situations, to understand them better, and to improve decisions" (*4*). The elaboration of the basic modeling cycle resonates with the

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writing standards and with the science practices, e.g., "(5) validating the conclusions by comparing them with the situation, and then either improving the model or, if it is acceptable, (6) reporting on the conclusions and the reasoning behind them. Choices, assumptions, and approximations are present throughout this cycle" (*4*).

Literacy and math standards include practices that are challenging to teach in science without support from teachers of other subjects. Standards for Speaking and Listening include, "Evaluate a speaker's point of view, reasoning, and use of evidence and rhetoric" (*3*). Standards for Mathematical Practice include, "Construct viable arguments and critique the reasoning of others" (*4*).

Operationalizing Inquiry

In this promising context, science standards have been drafted, working from the NRC framework, that operationalized "inquiry" with eight practices of science and engineering: (i) asking questions and defining problems; (ii) developing and using models; (iii) planning and carrying out investigations; (iv) analyzing and interpreting data; (v) using mathematics and computational thinking; (vi) constructing explanations and designing solutions; (vii) engaging in argument from evidence; and (viii) obtaining, evaluating, and communicating information (*2*).

The framework attempted to narrow the number of core disciplinary ideas, although reviewers of draft science standards have said that the volume of content undermines the sense making required by the practices (*11*). The framework retained the idea of crosscutting concepts (e.g., structure and function, stability and change of systems), and argued that practices, core disciplinary ideas, and crosscutting concepts should not be taught or assessed separately from each other. Each draft science performance expectation incorporates one or more disciplinary idea, practice, and/or crosscutting concept. These performance expectations also cross-reference the literacy and math standards; the convergence is shown in the chart (*12*).

Science educators have decried the common practice of reading textbooks instead of doing investigations; the former is still alive and well (*13*). Literacy educators are concerned about increased emphasis on informational text in the CCSS (*14*). It is time to embrace the coherence and learning that can be achieved by making meaningful connections between and among direct experience with science and engineering practices and reading, writing, speaking, and listening (*15*).

What's Next?

Forty-five states have adopted the CCSS. If a substantial number of states adopt the NGSS, it increases the likelihood that developers and publishers of instructional and assessment materials will focus on creating a common set of tools, at least at elementary and middle grades. If colleges and universities accept high school courses that are based on the standards and the College Board continues to revise the Advanced Placement syllabi, high schools are more likely to follow them.

In addition to sufficient time and resources for educators and parents to learn how to support these more ambitious expectations, there are several challenges that scientists, educators, and policy-makers should consider. Advocates for high-quality science education for all students need to participate in conversations at the local and state level where educational policy is enacted. Scientists from higher education, research organizations, and corporations influence science education and can align their contributions with educational goals in the standards.

Historically, the United States has provided limited opportunity to learn science to most of its students and advanced training to a privileged few, focusing on the pipeline for future scientists and innovators without concomitant attention to a science literacy for citizenship. The system needs to be transformed to affirm high standards of accomplishment for all students and to provide resources for all students to reach them (*8*).

Although the literacy and math standards were widely adopted, and 26 states have served as partners in developing NGSS, momentum may be slowing; some states may reject the NGSS because of the inclusion of evolution and climate change (*16*). The National Center for Science Education, a defender of teaching evolution for more than three decades, broadened its mission to include the defense of teaching climate science.

Science education benefits from the learning sciences; scientists interested in the most effective teaching of science need to learn from education research. Formal schooling has been criticized as ineffective at motivating and inspiring students (*17*) and inadequate at recognizing the relation between interest and accomplishment (*18*). The NGSS can provide a platform for formal education to become more motivating. Many people are inspired by science in informal settings; parallel attention to the NGSS can contribute to "a wide-ranging and thriving ecosystem of opportunities that respond to the needs of children as well as communities" (*19*). Education and public outreach activities associated with research grants, whether in or out of school, should provide both preparation and inspiration. Local school districts, after-school providers, and informal science institutions need to create a coherent strategy for the regional science learning ecosystem.

This new round of standards development is an opportunity to improve science education that comes around once for each generation. We need to inform ourselves, figure out whether and how we want to get involved, and be intentional about our participation.

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The Education Task Force of the Illinois Business Roundtable has concluded that "the business community, in partnership with political and education leaders, must play a significant leadership role in education reform (*9*)." Recognizing that "education improvement is a marathon and not a hundred-yard dash" and that "education reform needs to be a collaborative, not adversarial, effort," we have helped to create the Career Pathways Program, where businesses are working with the Illinois State Board of Education to bring practical, experience-based curricula into the classroom that can help ensure that students are either job ready or college ready when they graduate from high school (*10*).

Nationally, academic and business leaders have come together in efforts to create effective learning environments outside of the classroom experience. For example, FIRST robotics competitions were founded on the premise that students can succeed when they compete, not just in a simulated game environment, but in the real world where there are winners and losers (*11*). These types of activities need to become part of formal schooling, not merely optional add-ons.

In summary, what can business do? First, be a strong advocate for exposing students to more hands-on problem-solving activities in the classroom. Second, help to provide scarce resources by increasing sponsorship of programs that engage students in such activities. Third, create more internship opportunities that allow students to be exposed to real-world work environments and directly learn what jobs are about. Fourth, support initiatives to question, and limit, the television, computers, and electronic games that can divert students' time and attention away from other world experiences needed for future success. We believe that professional success today and in the future is more likely for those who have practical experience, work well with others, build strong relationships, and are able to think and do, not just look up things on the Internet.

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REVIEW

Outside the Pipeline: Reimagining Science Education for Nonscientists

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Educational policy increasingly emphasizes knowledge and skills for the preprofessional "science pipeline" rather than helping students use science in daily life. We synthesize research on public engagement with science to develop a research-based plan for cultivating competent outsiders: nonscientists who can access and make sense of science relevant to their lives. Schools should help students access and interpret the science they need in response to specific practical problems, judge the credibility of scientific claims based on both evidence and institutional cues, and cultivate deep amateur involvement in science.

For half a century, the world's wealthiest countries have asked their education systems to teach science to all students, including those who will not go on to scientific careers (*1*). Under slogans such as "science literacy" and "science for all," schools have attempted to prepare all students to make sense of science in daily life. With the exception of modest and isolated gains in conceptual knowledge (*2*), it is not clear that these campaigns have enhanced people's ability to function in a world where conflicting health advice clutters the Internet, research is filtered through political screens, and the media strips context from scientific claims.

These results should provoke renewed interest in the relationship between science education and public engagement with science and the pursuit of more fruitful forms of science literacy. Instead, many scientists and policy-makers are turning their attention away from the role of science in daily life and advocating a greater focus on the so-called "pipeline": preprofessional education that delivers science-ready students to colleges and universities (*3*). Even crusaders for science literacy take for granted that scientific training—of the same sort that prepares students for scientific practice—will help nonscientists navigate fields as diverse as personal health, politics, the economy, leisure, and employment (*1*, *4*, *5*). There is little empirical evidence to support this assumption. On the other hand, a growing number of studies show untrained citizens engaging with science in adaptive ways (*6*). These citizens, whom Feinstein refers to as "competent outsiders" (*7*), identify relevant pieces of science and understand their local or personal implications without relying on school-based knowledge of particular scientific methods or concepts (*6*, *8*).

How can education help more people act like competent outsiders? We synthesize evidence to develop a research-based plan for cultivating competent outsiders: nonscientists who can access and interpret the science most relevant to their lives. We reconsider established goals of science education in light of three central findings about public engagement with science and discuss implications for research and practice.

How People Interact with Science

Research shows that different groups interpret science differently (*6*, *9*–*12*). An Alzheimer's advocacy group, biotech investment firm, and religious coalition may all be interested in stem cell research, but different motivations underlie their interest and shape their engagement. Social, cultural, and demographic differences influence how people engage with science, both in school (*13*) and out (*6*, *11*). For example, communications researchers have identified six demographically distinct groups of Americans who respond to news about climate change in predictable, group-specific ways (*11*). Local knowledge and experience, such as the history of tension between rural residents and a nuclear power plant (*14*), can play an important role. There are many different "publics" for science, each with different concerns and resources for making sense of the world.

To complicate matters, science is not a single, uniform thing. Science education places particular value on experimentation, but some fields rely on observational data or simulations, whereas others are devoted to theoretical inquiry. Even closely related fields can diverge on important matters, such as the validity of research methods or the nature of acceptable evidence (*15*). Nonscientists typically interact with specific manifestations of science rather than "science" as a whole (*6*, *12*, *16*). Although scientists may agree on abstract principles (such as hypothesis-testing) and

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methodological heuristics (such as model-building), the science of climate modeling is very different from the science of clinical trials, and understanding the family resemblance between them may not help a layperson make sense of evidence.

This leads to perhaps the most important finding: Although some people are interested in science for its own sake, many engage with science in response to situation-specific needs and tend to be interested in science only insofar as it helps them solve their problems (*6–10, 12*). Thus, a mother seeking therapies for her autistic son may explore research literature, but she is not attempting to understand that literature from a scientist's perspective. Instead, she labors to integrate what she learns with her knowledge of local services and her first-hand understanding of her child (*16*). Context shapes the process of engagement, and scientific principles take on different significance in different contexts, where they are laden with social and ethical implications (*8, 10, 12*). The challenges of daily life are what cognitive scientists call ill-structured problems, defined in personal and practical terms. Scientific understanding may contribute to the solution, but will rarely be the entire solution. It is important to be realistic about the sort of understanding people seek—and need—to make decisions (*17*).

