

# The Many Faces of Inductive Teaching and Learning

By Michael Prince  
and Richard Felder



This study examines the effectiveness and implementation of different inductive teaching methods, including inquiry-based learning, problem-based learning, project-based learning, case-based teaching, discovery learning, and just-in-time teaching.

Science courses are traditionally taught deductively. The instructor first teaches students relevant theory and mathematical models, then moves on to textbook exercises, and eventually—maybe—gets to real-world applications. Often the only motivation students have to learn the material, beyond grades, is the vague promise that it will be important later in the curriculum or in their careers. Failure to connect course content to the real world has repeatedly been shown to contribute to students leaving the sciences (Seymour and Hewitt 1997; Kardash and Wallace 2001).

A better way to motivate students is *inductive teaching*, in which the instructor begins by presenting students with a specific challenge, such as experimental data to interpret, a case study to analyze, or a complex real-world problem to solve. Students grappling with these challenges quickly recognize the need for facts, skills, and conceptual understanding, at which point the teacher provides instruction or helps students learn on their own. Bransford, Brown, and Cocking (2000) survey extensive neurological and psy-

**Michael Prince** (prince@bucknell.edu) is a professor in the Department of Chemical Engineering at Bucknell University in Lewisburg, Pennsylvania. **Richard Felder** (rmfelder@mindspring.com) is the Hoechst Celanese Professor Emeritus of Chemical and Biomolecular Engineering at North Carolina State University.

chological research that provides strong support for inductive teaching methods. The literature also demonstrates that inductive methods encourage students to adopt a deep approach to learning (Ramsden 2003; Norman and Schmidt 1992; Coles 1985) and that the challenges provided by inductive methods serve as precursors to intellectual development (Felder and Brent 2004).

Inductive teaching methods come in many forms, including discovery learning, inquiry-based learning, problem-based learning, project-based learning, case-based teaching, and just-in-time teaching. Few studies have examined these methods as a group. Prince and Felder (2006) provide an extensive analysis of the conceptual frameworks and research bases for inductive teaching, review applications of inductive methods in engineering education, and state the roles of other student-centered approaches, such as active and cooperative learning, in inductive teaching. This paper briefly reviews the distinguishing features of the principal inductive methods, describes illustrative applications in the sciences, discusses practical issues of implementation, and suggests resources for instructors who wish to use one or more inductive methods in their own teaching.

## Inductive teaching methods

What inductive methods have in common is that students are presented

with a challenge and then learn what they need to know to address the challenge. The methods differ in the nature and scope of the challenge and in the amount of guidance students receive from their instructor as they attempt to meet the challenge.

### *Inquiry-based learning*

In *inquiry-based learning* (also known as *inquiry-guided learning* or *guided inquiry*), students are presented with a challenge (such as a question to be answered, an observation or data set to be interpreted, or a hypothesis to be tested) and accomplish the desired learning in the process of responding to that challenge. As with all inductive methods, the information needed to address the challenge would not have been previously covered explicitly in lectures or readings, although it would normally build on previously known material. Inquiry has frequently been found to be more effective than traditional science instruction at improving academic achievement and the development of thinking, problem-solving, and laboratory skills (Smith 1996; Haury 1993; McReary, Golde, and Koeske 2006; Shymansky, Hedges, and Woodworth 1990; Rubin 1996; Oliver-Hoyo and Allen 2005; Oliver-Hoyo et al. 2004). Colburn (2006) recommends focusing inquiry-based activities around questions that call for experimental investigation, involve materials and situations

somewhat familiar to students, and pose a sufficient level of challenge to promote skill development.

Inquiry-based methods have been used in many different disciplines, including physics (Fencl and Scheel 2005; McDermott 1995; Thacker et al. 1994; Heflich, Dixon, and Davis 2001), biology (Chamanay and Lang; Londraville et al. 2002), and chemistry (Jalil 2006; Lewis and Lewis 2005; Oliver-Hoyo, Allen, and Anderson 2004; Oliver-Hoyo and Allen 2005).