Reconsidering the Goals of Science Education

These findings about public engagement with science strain the credibility of established approaches to science education. Scientists, educators, and policy-makers claim that science education is useful (*1–3, 5*), but what use is it to know a canonical collection of facts or an allegedly generic scientific method if people engage with specific pieces of science in highly contextualized ways? Can education prepare students for the deep idiosyncrasy of daily life? Evidence on public engagement indicates that students should still know science, think scientifically, and appreciate science—but it may be necessary to reconsider the established interpretation of these goals and the strategies used to achieve them.

Knowing Science: From Knowing the Textbook to Accessing the Science You Need

No set of scientific concepts and principles, no matter how carefully chosen, will be sufficient preparation for future engagement with science. This is a consequence of the unpredictable path of scientific progress, shifting social and political demands on scientific knowledge, and the variety of contexts and motives that drive public engagement. Even if it were possible to predict the future of science, one could never anticipate how science will ripple through the diverse future lives of students (*4, 9, 12*). Yet prior knowledge is only one piece of the sense-making apparatus that people use in their encounters with science. When reading a scientific article, a person draws on prior knowledge to interpret the text, but she does not stop when she is unfamiliar with a concept or uncertain of implications; she looks up the concept online, cross-references a second article, discusses the matter with friends, and seeks out complementary expertise (*6, 16, 18*). People employ social and material resources to solve problems and answer questions, and encounters with science are an impetus for new learning as well as tests of prior knowledge.

Resources alone do not guarantee fruitful engagement with science: The same literature that reveals impressive sense-making ability among laypeople also reveals failures, frustrations, and uneven competence (*6, 12, 16*). Science education should prepare more students to access and interpret scientific knowledge at the time and in the context of need. Public engagement with science is not simply the application of scientific knowledge; it requires translating a daily problem into scientific terms and reconstructing the scientific answer amid the constraints of daily life (*6, 12, 16*). A rural resident worried about pesticide contamination must learn to express his concerns in questions that science can answer: What pesticides, at what doses, are most harmful? Are there reliable tests for pesticides in my children's air or water? These questions lead to answers that must then be translated back into local reality: Who will help me test my water? What can I do to mitigate the risks? The decision-making process incorporates both scientific and nonscientific information.

One promising approach for preparing students to succeed in such circumstances is Problem-Based Learning (PBL), which confronts students with ill-structured challenges, asking them to extend their existing knowledge and develop concrete solutions (*19*). PBL can produce durable knowledge gains and foster metacognitive skills that underlie self-directed learning, although researchers have yet to identify which features of PBL contribute most to learning (*19, 20*). Developed in medical schools, PBL needs further validation in kindergarten through grade 12 (K-12) settings, but it shares features with other promising pedagogies specific to K-12, such as Science-Technology-Society (STS) and Place-Based Education (*21, 22*). All of these mimic public engagement with science by making the problem a focus for learning, allowing students to develop complex questions and test the adequacy of their answers, and, in many cases, using authentic social and practical problems that cannot be defined in purely scientific terms.

Fundamental problems of research and practice must be addressed before these pedagogies can be used to greatest effect. Little is known about using them together, or over time, to help students recognize when and how science is relevant. Students frequently struggle to apply what they have learned in one specific context to another; on the other hand, teaching generic problem-solving skills appears to have limited value (*23, 24*). Finding the right level of specificity, and honing strategies to connect multiple learning episodes, are problems of longstanding interest to researchers and educators (*23, 25*). Educators and researchers should work together to adapt problem-focused pedagogies for a broad range of audiences, develop appropriate assessments, and—critically—find the most productive balance between these strategies and other means of presenting disciplinary science content.

Thinking Scientifically: From Practicing Science to Judging Scientific Claims

"Thinking scientifically" has been interpreted in many ways, from the trial-and-error experimentalism of early progressives to the scientific method dogma of the post-war era and the more flexible (if also more vague) idealism of scientific inquiry (*1, 5*). In the United States, the forthcoming Next Generation Science Standards decompose scientific inquiry into distinct but interconnected "scientific practices" such as modeling, argumentation from evidence, and communication of results. This is an important step forward. It rejects the empirically dubious notion of a single scientific method, offers greater specificity than most inquiry frameworks, and better represents the collaborative and iterative aspects of scientific work (*5*).

Yet the scientific practices approach still emphasizes the scientist's "insider" perspective, neglecting cues that help outsiders make informed judgments. Nonscientists rarely need to replicate the iterative processes of systematic research, and literature suggests that it is difficult to transfer principles of research design, learned in disciplinary contexts, to the highly variable circumstances of daily life (*23, 24*). On the other hand, nonscientists do need to judge the trustworthiness and local validity of putatively scientific claims. Studies show that competent outsiders make sophisticated judgments about the credibility of scientific claims based on cues like professional reputation, publication venue, institutional affiliation, and potential conflicts of interest, even when they do not understand technical nuances of experimental design or laboratory technique (*6, 8, 10*). In one classic sociological study, local knowledge and historical context, combined with direct observation of scientists in the field, helped farmers make sophisticated counterarguments to government-sponsored studies when their grazing lands were contaminated by radioactive fallout (*14*). Studies have emphasized the importance of trust, reputational networks, and heuristic reasoning in judgment and decision-making (*10, 26*).

Science education could do far more to help people judge scientific claims based on the information available to them. This is important given the decline in dedicated science journalism at for-profit news organizations; increasingly, citizens are turning to the Internet, with its variable quality and political motivations, for science news (*10*). Lessons that focus on scientific argumentation and communication are part of the solution because they help students understand how scientists evaluate evidence and how research is packaged for presentation to various audiences (*5, 27*). Yet even this shortchanges the histories, institutions, and norms that contribute to the reliability of scientific knowledge. Competent outsiders appreciate the socio-political nuances

of "how science really works," including scientific credentials, the role of peer review in research funding and publication, and the differing perspectives of the many types of research organizations (*8*, *10*). They can navigate the changing world of popular science media, recognizing signs of source bias and understanding the difference between journalistic and scientific accounts of research (*10*).

This material can be dry and inaccessible when presented out of context, but promising pedagogies offer platforms for examining scientific credibility in realistic contexts. In Socio-Scientific Issue Discussions (SSID), students engage in structured conversation about a science-inflected social problem, with the goal of uncovering epistemic and ethical nuances at the interface of science and daily life (*28*). Other strategies focus on the creation and interpretation of science texts, ranging from research articles to popular science journalism (*29*, *30*). These pedagogies must be refined to reveal the social and institutional structures of science. Although both address the credibility and usefulness of different sources, and both provide apt venues for exploring issues of institutional trust, work is needed to develop a systematic and developmentally appropriate set of scaffolds for learning about topics such as peer review and conflicts of interest.

Appreciating Science: From Positive Feelings to Deep and Durable Involvement

Most adults in high-income countries express mild but consistent interest in scientific topics (*31*), but formal education may have little to do with this: A substantial fraction of students in those same countries lose interest in science as they progress through school (*32*). Schools may lag behind informal learning environments in their ability to inspire and develop students' interest in science (*33*). Older, top-down mechanisms for public engagement are being joined by science cafes, participatory science games, and maker spaces (community-oriented places that foster collaboration and resource-sharing in small-scale design and fabrication projects). Children and adults may connect with science through "citizen science" and "professional-amateur" communities dedicated to phenology, astronomy, and even molecular biology (*18*). People who interact with science through these platforms do so for widely varying reasons connected to personal interest and social identity (*18*, *33*). In this rich and dynamic context, how and why should schools continue to foster appreciation of science?

Research suggests that deep, personal interest in some field of science provides motivation for future interactions, even with science in unrelated fields. Students who pursue their own science-related interests have a stronger sense of their ability to learn science in the future (*33*) and are less likely to lose interest over time (*34*). Their involvement in personally or socially meaningful science-related activities can lead to learning experiences that resemble project-based learning and socio-scientific issue discussions (*35*). When students find a particular scientific topic compelling, they seek experiences that prepare them for future encounters with science. Knowledgeable amateurs can become powerful resources for their communities (*9*, *18*, *33*).

Schools wishing to develop deep and durable involvement in science should embrace the diversity of student interests—a challenge for educational systems accustomed to pushing everyone toward the same goal. Three pathways hold promise. First, educators can use the flexibility provided by project- and place-based pedagogies to help students identify and develop individual interests and expertise. Second, schools can pursue partnerships with museums, which excel at sparking curiosity, and with afterschool clubs and community organizations, which provide flexible spaces for ongoing exploration (*33*). Third, educators can integrate science-based games and citizen science engines like FoldIt and GalaxyZoo into their curricula. Researchers should develop efficient ways to track the development of lasting student interests and identify productive ways to integrate informal experiences and game-based technologies into schools and classrooms (*33*).

Implications

On the way to becoming competent outsiders, students should learn to (i) access and interpret science in the context of complex, real-world problems; (ii) judge the credibility of scientific claims based on both social and epistemic cues; and (iii) cultivate deep and durable involvement in science, even when it takes them away from the formal curriculum. In practice, this means moving strategies such as PBL, SSID, and interest-driven student exploration from the pedagogical margins to the center. Allotting more time and resources to these strategies will result in a better balance between preprofessional science education and science education for nonscientists; given that PBL is used in a range of academically rigorous contexts, it may pay dividends for future scientists as well.

These strategies are works in progress. Too few studies investigate the challenges of moving from practical problems to scientific questions and integrating science back into practical solutions. Too few studies identify skills needed to reverse-engineer a robust and coherent knowledge structure using real-world resources. Educational research on scientific epistemology neglects the diverse circumstances in which people encounter scientific claims, as well as the social and institutional knowledge that contributes to evaluating those claims. Research on deep and durable involvement in science is in its infancy; although there are portraits of success in games-based learning and informal science education, practice outstrips research. There is an urgent need to understand how and why these settings succeed (and fail) to transform attitudes, motivation, and identities.