The POGIL (Process-Oriented Guided Inquiry Learning) website ([www.pogil.org](http://www.pogil.org)) contains reports of implementations on several campuses, instructional materials for different branches of chemistry, and a video showing an implementation of the method in an introductory chemistry class. *ChemConnections* (<http://mc2.cchem.berkeley.edu>) surveys inquiry-based instructional modules developed at the University of California at Berkeley for the first two years of the chemistry curriculum. The *ChemCollective* ([www.chemcollective.org/find.php](http://www.chemcollective.org/find.php)) archives resources for inquiry-based chemistry instruction, including virtual laboratory experiments, concept tests, problem scenarios, and simulations. Lee (2004) reports on a series of inquiry-based courses in different disciplines at North Carolina State University, including chemistry and physics in large classes (Oliver-Hoyo and Beichner 2004), microbiology (Hyman and Luginbuhl 2004), and wood and paper science (Kirkman et al. 2004).

Any instruction that begins with a challenge for which the required knowledge has not been previously provided technically qualifies as inquiry-based learning, and the scope of the inquiry may vary from a portion of a single lecture to a major term project. In this sense, all inductive methods are variants of inquiry, differing essentially in the nature of the challenge and the type and degree of support provided by the instructor. We will adhere to common usage by using the terms problem-based learning, project-based learning, and discovery learning to refer to instruction that

has the defining characteristics of those methods, and use inquiry-based learning as an umbrella category for any other inductive approach.

### *Discovery learning*

In *discovery learning*, students are confronted with a challenge and left to work out the solution on their own (Bruner 1961; French 2006). The instructor may provide feedback in response to student efforts but offers little or no direction before or during those efforts. The lack of structure and guidance provided by the instructor and the trial and error consequently required of students are the defining features of discovery learning relative to other inductive methods. This extreme form of inductive teaching was developed for precollege education and has rarely been used in undergraduate classes, and there is little empirical evidence for its effectiveness in that setting. (There is significant evidence for the benefits of involving undergraduate students in independent research [Seymour et al. 2004], but undergraduate research does not usually qualify as discovery learning because the advisor typically provides significant structure and guidance.)

More common than pure discovery are variants such as *guided discovery*, in which the instructor provides some structure and support (Spencer and Jordan 1996). Depending on the nature of the initial challenge and the extent of the guidance, these variants would typically fall into one or another of the other categories that follow.

### *Problem-based learning*

In *problem-based learning* (PBL), students—usually working in teams—are confronted with an ill-structured open-ended real-world problem to solve, and take the lead in defining the problem precisely, figuring out what they know and what they need to determine, and how to proceed to determine it. They formulate and evaluate alternative solutions, select the best one and make a case for it, and evaluate lessons learned. When they identify the need for instruction on new material, the

instructor either provides it or guides the students to obtain the required information themselves.

Several examples of PBL implementations are given in chapters of the edited volume of Duch, Groh, and Allen (2001). In Chapter 18, Susan Groh outlines a series of problems in a case study called “Winter Woes” that she used in a general chemistry course. The students are given several scenarios having to do with a cold and icy winter day: their car is running rough (Could water have gotten into the fuel lines at the prevailing weather conditions? What can be done if it did?); they need to choose from among several salts with different costs to use for de-icing a sidewalk; and they need to select from among several desalination processes to purify the city’s water supply after a retaining wall failed and tons of rock salt were carried into the reservoir. In Chapter 21, Barbara Williams presents a first-year physics problem in which someone stands on a scale in an elevator and the students must figure out how the scale readings would vary as the elevator moves up and down.

PBL originated, and is extensively practiced, in medical education and other health-related disciplines (Savin-Baden and Major 2004). PBL problems in chemistry and physics (among other fields) and guidance on how to use them are given in Duch, Groh, and Allen (2001) and on websites maintained at the University of Delaware ([www.udel.edu/pbl](http://www.udel.edu/pbl)) and Samford University ([www.samford.edu/pbl](http://www.samford.edu/pbl)), both of which provide links to many additional resources.