Educators should not wait for these questions to be answered. Useful research requires real-world cases to study, and it is educators who will do much of the work of adapting project-based learning and other strategies to diverse K-12 settings. Predictable challenges loom: School schedules, parent expectations, and high-stakes testing militate against pedagogies that sacrifice short-term knowledge gains for complex skills, increased motivation, and a narrower but longer-lasting body of knowledge. Teachers and administrators should work together to clear space for pilot programs that test and demonstrate the value of these approaches. It may be most effective to deploy them as solutions to other widely acknowledged problems. For example, STS education produces motivational gains among students who are less likely to enroll in science courses (*21*), whereas PBL has found early champions in gifted education, with students who may have exhausted their local course offerings (*19*). Pilot programs conducted in these contexts can serve as beachheads for broader adoption.

Scientists may be allies or adversaries in reform. Some have played a decisive role in pedagogical and curricular progress, whereas others have defended the battlements for the established facts-and-principles approach (*1*). The scientific pipeline dominates educational discourse today, but it is those outside the pipeline who would benefit most from reform. Serving their needs requires a different sort of activism, and new attention to evidence about how, when, and why people interact with science.

Grand Challenges

Help students explore the personal relevance of science and integrate scientific knowledge into complex practical solutions. Teaching science in this way requires a focus on authentic problems that often cannot be defined in purely scientific terms.

Develop students' understanding of the social and institutional basis of scientific credibility. Science education should empower students to make reasonable judgments about the trustworthiness and local validity of scientific claims, even when they don't have deep background knowledge or access to expertise.

Enable students to build on their own enduring, science-related interests. Schooling that fosters the development of idiosyncratic interests, habitual curiosity, and lifelong science-related hobbies will strengthen students' motivation and confidence in future learning experiences.

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REVIEW

Generating Improvement Through Research and Development in Education Systems

M. Suzanne Donovan

To effectively address problems in education, research must be shaped around a problem of practice. Reorienting research and development in this way must overcome three obstacles. First, the incentive system for university researchers must be changed to reward research on problems of practice. Second, the contexts must be created that will allow the complexity of problems of practice to be understood and addressed by interdisciplinary teams of researchers, practitioners, and education designers. And third, meaningful experimentation must become acceptable in school systems in order to develop a better understanding of how to effectively stimulate and support the desired changes.

The connection between research and practice in the field of education has been weak (*1*). The "knowing-doing gap" is lamented in other fields as well, including business management (*2*) and medicine (*3*). But it is difficult to find a parallel in education to the design of digital devices by technology companies that have fundamentally changed how we go about our daily lives, or the application of biomedical research to save lives in extreme circumstances.

How might we make use of research knowledge to pursue new possibilities and design new tools and processes to improve education? The fact that other sectors have made major strides in some regards, yet struggle to reliably incorporate verified improvements into practice, highlights two distinct challenges. One is a design challenge: When research informs designs that solve a problem from the point of view of the users, barriers to change disintegrate (*4*). Doctors, for example, use magnetic resonance imaging because it allows them to see what they otherwise cannot without risky or invasive procedures. And people have changed routine behavior enthusiastically when given access to technological innovations such as smartphones and Internet search engines. But when an innovation requires that people change their behavior to achieve goals others have set—to get hospital physicians to wash their hands or to use checklists that reduce errors (*5*), or to motivate teachers to engage students in classroom discourse rather than to teach through lectures (*6*)—it is an implementation challenge (*7*). The challenges are interrelated: Greater success at designing for the user implies fewer implementation barriers. If it is made easier for doctors to disinfect their hands, they are more likely to do so. But school systems and hospitals are intended to serve the goals of others, making improvements in practice desirable whether or not the user embraces the change. Research and development (R&D) will therefore need to address both design and implementation challenges.

While the task is far from simple, its components can be described in the most basic terms. They are (i) identifying the right problem, (ii) developing effective solutions, and (iii) getting effective solutions to spread.

Identifying the Right Problem

Scientific research can be driven either by theory or by problems of practice. Research that contributes to both falls into "Pasteur's quadrant" (*8*). The National Institutes of Health and the National Science Foundation support programs of "translational research" intended to make advances in research knowledge usable for practice (*9*, *10*). The term "translational" suggests that the required knowledge is in hand. It needs only to be put into the language of practice.

Rarely do problems of education practitioners map neatly onto areas of scientific research, however. Even in the case of pasteurization, translation would be a mischaracterization. Pasteur's scientific breakthrough came with a commission to work on a practical problem: the spoiling of wine (*11*). The problem-solving research did not end with the realization that bacteria cause the spoiling, nor with the evidence that heat could be used to destroy bacteria. The heating process changes the end product—whether wine or milk—affecting taste, appearance, and digestibility (*12*). It took decades of work on the time and temperature of heating and cooling to develop the process of pasteurization that revolutionized the delivery of milk (*13*). The translation metaphor conceals the way in which research that solves problems of practice is shaped and

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REVIEW

Proficiency in Science: Assessment Challenges and Opportunities

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Proficiency in science is being defined through performance expectations that intertwine science practices, cross-cutting concepts, and core content knowledge. These descriptions of what it means to know and do science pose challenges for assessment design and use, whether at the classroom instructional level or the system level for monitoring the progress of science education. There are systematic ways to approach assessment development that can address design challenges, as well as examples of the application of such principles in science assessment. This Review considers challenges and opportunities that exist for design and use of assessments that can support science teaching and learning consistent with a contemporary view of what it means to be proficient in science.

We face extraordinary promise for the future of science learning, juxtaposed with substantial challenges in achieving the vision of what it means to be proficient in science (*1*). Among those challenges are determining how the proficiency of our students will be assessed relative to that vision and doing so in ways that support, rather than inhibit, teaching and learning. Educational assessments ought to be statements about what scientists, educators, policy-makers, and parents want students to learn and become. It is well established that what we choose to assess will end up being the focus of instruction. So, it is critical that science assessments, both external and internal to the classroom, best represent the proficiencies we desire. This Review argues that much of what is needed to effectively assess science learning, either at the classroom level or for purposes of system monitoring, has yet to be created and that design and implementation challenges are substantial. Even so, there are promising cases from which to learn and build (*2*).

Shared Perspectives on Proficiency

A disjuncture exists between students' knowledge of science facts and procedures, as assessed by typical achievement tests, and their understanding of how that knowledge can be applied through the practices of scientific reasoning, argumentation, and inquiry (*3*, *4*). This problem is recognized in reports spanning kindergarten (K) to grade 16+ (K-16+) that simultaneously present a consistent description of what proficiency in science should be (*1*, *5*–*11*). Seldom has such a consistent message been sent as to the need for change in what we expect students to know and be able to do in science, how science should be taught, and how it should be assessed. The emergent definition of proficiency is perhaps most clearly expressed in three major elements of the U.S. National Research Council (NRC) Framework for K-12 Science Education (*1*): (i) core or "big" ideas within disciplinary areas, (ii) practices of scientific and engineering reasoning, and (iii) cross-cutting concepts. Collectively they define what it means to know science, not as separate elements but as intertwined aspects of knowledge and understanding [see also (*12*)]. It is not just the description of each and their intersection that matters but also that the meaning of proficiency is realized through performance expectations about what students at various levels of educational experience should know and be able to do. These statements move beyond vague terms such as "know" and "understand" to more specific statements like "analyze," "compare," "explain," "argue," "represent," "predict," "model," etc. in which the practices of science are wrapped around and integrated with core content. Educators and researchers are also recognizing that proficiency develops over time and increases in sophistication and power as the product of coherent systems of curriculum, instruction, and assessment.

The virtue of such a view is that science educators are poised to better define the outcomes desired from their instructional efforts, which in turn guides the forms of assessment that can help them know whether their students are attaining the desired objectives, as well as how they might better assist them along the way. It is very important for the science education community, and policy-makers and the public more broadly, to develop a shared perspective on what constitutes high-quality and valid science assessments across K-16+ if assessments are to support teaching and learning and attainment of the desired science education outcomes.

Proficiency, Performance Expectations, and Assessment Design Challenges

The NRC Framework uses the logic of progressions to describe students' developing proficiency in three intertwined domains—practices, cross-cutting concepts, and core ideas—in a coherent way across grades K through 12. The framework builds in the idea of a progression of student understanding across the grades by specifying grade-band end-point targets at grades 2, 5, 8, and 12 for each component of each core idea. The framework also provides sketches of possible progressions for acquiring each practice or cross-cutting concept but does not indicate the expectations at any particular grade level. The Next Generation Science Standards (NGSS) (*7*) build on these suggestions and include tables that define what each practice might encompass and the expected uses of each cross-cutting concept for students at each grade level.

This integrated perspective of what it means to know science suggests that assessment should help determine where a student can be placed along a sequence of progressively more "scientific" understandings of a given core idea that by definition includes successively more sophisticated applications of practices and cross-cutting concepts. This is an unfamiliar idea in the realm of science assessments, which have more often been viewed as simply measuring whether students know particular grade-level content. It means that assessments must strive to be sensitive both to grade-level appropriate performances and to intermediate performances that may be appropriate at somewhat lower or higher grade levels. This is particularly important for the design of assessment materials and resources that can be used in classrooms to support instruction.