A meta-analysis of the effectiveness of problem-based learning was published by Dochy et al. (2003). Their results suggest that students may acquire more knowledge in the short term when taught conventionally but are likely to retain knowledge longer when taught with problem-based learning. The results for skill development consistently favored PBL instruction. Prince (2004) examined several meta-analyses and concluded that PBL improves students’ skill development,

retention of knowledge, and ability to apply learned material, but it does not have a statistically significant effect on academic achievement as measured by exams. Prince and Felder (2006) cite studies reporting a robust positive effect of PBL on development of a variety of problem-solving skills, conceptual understanding, ability to apply meta-cognitive and reasoning strategies, teamwork skills, and even class attendance.

Problem-based learning is arguably the most difficult to implement of all the inductive teaching methods. It is time-consuming to construct authentic open-ended problems whose solution requires the full range of skills specified in the instructor's learning objectives, so instructors are advised to use problems that have already been developed and tested, if such problems can be located (e.g., at the University of Delaware PBL Clearinghouse). PBL gives students the responsibility of defining the knowledge and skills they need to proceed with each phase of the problem, and so instructors must be prepared to go in directions that may not be familiar or comfortable. Moreover, PBL involves a spectrum of instructional features likely to provoke student resentment and resistance, including complex problems that have no unique solutions, the need for students to define for themselves what they need to know to solve them, and the logistical and interpersonal problems that inevitably arise when students work in teams. Instructors who lack the subject knowledge and self-confidence that normally come only with extensive experience and training could easily find themselves overwhelmed by the negative responses of their students.

### *Project-based learning and hybrid (problem/project-based) methods*

*Project-based learning* involves assignments that call for students to produce something, such as a process or product design, a computer code or simulation, or the design of an experiment and the analysis and interpreta-

tion of the data. The culmination of the project is normally a written or oral report summarizing what was done and what the outcome was. Project-based learning implementations in science curricula have not been extensively reported, although some of the applications cited in this article for inquiry-based learning could be considered project-based as well. Several implementations of *service learning* (a form of project-based learning in which the projects involve some type of community service) have been reported in chemistry courses (Draper 2004; Kesner and Eyring 1999; O'Hara, Sanborn, and Howard 1999).

Strictly speaking, in project-based learning students mainly apply previously acquired knowledge and the final product is the central focus of the assignment, while in problem-based learning, students have not previously received formal instruction in the necessary background material and the solution process is more important than the final product. In practice the distinction between the two methods is not necessarily that clean, and instructional programs have recently adopted approaches that are hybrids of both methods (Kolmos, personal communication; Tan et al. 2003; Galand and Frenay 2005).

Studies comparing project-based learning to conventional instruction have yielded results similar to those obtained for problem-based learning, including significant positive effects on problem-solving skills, conceptual understanding, and attitudes to learning, and comparable or better student performance on tests of content knowledge (Thomas 2000; Mills and Treagust 2003). Mills and Treagust (2003) note, however, that students taught with project-based learning may gain a less-complete mastery of fundamentals than conventionally taught students acquire, and some of the former students may be unhappy over the time and effort required by projects and the interpersonal conflicts they experience in team work. Moreover, if the project work is done

entirely in teams, students may be less equipped to work independently.

Project-based learning falls between inquiry and problem-based learning in terms of the challenges it poses to instructors. Projects and the knowledge and skills needed to complete them may be relatively well defined and known from previous parts of the curriculum, which lessens the likelihood of student resistance, and they may be defined in a manner that constrains students to territory familiar to the instructor, which further reduces the difficulty of implementation. Projects are usually done by student teams but they may also be assigned to individuals, which avoids many logistical and interpersonal problems but also cuts down on the range of skills that can be developed through the project. The challenge of project-based learning is to define projects with a scope and level of difficulty appropriate for the class, and if the end product is a constructed device or if the project involves experimentation, the appropriate equipment and laboratory and shop facilities must be available. Hybrid (problem/project-based) approaches encompass all of the difficulties associated with both methods and so can be particularly challenging to implement.

### *Case-based teaching*

In *case-based teaching*, students study historical or hypothetical cases involving scenarios likely to be encountered in professional practice. Students are challenged to explore their existing preconceptions and modify them to accommodate the realities of the cases (Lundeberg, Levin, and Harrington 1999). Compared to typical problems used in problem-based learning, cases tend to be relatively well structured and rich in contextual details, and students apply material that is already somewhat familiar (Lohman 2002).

Cases are most commonly thought of in the context of law and management science education, but they have also been used extensively in science (Herreid 1997).

The National Center for Case Study Teaching in Science (<http://ublib.buffalo.edu/libraries/projects/cases/case.html>) at the University of Buffalo archives case studies in the physical, chemical, and biological sciences, mathematics and computer science, medicine, engineering, psychology, and ethics. Another website (<http://edr1.educ.msu.edu/references/view-article.asp>), developed jointly at the University of Buffalo and Michigan State University, summarizes articles assessing both case-based instruction and problem-based learning in many different fields.

The key to case-based instruction is having cases that are clear and realistic and encompass all of the teaching points the instructor wishes to convey. Constructing such cases can be extraordinarily time consuming. Using case-based instruction may therefore be considered moderate in difficulty (roughly comparable to project-based learning) if suitable prewritten cases are available, and second in difficulty among induc-

tive methods only to problem-based learning if instructors must create and analyze the cases themselves.

Studies have shown that relative to conventional teaching, case-based instruction significantly improves student retention (Fasko 2003), reasoning and problem-solving skills (Levin 1997; Fasko 2003), higher-order skills on Bloom's taxonomy (Gabel 1999), the ability to make objective judgments (Dinan 2002), the ability to identify relevant issues and recognize multiple perspectives (Lundeberg et al. 1999), and awareness of ethical issues (Lundeberg, Levin, and Harrington 2002). Lundeberg and Yadav (2006) carried out a meta-analysis and concluded that cases have a positive impact on faculty and student attitudes, class attendance, and faculty perceptions of learning outcomes. They also note that the reported comparisons of the effectiveness of case studies versus traditional instruction depend strongly on the assessment tasks and that "the higher the level of knowledge and

thinking required on the assessment task, the more likely that case-based teaching will produce greater gains in student understanding." Studies of the effect of case-based instruction on the acquisition and recall of factual knowledge are inconclusive (Fasko 2003; Katsikitis et al. 2002).

### *Just-in-time teaching*

In *just-in-time teaching* (JiTT), students respond electronically to conceptual questions before each class, and the instructor adjusts the lesson to react to misconceptions revealed by students' responses. Since the conceptual questions involve material not yet covered in class, the method qualifies as inductive. JiTT was developed jointly by physics faculty at Indiana University-Purdue University Indianapolis, the U.S. Air Force Academy, and Davidson College, and can be combined with almost any in-class active learning approach (Modesitt, Maxim, and Akingbehin 1999; Novak et al. 1999). The *Just-in-Time Teaching* website (<http://webphysics.iupui>.

**TABLE 1**

### Instructional demands imposed by inductive teaching methods.

Method	Required resources	Planning time and instructor involvement	Student resistance
Inquiry	None	Small	Minimal
Cases (individual)	Cases	Small (existing cases); considerable (original cases)	Minimal
Project-based (individual)	Facilities for experimental projects	Small (same project, no facilities maintenance); moderate (different projects, facilities maintenance) <sup>a</sup>	Minimal
Just-in-time teaching	Web-based course management system	Moderate (continual need to adjust lesson plans to reflect student answers to pre-class questions)	Moderate
Cases (teams)	Cases	Considerable (team management) <sup>b</sup>	Considerable <sup>b</sup>
Project-based (teams)	Facilities for experimental projects	Considerable (team management, facilities maintenance <sup>a</sup> )	Considerable <sup>a,b</sup>
Problem-based	Problems	Considerable (existing problems), extensive (original problems) <sup>b</sup>	Major <sup>c</sup>
Hybrid (problem/project-based)	Problems, facilities for experimental projects	Considerable (existing problems), extensive (original problems) <sup>a,b</sup>	Major <sup>c</sup>

<sup>a</sup> Assuming that experimental facilities are required for student projects and that the instructor (as opposed to a technician) is involved in maintaining them.

<sup>b</sup> Assuming that cooperative learning principles are followed for team projects. If, for example, students can self-select teams and the instructor makes no effort to assess individual knowledge and performance or to intervene in team conflicts, the demands on the instructor are the same as for individual assignments using the same method.

<sup>c</sup> Resistance follows both from the burden of responsibility for their own learning placed on students and the additional demands imposed by cooperative learning. Hybrid methods may also involve problems of facilities maintenance.