The NRC Framework states that assessment tasks must be designed to gather evidence of students' ability to apply the practices and their understanding of the cross-cutting concepts in the contexts of problems that also require them to draw on their understanding of specific disciplinary ideas. It suggests using a model put forward in Science Standards for College Success (*13*) by expressing standards in terms of performance expectations. The organization Achieve and its partners in NGSS development have elaborated these guidelines into standards that are clarified by descriptions of the ways in which students at each grade are expected to apply both the practices and the cross-cutting concepts and of the knowledge they are expected to have of the core ideas. The NGSS appear as sets of performance expectations related to a particular aspect of a core disciplinary idea (see the draft example in Fig. 1). Each performance expectation asks students to use a specific practice in the context of a specific element of the disciplinary knowledge relevant to the particular aspect of the core idea. Across the set of expectations at a given grade level, each practice and cross-cutting concept appears with multiple standards.

Performance expectations also may include boundary statements that identify limits to the level of understanding or context appropriate for a grade level and clarification statements that offer additional detail and examples. But standards and performance expectations, even as explicated in the NGSS, lack sufficient detail to create an assessment.

From NRC Frameworks, Standards, and Performance Expectations to Assessments

The design of valid and reliable science assessments hinges on elements that include but are not

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restricted to what is articulated in disciplinary frameworks and standards such as those illustrated above (*14*, *15*). In the design of assessment items and tasks related to performance expectations, one needs to also consider (i) the kinds of conceptual models and evidence in which we expect students to engage, (ii) grade-level appropriate contexts for assessing performance expectations, (iii) options for task design features (e.g., computer-based simulations or animations, paper-pencil writing and drawing) and which of these are essential for eliciting students' ideas about the performance expectation, and (iv) the types of evidence that will reveal levels of student understanding and skill.

Assessment involves evidentiary reasoning (*14*), so it has proven useful to be more systematic in framing assessment development as an evidence-centered design process (ECD) [e.g., (*15*, *16*)]. The process starts by defining the claims that one wants to be able to make about student proficiency—the ways in which students are supposed to know and understand some particular aspect of a domain. Examples might include aspects of force and motion or heat and temperature. The most critical aspects of defining these are to be as precise as possible about what matters and to express this in the form of verbs such as "model," "explain," "predict," etc. In essence, the performance expectations found in the NGSS are claims about student proficiency.

Claims about the student must be linked to forms of evidence that would support those claims. Evidence statements capture features of work products or performances that would give substance to the claims. This includes which features need to be present and how they are weighted—what matters most, least, or not at all. If evidence in support of a claim about a student's knowledge of the laws of motion is that the student can analyze a physical situation in terms of the forces acting on all the bodies, then the evidence might be drawing a free-body diagram with all the forces labeled, including their magnitudes and directions.

The precision that comes from elaborating the claims and evidence statements pays off when it is time to design tasks or situations to provide the requisite evidence. Tasks are not designed or selected until it is clear what forms of evidence are needed to support the range of claims appropriate to a given assessment situation. The tasks need to provide necessary evidence and should allow students to show what they know in ways that are as unambiguous as possible with respect to what the performance implies about student knowledge and skill (*17*).

Science Assessment Example Cases

Given the relative newness of the NRC Framework, it is no surprise that comprehensive sets of assessment examples that align completely with the NGSS performance expectations do not exist. Many of the tasks that have been used for classroom

4-LS1 From Molecules to Organisms: Structures and processes

4-LS1 From Molecules to Organisms: Structures and processes

Students who demonstrate understanding can:

4-LS1-a. Use simple models to describe that plants and animals have major internal and external structures, including organs, that support survival, growth, behavior, and reproduction. [Clarification Statement: Examples of structures include thorns, stems, roots stamens, ovaries, heart, brain, skin, or bones.] [Assessment Boundary: Students are responsible for the overall functions of major structures, but the mechanisms of how they function within a system are not assessed. Students are not expected to memorize different types of structures but should be able to use information given.]

4-LS1-b. Design, test, and compare solutions that replace or enhance the function of an external animal structure necessary for survival.* [Clarification Statement: Students might compare solutions for mobility based on the strength of different materials used.]

4-LS1-c. Construct models to describe that animals' senses receive different types of information from their environment, process the information in the brain, and respond to the information in different ways. [Clarification Statement: Examples of models could be diagrams or analogies.] [Assessment Boundary: Students are not expected to know the mechanisms by which the brain stores and recalls information, nor the mechanisms of how sensory receptors function.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Developing and Using Models
Modeling in 3–5 builds on K–2 models and progresses to building and revising simple models and using models to represent events and design solutions.
- Develop a model using an analogy, example, or abstract representation to describe a scientific principle or design solution. (4-LS1-c)
- Identify limitations of models. (4-LS1-c)
- Use a simple model to test cause and effect relationships concerning the functioning of a proposed object, tool or process. (4-LS1-a)

Constructing Explanations and Designing Solutions
Constructing explanations and designing solutions in 3–5 builds on prior experiences in K–2 and progresses to the use of evidence in constructing multiple explanations and designing multiple solutions.
- Use evidence (e.g., measurements, observations, patterns) to construct a scientific explanation or design a solution to a problem. (4-LS1-b)
- Apply scientific knowledge to solve design problems. (4-LS1-b)

Obtaining, Evaluating, and Communicating Information
Obtaining, evaluating, and communicating information in 3–5 builds on K–2 and progresses to evaluating the merit and accuracy of ideas and methods.
- Compare and/or combine across complex texts and/or other reliable media to acquire appropriate scientific and/or technical information. (4-LS1-a)
- Use multiple sources to generate and communicate scientific and/or technical information orally and/or in written formats, including various forms of media and may include tables, diagrams, and charts. (4-LS1-a)

Disciplinary Core Ideas

LS1.A: Structure and Function
- Plants and animals have both internal and external structures that serve various functions in growth, survival behavior, and reproduction. (4-LS1-a), (4-LS1-b)

LS1.D: Information Processing
- Different sense receptors are specialized for particular kinds of information, which may be then processed and integrated by the animal's brain, with some information stored as memories. Animals are able to use their perceptions and memories to guide their actions. Some responses to information are instinctive—that is, animals' brains are organized so that they do not have to think about how to respond to certain stimuli. (4-LS1-c)

ETS1.C: Optimizing the Design Solution
- Different solutions need to be tested in order to determine which of them best solves the problem given the criteria and the constraints. (*secondary to 4-LS1-b*)

Cross-cutting Concepts

Structure and Function
- Substructures have shapes and parts that serve functions. (4-LS1-a), (4-LS1-b), (4-LS1-c)

Influence of Engineering, Technology, and Science on Society and the Natural World
- Engineers improve existing technologies or develop new ones to increase their benefits, decrease known risks, and meet societal demands. (4-LS1-b)

Fig. 1. Example of a set of possible grade 4 standards in life science from the January 2013 preliminary draft of the NGSS.

assessment, and those found in large-scale state, national, and international tests, focus primarily on science content or on aspects of scientific inquiry separate from content. With few exceptions, such assessments do not integrate core concepts and science practices in the ways intended by the NRC Framework or NGSS. Nevertheless, we can draw from example cases to illustrate what is needed, many of which have used an ECD approach to guide assessment design and validation. The examples are diverse in several ways—including the science content and practices represented, age and grade level, intended use (at the classroom, state, national or international level; whether the consequences of student performance have low or high stakes), as well as the innovative use of technology.

Classroom Instruction and Assessment

Several projects have developed assessments for use in classroom instruction with a particular emphasis on the integration of core science concepts with one or more science practices such as modeling; evidence-based explanation and argumentation; and/or the design of investigations to test hypotheses, analyze results, and construct explanations from data. Some of the clearest examples can be found in a volume edited by Alonzo and Gotwals (*18*) focused on learning progressions and in a special issue on assessment of the *Journal of Research on Science Teaching* (*19*). Additional examples include the SimScientists (*20, 21*), Science ASSISTments (*22*), and BioKids projects (*23*).

Several of these projects illustrate the feasibility of designing tasks and situations, whether in paper-and-pencil format or mediated via simulations embedded in technology, that challenge students to reason with and about core science concepts in life and physical science. They demonstrate ways to obtain forms of evidence that can serve multiple purposes, such as measurement of student proficiency as well as diagnosis of student thinking for instructional improvement. The SimScientists project has shown how assessment situations and tasks involving dynamic simulations of science phenomena can be built from a principled design process that supports classroom formative assessment as well as summative assessment in large-scale state programs (*21*).

National and International Large-Scale Assessment

Much of what students and teachers experience as science assessments is external to regular classroom instruction and comes in the form of large-scale state tests, for example, administered in response to the U.S. No Child Left Behind legislation. Although the quality of such state assessments varies, none approximates the performance expectations discussed in the NRC Framework and NGSS. In contrast, there are two large-scale assessment programs that more closely exemplify aspects of science proficiency that involve science practices: the U.S. National Assessment of Educational Progress (NAEP) and the Programme for International Student Assessment (PISA).

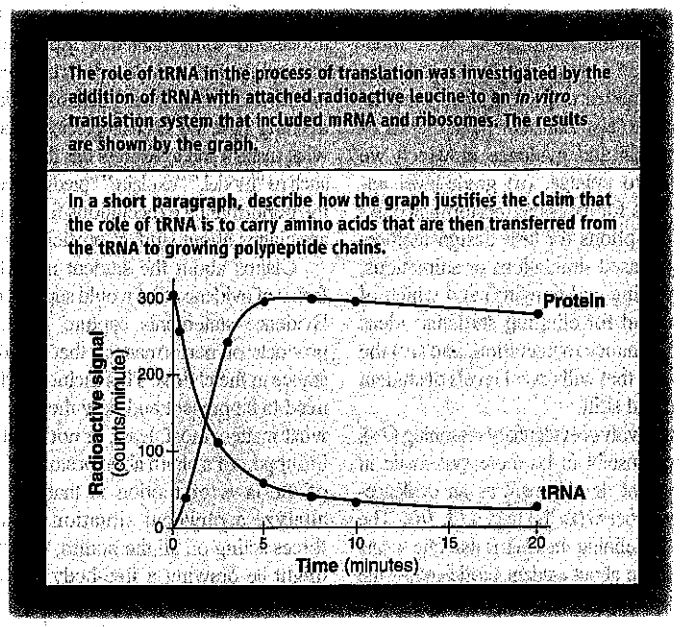

Fig. 2. A sample of a short constructed response item for the new AP biology exam.