[edu/jitt/jitt.html](http://edu/jitt/jitt.html)) provides information and resources for JiTT.

An assessment of the effectiveness of JiTT in physics instruction (Novak et al. 1999) showed normalized student gains on the Force Concept Inventory of 35–40%, and JiTT reduced student attrition by 40% compared to traditionally taught physics courses. Marrs and Novak (2004) found that the use of JiTT in a large-enrollment introductory biology course for nonmajors led to improved pretest-posttest gains, course retention, class preparation, classroom interactivity, and student study habits, and Slunt and Giancarlo (2004) found that JiTT led to improved student performance and engagement in general chemistry and organic chemistry courses.

Just-in-time teaching is somewhat demanding to implement, for several reasons. It requires preparation of conceptual questions prior to every lecture and a web-based course management system that can tabulate students' responses for the instructor to review. It also requires flexibility on the part of instructors, who must adjust their lesson plans for each lecture in reaction to students' responses and could end up following significantly different schedules for different classes. The overall difficulty of implementation depends considerably on the ease of use and reliability of the course management software and on whether the questions already exist or must be made up by the instructor.

### Selection and implementation of an inductive teaching method

While studies supporting the different inductive methods vary in both quantity and persuasiveness, the collective evidence favoring inductive teaching over traditional deductive pedagogy is unequivocal. Induction is supported by widely accepted educational theories, cognitive science, and empirical research.

Inductive methods are not trivial to implement, however. Relative to traditional deductive teaching, they impose more logistical problems,

require more planning and possibly more resources, and are more likely to arouse student resistance and interpersonal conflicts (Felder and Brent 1996). The less explicit instruction and guidance students are given before and while they are addressing a challenge, the greater the resistance is likely to be. Moreover, instructional methods that call for the use of cooperative (team-based) learning pose additional problems, such as the needs to assess individual student performance in a team environment and to equip students to deal with the interpersonal and communication problems that inevitably arise in teamwork.

Table 1 compares the relative demands of the methods discussed in the preceding sections. The resources listed are only those that are difficult to prepare or costly to obtain. The suggested levels of difficulty refer to the difficulty for the instructor, not the students.

We propose that instructors contemplating adoption of an inductive method consider the following questions, and base their selected method on the answers.

*1. What are your instructional objectives for the course or specified topic? Are at least some of them at high cognitive levels?*

If instructional objectives are at a low cognitive level, requiring almost exclusively rote memorization of facts or mechanical substitution into formulas, there is no reason to use an inductive method. Low-level material is most effectively and efficiently taught by giving students a study guide for tests that specifies what they should memorize and the types of calculations they might be required to perform on tests, and providing examples and practice (in and out of class) in the calculations.

*2. How experienced are you with active or inductive teaching and using student teams? Are you on a tenure track but not yet tenured?*

Inexperienced instructors who are still trying to figure out how to deal with the routine problems associated with

teaching of any type can easily be overwhelmed by the additional challenges imposed by inductive methods. Instructors with little or no experience using inductive methods are advised to avoid the more difficult ones (see Table 1), and methods that call for extensive teamwork should automatically be considered difficult. This rule of thumb is particularly true for untenured assistant professors, who can ill afford the excessive time demands and negative student ratings that often accompany inexperienced implementations of difficult methods.

*3. Are resources (e.g., PBL problems, case studies, or just-in-time teaching exercises and the computer facilities needed to process them) available for the subject you are teaching?*

The more resource-intensive the method, the greater the need for existing resources or external support to implement it. Instructors should be mindful of the time demands of each method and take advantage of existing resources, experienced colleagues, and teaching center consultants who can offer tips on implementing the method and dealing with problems that arise in its use. ■

### References

- Bransford, J.D., A.L. Brown, and R.R. Cocking, eds. 2000. *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academy Press. Available online at [www.nap.edu/books/0309070368/html](http://www.nap.edu/books/0309070368/html).
- Bruner, J.S. 1961. The act of discovery. *Harvard Education Review* 31 (1): 21–32.
- Chamanay, K., and E. Lang. Teaching cell biology today: Incorporating contemporary issues into a collection of teaching modules. Project Kaleidoscope. [www.pkal.org/documents/TeachingCellBiologyToday.cfm](http://www.pkal.org/documents/TeachingCellBiologyToday.cfm).
- Colburn, A. 2006. What teacher educators need to know about inquiry-based instruction. Paper presented at the annual meeting of the Association for the Education of Teachers in Science, Ak-