The NAEP 2009 and 2011 assessments were constructed from a framework document that identified specific areas of content in the life, physical, and Earth and space sciences, as well as a set of science practices: (i) identifying science principles, (ii) using science principles, (iii) using scientific inquiry, and (iv) using technological design. Item types fell into two broad categories: selected-response items (such as multiple choice) and constructed-response items (such as short answer). To further probe students' abilities to combine their understanding with the investigative skills that reflect practices, a subset of the students completed hands-on performance or interactive computer tasks (*3, 4, 24, 25*). In contrast to NAEP, which is administered to 4th-, 8th-, and 12th-grade students, the PISA assessment is administered only to 15-year-olds. The most recent PISA science assessment results are based on a framework that includes science proficiencies that overlap with the science practices of the NRC Framework and NGSS, as well as aspects of the NAEP framework (*26, 27*).

What are especially important about both NAEP and PISA are the sets of simple and complex science assessment tasks that demand reasoning about science content as described in the NRC Framework and NGSS. Both assessment programs are a source of examples of the types of performances that align with the descriptions of proficiency discussed earlier. Neither NAEP nor PISA represent static assessment programs. Both undergo major revisions to the framework used to guide assessment design and task development, and both are increasingly moving to incorporate technology as a key aspect of task design and assessment of student performance. It is likely that the NAEP framework will be revised within the next decade, and work is already under way in revising the PISA science framework for 2015. Changes in both will ostensibly move in directions that even more closely align with the NRC Framework. Thus, both might constitute reasonable ways to monitor overall progress of science teaching and learning in U.S. classrooms in ways consistent with implementation of the NRC Framework and NGSS.

Advanced Placement (AP) Science

A contemporary approach to rethinking science proficiency can be found in the redesign of the AP courses and assessments for biology, chemistry, and physics (*8, 9, 28, 29*). The AP program offers college-level curricula to high school students. Starting in 2006, the College Board, which administers AP, with support from the U.S. National Science Foundation, initiated a process that started by redefining the focus, critical content, and science practices that should define proficiency at the end of each AP science course (*30*). This would then guide development of both a curriculum framework for each course as well as the high-stakes assessment often used by colleges for purposes of granting course credit and/or advanced course placement.

Using the complementary processes of backward design (*31*) and ECD, a framework was developed for each science discipline that is organized in terms of disciplinary big ideas, enduring understandings, and supporting knowledge as well as a set of seven science practices. This structure parallels that of the core ideas and science practices in the NRC Framework. Similar to what is advocated in the NRC Framework and

Grand Challenges

Design valid and reliable assessments reflecting the integration of practices, cross-cutting concepts, and core ideas in science. The performance expectations of the Next Generation Science Standards (NGSS) pose significant challenges for assessment design. Considerable research and development will be needed to create and evaluate assessment tasks and situations that can provide adequate evidence of the proficiencies implied in the NGSS. This research must be carried out in instructional settings where students have had an adequate opportunity to construct the integrated knowledge envisioned by the National Research Council Framework and the NGSS.

Use assessment results to establish an empirical evidence base regarding progressions in science proficiency across K-12. Much of what is assumed in the NGSS regarding learning progressions needs to be validated through empirical research. This validation requires assessment tasks and situations that can be used across multiple age and grade bands so that we can determine how proficiency changes over time with appropriate instruction. The empirical results can then be used to support the design of more effective curriculum materials and instructional practices.

Build and test tools and information systems that help teachers effectively use assessments to promote learning in the classroom. For teachers to effectively implement assessment as part of their pedagogy, they need tools for presenting tasks and collecting and scoring student performance. They also need smart systems that provide actionable information about the meaning and implications of student performance relative to instruction and student learning. Such systems will need to be designed in collaboration with learning scientists and teachers to ensure their validity, usability, and utility.

realized in the NGSS, performance expectations or learning objectives were defined within each discipline to reflect the blending of core ideas with science practices. Through application of ECD, sets of claim-evidence pairs were elaborated in each science discipline to focus and support course instruction as well as development of assessment tasks for new AP exams.

The first of those exams will be given in May 2013 in biology, with chemistry to follow in 2014 and physics in 2015. To help teachers and students orient to the new course and exam, a wealth of materials including sample assessments were provided (*32*). To reflect the shift in focus demanded by integration of science practices with core content ideas, new item types were created, and a greater emphasis is being placed on constructed response questions. Figure 2 provides an example of a short constructed response item that involves the integration of conceptual knowledge with aspects of the practices.

AP science redesign is still a work in progress. Much remains to be determined about the quality and impact of the new exams on student learning and classroom instructional practice. But AP science instruction and assessment are changing in ways closely aligned with the perspective on science proficiency described earlier.

The Road Ahead

Assessment is a key element in the process of educational change and improvement. Done well, it can signify what we want students to know and be able to do and help educators create learning environments that support attainment of those objectives. Done poorly, it sends the wrong signals and skews teaching and learning. Our greatest danger may be a rush to turn the NGSS into sets of assessment tasks for use on high-stakes state accountability tests before we have adequately engaged in research, development, and validation of the range of tasks and tools needed to get the job done properly. Most especially we must ensure that teachers are given the time, support, and assessment tools to create instructional environments where their students have adequate opportunities to learn what is now expected of them.

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10.1126/science.1232065

THE ROAD LESS TRAVELED

Sticking with STEM

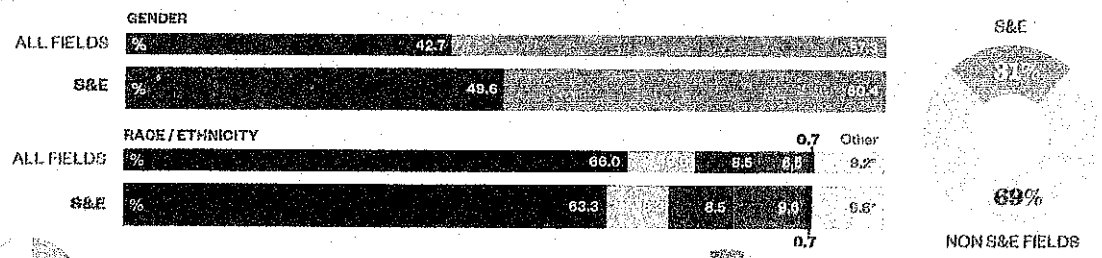
Future prosperity in the United States, some experts say, depends on an education program that piece by piece prepares students for jobs in science, technology, engineering and math (STEM). But there's one big problem: Many people who show some interest and ability in STEM early on don't stay with it. Today researchers, policy makers and employers are trying to understand how to foster the skills and enthusiasm to keep people on the STEM path for life. —**ELIZABETH QUILL**

- Male
- Female
- White
- Black
- Hispanic
- Asian / Pacific islander
- American Indian / Alaska native

ON LABOR

Contrary to conventional wisdom, roughly the same percentage of students who intend to major in a science and engineering (S&E) field end up graduating in one. Likewise, racial and ethnic minorities attain college degrees in S&E fields at roughly the same rate as they attain degrees in all fields.

U.S. BACHELOR'S DEGREES AWARDED, 2009



49% of female STEM college students say they chose their field because of a desire to make a difference, compared with 34% of male STEM students.

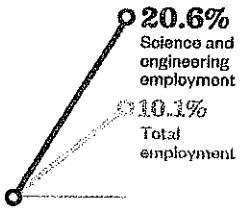
1 in 10 students who receive a bachelor's degree in S&E go on to receive an S&E doctoral degree.

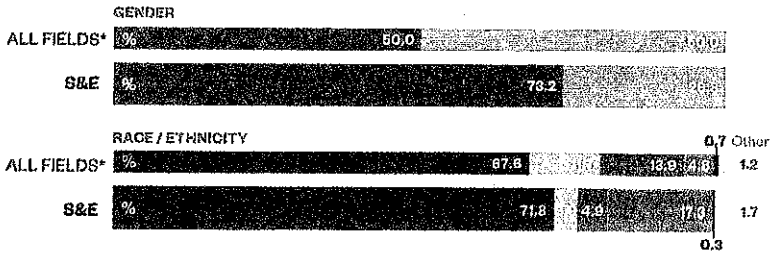
* Includes temporary residents

WORKFORCE

As students graduate and get jobs, many leave the STEM path. Compared with the total U.S. working-age population, women, blacks and Hispanics are underrepresented in S&E jobs.