- ron, OH. Available at [www.csulb.edu/~acolburn/AETS.htm](http://www.csulb.edu/~acolburn/AETS.htm).
- Coles, C.R. 1985 Differences between conventional and problem-based curricula in their students' approaches to studying. *Medical Education* 19(4): 308–09.
- Dinan, F. 2002. Chemistry by the case. *Journal of College Science Teaching* 32 (1): 36–41.
- Dochy, F., M. Segers, P. Van den Bossche, and D. Gijbels. 2003. Effects of problem-based learning: A meta-analysis. *Learning and Instruction* 13: 533–68.
- Draper, A.J. 2004. Integrating project-based service-learning into an advanced environmental chemistry course. *Journal of Chemical Education* 81 (2): 221–24.
- Duch, B.J., S.E. Groh, and D.E. Allen. 2001. *The power of problem-based learning*. Sterling, VA: Stylus.
- Fasko, D. 2003. Case studies and method in teaching and learning. Paper presented at the annual meeting of the Society of Educators and Scholars, Louisville, KY.
- Felder, R.M., and R. Brent. 1996. Navigating the bumpy road to student-centered instruction. *College Teaching* 44 (2): 43–47. Available online at [www.ncsu.edu/felder-public/Papers/Resist.html](http://www.ncsu.edu/felder-public/Papers/Resist.html).
- Felder, R.M., and R. Brent. 2004. The intellectual development of science and engineering students. Pt. 1: Models and challenges; Pt. 2: Teaching to promote growth. *Journal of Engineering Education* 93 (4): 269–77; 93 (4): 279–91. Pt. 1 available online at [www.ncsu.edu/felder-public/Papers/IntDev-I.pdf](http://www.ncsu.edu/felder-public/Papers/IntDev-I.pdf); Pt. 2 available online at [www.ncsu.edu/felder-public/Papers/IntDev-II.pdf](http://www.ncsu.edu/felder-public/Papers/IntDev-II.pdf).
- Fencl, H., and K. Scheel. 2005. Engaging students. *Journal of College Science Teaching* 35 (1): 20–24.
- French, D. 2006. Don't confuse inquiry and discovery. *Journal of College Science Teaching* 35 (6): 58–59.
- Gabel, C. 1999. Using case studies to teach science. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Boston.
- Galand, B., and M. Frenay. 2005. L'approche par problèmes et par projets dans l'Enseignement Supérieur: Impact, enjeux et défis [Problem- and project-based learning in higher education: Impact, implementation, and challenges], Louvain-la-Neuve: Presses Universitaires de Louvain. A video of Professor Frenay presenting (in English) a description of the Louvain curriculum and summarizing the assessment and evaluation of its effectiveness can be viewed online at [http://video.aau.dk/lectures/I20/I20\\_UCPBL.html](http://video.aau.dk/lectures/I20/I20_UCPBL.html).
- Haury, D. 1993. Teaching science through inquiry. (ERIC Document Reproduction no. ED 359 048).
- Heflich, D., J. Dixon, and K. Davis. 2001. Taking it to the field: The authentic integration of mathematics and technology in inquiry-based science instruction. *Journal of Computers in Mathematics and Science Teaching* 20 (1): 99.
- Herreid, C.F. 1997. What is a case? *Journal of College Science Teaching* 27 (2): 92–94.
- Hyman, M., and G. Luginbuhl. 2004. Inquiry-guided learning and the undergraduate major in the department of microbiology. In *Teaching and learning through inquiry: A guidebook for institutions and instructors*, ed. V.S. Lee, 129–41. Sterling, VA: Stylus.
- Jalil, P.A. 2006. A procedural problem in laboratory teaching: Experiment and eXplain, or vice versa? *Journal of Chemical Education* 83 (1): 159–63.
- Kardash, C., and M. Wallace. 2001. The perceptions of science classes survey: What undergraduate science reform efforts really need to address. *Journal of Educational Psychology* 93 (1): 199–210.
- Katsikitis, M., P.J. Hay, R.J. Barrett, and T. Wade. 2002. Problem- versus case-based approaches in teaching medical students about eating disorders: A controlled comparison. *Educational Psychology* 22 (3): 277–83.
- Kesner, L., and E.M. Eyring. 1999. Service-learning general chemistry: Lead paint analyses. *Journal of Chemical Education* 76 (7): 920–23.
- Kirkman, A.G., M.V. Byrd, H. Jameel, and J.A. Heitman. 2004. The challenge of implementing an inquiry-guided approach in a highly technical curriculum. In *Teaching and learning through inquiry: A guidebook for institutions and instructors*, ed. V.S. Lee, 143–56. Sterling, VA: Stylus.
- Lee, V.S., ed. 2004. *Teaching and learning through inquiry: A guidebook for institutions and instructors*. Sterling, VA: Stylus.
- Levin, B. 1997. The influence of context in case-based teaching: Personal dilemmas, moral issues or real change in teachers' thinking? Paper presented at the annual meeting of the American Educational Research Association, Chicago. Quoted in Lundeberg et al. 2002, 89.
- Lewis, S.E., and J.E. Lewis. 2005. Department from lectures: An evaluation of a peer-led guided inquiry alternative. *Journal of Chemical Education* 82 (1): 135–39.
- Lohman, M. 2002. Cultivating problem-solving skills through problem-based approaches to professional development. *Human Resource Development Quarterly* 13 (3): 243.
- Londrville, R., P. Niewiarowski, R. Laipply, and K. Owens. 2002. Inquiry-based laboratories for introductory biology. *Society for Integrative and Comparative Biology* 42 (6): 1267.
- Lundeberg, M., B. Levin, and H. Harrington. 1999. *Who learns what from cases and how? The research base for teaching and learning with cases*. Mahwah, NJ: Lawrence Erlbaum Associates.
- Lundeberg, M., K. Mogen, M. Bergland, K. Klyczek, D. Johnson, and E. MacDonald. 2002. Fostering ethical awareness about human genetics through multimedia-based cases. *Journal of College Science Teaching* 32 (1): 64–69.
- Lundeberg, M.A., and A. Yadav. 2006.