EXPECTED GROWTH RATE BETWEEN 2008 AND 2018



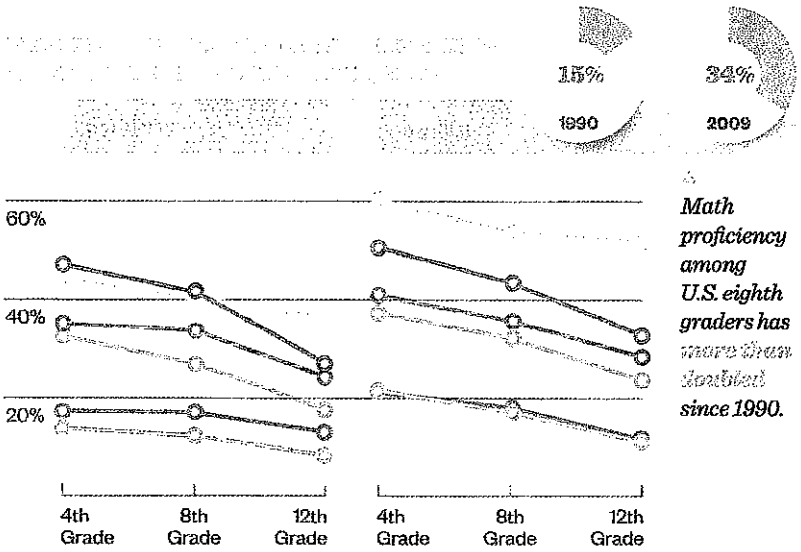


DISTRIBUTION OF U.S. WORKERS, 2008

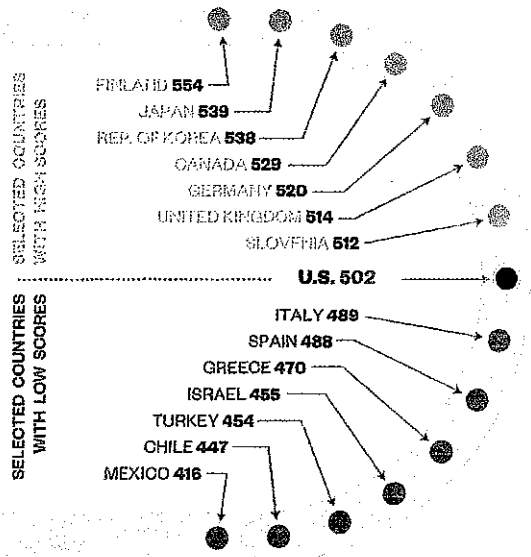
* Figures represent total U.S. population of working age

SOURCES: NATIONAL CENTER FOR EDUCATION STATISTICS; PROGRAM FOR INTERNATIONAL STUDENT ASSESSMENT; HIGHER EDUCATION RESEARCH INSTITUTE AT THE UNIVERSITY OF CALIFORNIA, LOS ANGELES; NATIONAL SCIENCE FOUNDATION; MICROSOFT CORP.; U.S. BUREAU OF LABOR STATISTICS; U.S. CENSUS BUREAU

A majority of U.S. students aren't proficient in science and math, according to the National Assessment of Educational Progress, though there have been gains. Some experts worry that U.S. students are falling behind students in other developed nations.

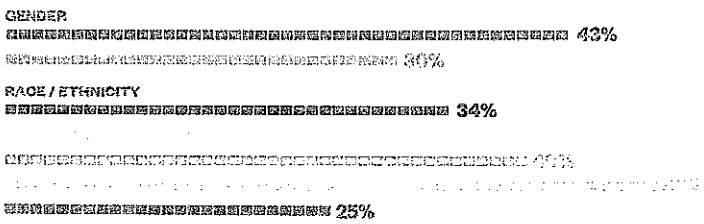


Math proficiency among U.S. eighth graders has more than doubled since 1990.



Students in schools that offer more science-related extracurricular activities tend to perform better on the science literacy test.

* Average science literacy scores for 15-year-olds taking the Program for International Student Assessment (PISA) test. Scores range from 1 to 1,000.



70% of U.S. high-school graduates enter college immediately.

35% of freshmen intend to major in an S&E field.

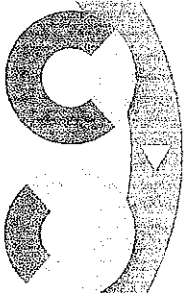
Median annual earnings in 2010...

for all U.S. employees:
$33,840

for S&E employees:
$75,820

Only about half of all employees with their highest degree in S&E work in S&E or a related field.

74% of science and engineering employees have a bachelor's degree or higher, compared with 27% of other employees.



S&E DEGREE HOLDERS WORKING IN AN S&E FIELD, 2008

GRAPHIC BY 5W INFOGRAPHICS ORIGINAL GRAPHIC CONCEPT BY COLUMN FIVE MEDIA

Courses

PROBLEM-BASED LEARNING

As an MBA, you will have to be an accomplished problem-solver of organizational design and change situations. You will also have to be a self-directed learner your entire professional life, as knowledge in the field of management will change, and you will continuously be meeting new and unexpected challenges.

The consideration of these factors such as these dictates the wisdom of a problem-based, student-centered, self-directed program that will allow you, the student, in collaboration with your group and instructor, to design an experience tailor-made to your individual needs.

What is Problem-Based Learning (PBL)?

Problem-based learning (PBL) is an approach that challenges students to learn through engagement in a real problem. It is a format that simultaneously develops both problem solving strategies and disciplinary knowledge bases and skills by placing students in the active role of problem-solvers confronted with an ill-structured situation that simulates the kind of problems they are likely to face as future managers in complex organizations.

Problem-based learning is student-centered. PBL makes a fundamental shift--from a focus on teaching to a focus on learning. The process is aimed at using the power of authentic problem solving to engage students and enhance their learning and motivation. There are several unique aspects that define the PBL approach:

- Learning takes place within the contexts of authentic tasks, issues, and problems--that are aligned with real-world concerns.
- In a PBL course, students and the instructor become colearners, coplanners, coproducers, and coevaluators as they design, implement, and continually refine their curricula.
- The PBL approach is grounded in solid academic research on learning and on the best practices that promote it. This approach stimulates students to take responsibility for their own learning, since there are few lectures, no structured sequence of assigned readings, and so on.
- PBL is unique in that it fosters collaboration among students, stresses the development of problem solving skills within the context of professional practice, promotes effective reasoning and self-directed learning, and is aimed at increasing motivation for life-long learning.

Problem-based learning begins with the introduction of an ill-structured problem on which all learning is centered. The problem is one that MBA students are likely to face as future professionals. Expertise is developed by engaging in progressive problem solving. Thus, problems drive the organization and dynamics of the course. MBA students, individually and collectively, assume major responsibility for their own learning and instruction. Most of the learning occurs in small groups rather than in lectures. As teacher, my role changes from "sage on stage" to a "guide by the side." My role is more like that of a facilitator and coach of student learning, acting at times as a resource person, rather than as knowledge-holder and disseminator. Similarly, your role, as a student, is more active, as you are engaged as a problem-solver, decision-maker, and meaning-maker, rather than being merely a passive listener and note-taker.

Where Did PBL Come From and Who Else is Using It?

PBL originated from a curriculum reform by medical faculty at Case Western Reserve University in the late 1950s. Innovative medical and health science programs continued to evolve the practice of PBL, particularly the specific small group learning and tutorial process that was developed by medical faculty at McMaster University in Canada. These innovative and forward-looking medical school programs considered the intensive pattern of basic science lectures followed by an equally exhausting clinical teaching program to be an ineffective and dehumanizing way to

prepare future physicians. Given the explosion of medical information and new technology, as well as the rapidly changing demands of future medical practice, a new mode and strategy of learning was developed that would better prepare students for professional practice. PBL has spread to over 50 medical schools, and has diffused into many other professional fields including law, economics, architecture, mechanical and civil engineering, as well as in K-12 curricula. And the entire MBA program at Ohio University has been designed as an integrated curriculum using the PBL approach.

Why PBL?

Traditional education practices, starting from kindergarten through college, tend to produce students who are often disenchanted and bored with their education. They are faced with a vast amount of information to memorize, much of which seems irrelevant to the world as it exists outside of school. Students often forget much of what they learned, and that which they remember cannot often be applied to the problems and tasks they later face in the business world. Traditional classrooms also do not prepare students to work with others in collaborative team situations. The result: students tend to view MBA education as simply a "right of passage," a necessary "union card," and an imposed set of hurdles with little relevance to the real world. Education is reduced to acquiring a diploma (merely another commodity to be purchased in the marketplace), and the final grade becomes the overriding concern (rather than learning).

Research in educational psychology has found that traditional educational approaches (e.g., lectures) do not lead to a high rate of knowledge retention. Despite intense efforts on the part of both students and teachers, most material learned through lectures is soon forgotten, and natural problem solving abilities may actually be impaired. In fact, studies have shown that in 90 days students forget 90% of everything they have been told (Smilovitz, 1996). Motivation in such traditional classroom environments is also usually low.

Perhaps one of the greatest advantages of PBL is that students genuinely enjoy the process of learning. PBL is a challenging program which makes the study of organization design and change intriguing for students because they are motivated to learn by a need to understand and solve real managerial problems. The relevance of information learned is readily apparent; students become aware of a need for knowledge as they work to resolve the problems.

How Does PBL Work?

A PBL course is designed into a series of real-world, hands-on, PBL investigations. You will be working in small groups/teams with other students on problems that you are likely to encounter as a professional manager. You will begin a PBL investigation by being presented with an ill-structured organizational problem or scenario. Such a presentation may be in the form of a written statement, a video clip of a real manager at a company, or a guest speaker. Every PBL team will appoint a chairperson/leader and sometimes a recorder/secretary. Your PBL team will be guided in the use of a reiterative problem-solving process. Your team will applyy this problem solving process to find, analyze, and solve the presenting problem. Some PBL investigations may culminate in a student-created project/product, exhibitions, or other artifacts that address the driving questions. In some cases, the PBL investigation will culminate in an oral performance with managers from the business community in attendance.

As you work with each problem you can:

1. Develop your diagnostic reasoning and analytical problem-solving skills.
2. Determine what knowledge you need to acquire to understand the problem, and others like it.
3. Discover the best resources for acquiring that information.
4. Carry out your own personalized study using a wide range of resources.
5. Apply the information you have learned back to the problem.
6. Integrate this newly acquired knowledge with your existing understanding.

In short, you will be learning in a highly relevant and exciting manner to problem-solve and to develop self-directed study skills that build toward the skills and knowledge that you will need as a practicing manager.

The problem-solving process can be summarized according to three broad and reiterative phases.

Phase 1. First, your group will gather information and list it under a heading entitled: "What do we already know?" In this phase, you will entertain the problem in light of the knowledge that you already have from your own experience.

Your group will discuss the current situation surrounding the problem as it has been presented. This analysis requires discussion and agreement on the working definitions of the problems, and sorting out which issues and aspects of the situation are worthy of further investigation. This initial analysis should yield a problem statement that serves as a starting point for the investigation, and it may be revised as assumptions are questioned and new information comes to light.

Phase 2. Next, you will engage with the problem by also identifying under a second heading, "What do we need to know (to solve this problem)?" Here you will list questions or learning issues that must be answered to address missing knowledge, or to shed light on the problem. It is in this phase that your group will be analyzing the problem into components, discussing implications, entertaining possible explanations or solutions, and developing working hypotheses. This activity is like a "brainstorming" phase with evaluation suspended while explanations or solutions are written on a flipchart or chalkboard. Your group will need to formulate learning goals, outlining what further information is needed, and how this information can best be obtained.

Phase 3. The above list should inform your group in what to do in order to solve the problem. In this phase your group will discuss, evaluate, and organize hypotheses and tentative hypotheses. Your group will make a "What should we do?" list that formulates keeps track of such issues as what resources to consult, people to interview, articles to read, and what specific actions team members need to perform. It is in this phase that your group will identify and allocate learning tasks, develop study plans to discover needed information. You will be gathering information from the classroom, resource readings, texts, library sources, videos, and from external experts on the subject. As new information is acquired, your group will need to meet to analyze and evaluate it for its reliability and usefulness in applying it to the problem.

In short, you will be spending a great deal of time discussing the problem, generating hypotheses, identifying relevant facts, searching for information, and defining their own learning issues. Unlike traditional and standard classes, learning objectives are not stated up front. Rather, you and members of your group will be responsible for generating your own learning issues or objectives based on your group's analysis of the problem.

All during this process, as a student, you will be actively defining and constructing potential solutions. As an instructor, my role is primarily to model, guide, coach--to support you and your team through the learning and assessment process.

The majority of class time will be devoted to working in self-directed, PBL small group tutorials. A portion of class time will be allocated to "Resource Sessions," which may include simulations, case studies, and brief discussions to further explore concepts and issues which arise out of the PBL projects.

Transitioning to a PBL Classroom Environment

Students who are new to a PBL classroom environment may find it initially unsettling. This is because you are being asked to take responsibility for your own learning, to work on ill-structured problems where there isn't a pre-established "right answer," and where you are expected to structure your own approach to acquiring and using information to solve problems. In many respects, this environment mimics the "real-world." In business settings, there are no standardized objective tests, lectures, or routine and well defined assignments. Entering this new type of learning environment requires you a willingness on your part to accept risk and uncertainty, and to become a self-directed learner.

Establishing an Open Climate for PBL

Establishing an open climate is essential for problem-based learning. Every student should feel free to say whatever comes to mind, any ideas or comments, no matter how unsophisticated or inappropriate they might seem, without being put down or criticized. Most students have learned in their prior educational experiences not to speak up or volunteer their thoughts unless they are absolutely sure of the answer. Any show of ignorance was held against them.

Learning can never occur unless you can bring out their ideas and thoughts, and openly admit to confusion, lack of understanding, or ignorance..."I don't know" is a powerful first step to learning. The same is true for myself as the instructor. The instructor doesn't have all the answers or know everything; no one person can be an authority in everything, and no one should be expected to have all the answers. We can ALL learn in this course.

It is your responsibility, as a student, TO SPEAK UP when you are doubtful, unsure, or uncomfortable with comments or ideas made by others in the group. You also must be willing to speak up when you feel that another member of your group is making statements that you feel are incorrect.

Students must also develop the ability to openly and constructively express their opinions about the comments or ideas of others, or about the quality of other students' performance in the group. It is your responsibility to offer opinions in a friendly and constructive manner. Every student must learn to both *give* and *accept* constructive criticism.

PBL Assessment Philosophy

To Assess. The Latin origin of this term, *assidere*, literally means *to sit down beside.* Another way of thinking of assessment is to use careful judgment based on the kind of close observation that comes from "sitting down beside."

With PBL, assessment is not separate from instruction. Rather, assessment is integral to learning. The focus and purpose of assessment is *on learning*, on how it is done, and how it can be better, not on normative comparisons. Assessment is a continuous process that drives instruction. Further, assessment does not bring an end to learning; it provides information about how to continue to develop your skills, knowledge and abilities with respect to the course learning objectives. Having said this, it is important for you to think of assessment as an *active demonstration of your understanding and ability to apply this understanding.*

Words like "tests" and "examinations" have well established connotations of evalutating a student's *possession* of knowledge. We need a different process, and a new language, to identify how to assess a student's capability for *using* and *applying* knowledge. Education of an individual, understood in terms of developing a capbility for using and applying one's knowledge, cannot be adequately assessed by traditional testing. Grading on a curve, which sorts students into groups for administrative purposes, says nothing about how each student is using his or her talents or growing toward their potential.

With PBL, the instructor is no longer the sole yardstick by which your progress will be measured. Rather, my role as instructor is to help students monitor themselves, to monitor your own progress, to establish criteria for learning and quality work, and to help you devise your own goals for improvement. This means that I will not be the only judge of student work; students will learn to evaluate the work of their peers, as well as their own. In addition, your work may also be monitored and evaluated by real-world assessors--managers and executives from companies in the Bay Area.

Students will codevelop with the instructor relevant and meaningful assessments, and play an active role in developing criteria and setting standards of performance for high quality work. Assessments must have meaning for the learner. For assessments to be meaningful, they must have some connection to the real world, difficult enough to be interesting but not totally frustrating, and generative, where a real product, service, or valued information is being evaluated. This concept of assessment-as-learning focuses on what *learners achieve*--not what *teachers provide.*

Therefore, in this course, student assessment is a multidimensional process, integral to learning, that involves observing performances of individual learners in action and judging them on the basis of collaboratively determined developmental criteria, with resulting feedback to that learner. Assessments may involve a performance or demonstration, usually for a real audience (i.e., managers from the business community) and useful purpose (e.g., as part of student exhibition or learning conference). Assessment must be seamless and ongoing; it must be part of the PBL process. Students must also learn during assessment; it is not simpy a "grade" that is tacked on at the end of a paper or transcript.

In general, and at minimum, students will be assessed in three broad areas:

1. *Applied Competence.* Demonstrate the ability to use organizational design and change management concepts and frameworks to identify and anaylze variables that can influence an organization's overall effectiveness.
2. *Critical Thinking, Problem-Solving and Communicative Competence.* Identify problems and/or opportunities in organizational contexts and make specific recommendations, supported by theory, to improve the situation. Accurately and competently using theoretical frameworks from organization design and change literature to interpret and solve business problems, and effectively communicating your analyses to others in a variety of

professional contexts. Implementing your problem solving activities with a commitment to quality.

3. *Collaborative and Leadership Competence.* Collaborates as a member of a project team, taking the initiative in identifying and solving problems or pursuing opportunities for learning and improvement within your group.

Assessment must also be seen as fair and equitable. In the early part of the semester, a voluntary "student assessment task force" will be formed. This task force will consists of student representatives from each of the three sections of MGMT 842 and will work with the instructor in developing an overall assessment plan for all three sections. After every PBL project, group-based assessments will be conducted. These assessments are to help facilitate reflection on what you learned during the PBL project, and to receive direct feedback from your team members on your performance, contributions, and intellectual achievements.

Your Study Guides and Strategies starts here!

Cooperative learning series

Problem-based learning

Problem-based learning (PBL) is an exciting alternative
to traditional classroom learning.

With PBL, your teacher presents you with a problem, not lectures or assignments or exercises. Since you are not handed "content", your learning becomes active in the sense that you discover and work with content that you determine to be necessary to solve the problem.

In PBL, your teacher acts as facilitator and mentor,
rather than a source of "solutions."

Problem based learning will provide you with opportunities to
examine and try out what you know
discover what you need to learn
develop your people skills for achieving higher performance in teams
improve your communications skills
state and defend positions with evidence and sound argument
become more flexible in processing information and meeting obligations
practice skills that you will need after your education

A Summary of Problem-Based Learning:

This is a simplified model--more detailed models are referenced below.

The steps can be repeated and recycled.

Steps two through five may be repeated and reviewed as new information becomes available and redefines the problem.

Step six may occur more than once--especially when teachers place emphasis on going beyond "the first draft."

1. Explore the issues:

Your teacher introduces an "ill-structured" problem to you.
Discuss the problem statement and list its significant parts.
You may feel that you don't know enough to solve the problem but that is the challenge!
You will have to gather information and learn new concepts, principles, or skills as you engage in the problem-solving process.

2. List "What do we know?"

What do you know to solve the problem?
This includes both what you actually know and what strengths and capabilities each team member has.
Consider or note everyone's input, no matter how strange it may appear: it could hold a possibility!

3. Develop, and write out, the problem statement in your own words:

A problem statement should come from your/the group's analysis of what you know, and what you will need to know to solve it. You will need:
a written statement
the agreement of your group on the statement
feedback on this statement from your instructor.
(This may be optional, but is a good idea)

> **Note:** The problem statement is often revisited and edited as new information is discovered, or "old" information is discarded.

4. List out possible solutions

List them all, then order them from strongest to weakest
Choose the best one, or most likely to succeed

5. List actions to be taken with a timeline

What do we have to know and do to solve the problem?
How do we rank these possibilities?
How do these relate to our list of solutions?
Do we agree?

6. List "What do we need to know?"

Research the knowledge and data that will support your solution
You will need to information to fill in missing gaps.
Discuss possible resources
Experts, books, web sites, etc.
Assign and schedule research tasks, especially deadlines

If your research supports your solution,
and if there is general agreement, go to (7). If not, go to (4)

7. Write up your solution with its supporting documentation, and submit it.

You may need to present your findings and/or recommendations to a group or your classmates.

This should include the problem statement, questions, data gathered, analysis of data, and support for solutions or recommendations based on the data analysis: in short, the process and outcome.

Presenting and defending your conclusions:

The goal is to present not only your conclusions,
but the foundation upon which they rest. Prepare to
State clearly both the problem and your conclusion
Summarize the process you used, options considered, and difficulties encountered
Convince, not overpower
Bring others to your side, or to consider without prejudice your supporting documentation and reason
Help others learn, as you have learned
If challenged
and you have an answer, present it clearly
and you don't have an answer, acknowledge it and refer it for more consideration

Sharing your findings with teachers and students is an opportunity in demonstrating that you have learned. If you know your subject well, this will be evident. If a challenge arises that you cannot respond to, accept it as an opportunity to be explored. However, take pride in your attention to quality when you present. See also the Guide on presenting projects.

8. Review your performance

This debriefing exercise applies both to individuals and the group.
Take pride in what you have done well; learn from what you have not done well. Thomas Edison took pride in unsuccessful experiments as part of his journey to successful outcomes!

9. Celebrate your work!

Classroom learning series

Preparing for the classroom | Class "prep"/paying attention |
Classroom discussions | Taking notes in lectures | Influencing teachers |
Interviewing for class projects | Consent form for interviews |
Problem based learning | Using guided notes

For more information:

To be successful, PBL requires problem solving and critical thinking skills.

See our Study Guides on

Making decisions/solving problems and Thinking critically, and/or ask your teacher for help in developing collaborative skills.

The role of argument:
Through various stages of this process, you or your group will be expected to come to consensus on how to next proceed. While each member is expected to "argue" his or her viewpoint, the focus should be on the issues and reason, not personalities and emotion.
If your group has difficulty, refer to your teacher for assistance as a mediator, and/or see the Guide **Cooperative conflict resolution**
For more on working in groups, see **Learning with others** in the main index.
For more on types of arguments, organization, evidence, as well as techniques in problem-based learning, see Dr. Larry D. Spence (Director, Undergraduate Learning Initiatives, Pennsylvania State University) "Problem Based learning: Lead to Learn, Learn to Lead **.pdf version** | **.doc version**
See also: Problem-based Learning, especially in the context of large classes

Problem-Based Learning Faculty Institute

What is PBL?
Grant Overview
Examples
Events
Winter 2000 PBL Institute
Winter 2001 PBL Institute
Links

Supported by a grant from
The William and Flora Hewlett Foundation

What is Problem-Based Learning?

Dr. De Gallow, Director, Instructional Resources Center,
Project Director, Hewlett Grant

One of the primary features of Problem-Based Learning is that it is student-centered. ⬩Student-centered⬩ refers to learning opportunities that are relevant to the students, the goals of which are at least partly determined by the students themselves. This does not mean that the teacher abdicates her authority for making judgments regarding what might be important for students to learn; rather, this feature places partial and explicit responsibility on the students⬩ shoulders for their own learning. Creating assignments and activities that require student input presumably also increases the likelihood of students being motivated to learn.

A common criticism of student-centered learning is that students, as novices, cannot be expected to know what might be important for them to learn, especially in a subject to which they appear to have no prior exposure. The literature on novice-expert learning does not entirely dispute this assertion; rather, it does emphasize that our students come to us, not as the proverbial blank slates, but as individuals whose prior learning can greatly impact their current learning (Scardamalia, Bereiter, 1991) . Often they have greater content and skill knowledge than we (and they) would expect. In any case, whether their prior learning is correct is not the issue. Whatever the state of their prior learning, it can both aid and hinder their attempts to learn new information. It is therefore imperative that instructors have some sense of what intellectual currency the students bring with them. One way to determine this is by being witness to how students go about addressing intellectual challenges, especially those that seem at variance with their current understanding. Active, interactive, and collaborative learning, on which Problem-Based Learning is based, allows an instructor the rare opportunity to observe students⬩ learning processes.

The context for learning in PBL is highly context-specific. It serves to teach content by presenting the students with a real-world challenge similar to one they might encounter were they a practitioner of the discipline. Teaching content through skills is one of the primary distinguishing features of PBL. More commonly, instructors introduce students to teacher determined content via lecture and texts. After a specific amount of content is presented, students are tested on their understanding in a variety of ways. PBL, in contrast, is more

inductive: students learn the content as they try to address a problem.

The ⁄problems⁄ in PBL are typically in the form of ⁄cases⁄, narratives of complex, real-world challenges common to the discipline being studied. There is no right or wrong answer; rather, there are reasonable solutions based on application of knowledge and skills deemed necessary to address the issue [1]. The ⁄solution⁄ therefore is partly dependent on the acquisition and comprehension of facts, but also based on the ability to think critically. What does ⁄critical thinking⁄ refer to? The phrase is often bandied about but seldom defined. For our purposes, critical thinking refers to the ability to analyze, synthesize, and evaluate information, as well as to apply that information appropriate to a given context. It is both critical and creative in that synthesis, in particular, requires the learner to take what information is known, reassemble it with information not known, and to derive a new body of knowledge. Note that we⁄re not necessarily asking students to create new knowledge in the way a practicing scholar does; instead, we⁄re asking students to create something that is at least new to them. (It is not uncommon, for even undergraduates to develop some pretty sophisticated and ingenious solutions.)

The instructor is not passive during student learning, but neither does he take the traditional role of ⁄sage on the stage.⁄ The instructor⁄s role can be to model different kinds of problem-solving strategies, sometimes referred to as ⁄cognitive apprenticeship⁄ learning (Brown, Collins, & Newman, 1989). Students also can model for one another a variety of problem-solving strategies. The most common instructor role is to question the students about their learning process by asking meta-cognitive questions: ⁄How do you know that?⁄ ⁄What assumptions might you be making?⁄ These questions are meant to get students to become self-reflective about their learning processes, thus another primary feature of PBL is that it is process-centered more so than product-centered. This may seem contradictory as ⁄solving⁄ the problem is an important and critical aspect of PBL⁄hence its name. The point to be taken here, however, is that while content changes (especially in a rapidly changing technological world), the ability to problem-solve needs to be more portable. No one set of skills will suffice for all time, either; but the ability to generate problem-solving strategies is the skill ⁄with legs.⁄ Information trans-ferability is limited by the information available; how to find and create information is limited only by the learner⁄s willingness to participate. PBL, by having students demonstrate for themselves their capabilities, can increase students⁄ motivation to tackle problems.

Problem-based learning is also experiential in that participants experience what it is like to think as a practitioner. How do biologists think? What distinguishes the way a criminologist might address a problem as opposed to the way a mathematician might? How might these two specialists work together on a problem, a question more germane as disciplines become ever more inter-disciplinary? It is also a question of great concern to employers. Three major complaints from employers about college graduates are graduate⁄s poor written and verbal skills, their inability to problem-solve, and their difficulties working collaboratively with other profes-sionals. PBL can address all three areas.

Defining Characteristics of PBL:

WHAT:	HOW?	WHY?
Student-centered & Experiential	Select authentic assignments from the discipline, preferably those that would be relevant and meaningful to student interests. Students are also responsible for locating and evaluating various resources in the field.	Relevance is one of the primary student motivators to be a more self-directed learner
Inductive	Introduce content through the process of problem solving, rather than problem solving after introduction to content.	Research indicates that ◆deeper◆ learning takes place when information is introduced within a meaningful context.
Builds on/challenges prior learning	If the case has some relevance to students, then they are required to call on what they already know or think they know. By focusing on their prior learning, students can test assumptions, prior learning strategies, and facts.	The literature suggests that learning takes placewhen there is a conflict between prior learning and new information.
Context-specific	Choose real or contrived cases and ground the count in the kinds of challenges faced by practitioners in the field.	Again, context-specific information tends to be learned at a deeper level and retained longer.
Problems are complex and ambiguous, and require meta-cognition	Select actual examples from the ◆real life◆ of the discipline that have no simple answers. Require students to analyze their own problem solving strategies.	Requires the ability to use higher order thinking skills such as analysis, synthesis, evaluation, and creation of new knowledge.
Creates cognitive conflict	Select cases with information that makes simple solutions difficult: while the solution may	The literature suggests that learning takes place when there is a conflict between prior learning and new

	address one part of a problem, it may create another problem. Challenges prior learning as noted above.	information.
Collaborative & Interdependent	Have students work in small groups in order to address the presented case	By collaborating, students see other kinds of problem solving strategies used, they discuss the case using their collective information, and they need to take responsibility for their own learning, as well as their classmates.

[1] These "higher order" thinking skills are attributed to the work of Benjamin Bloom and colleagues (1956) in Bloom's Taxonomy, a hierarchical model of thinking skills.