- Assessment of case study teaching: Where do we go from here? Pts. 1 and 2. *Journal of College Science Teaching* 35 (5):10–13; 35 (6): 8–13.
- Marrs, K.A., and G. Novak. 2004. Just-in-time teaching in biology: Creating an active learner classroom using the internet. *Cell Biology Education* 3: 49–61.
- McCreary, C.L., M.F. Golde, and R. Koeske. 2006. Peer instruction in the general chemistry laboratory: Assessment of student learning. *Journal of Chemical Education* 83 (5): 804–10.
- McDermott, L.C. 1995. *Physics by inquiry*. New York: John Wiley & Sons.
- Mills, J.E., and D.F. Treagust. 2003. Engineering education—Is problem-based or project-based learning the answer? *Australasian Journal of Engineering Education*. [www.aeee.com.au/journal/2003/mills\\_treagust03.pdf](http://www.aeee.com.au/journal/2003/mills_treagust03.pdf).
- Modesitt, K.L., B. Maxim, and K. Akingbehin. 1999. Just-in-time learning in software engineering. *Journal of Computers in Mathematics and Science Teaching* 18 (3): 287–301.
- Norman, G.R., and H.G. Schmidt. 1992. The psychological basis of problem-based learning: A review of the evidence. *Academic Medicine* 67 (9): 557–65.
- Novak, G.M., E.T. Patterson, A.D. Gavrín, and W. Christian. 1999. *Just-in-time teaching: Blending active learning with web technology*. Upper Saddle River, NJ: Prentice Hall.
- O'Hara, P.B., J.A. Sanborn, and M. Howard. 1999. Pesticides in drinking water: Project-based learning within the introductory chemistry curriculum. *Journal of Chemical Education* 76 (12): 1673–77.
- Oliver-Hoyo, M., and D. Allen. 2005. Attitudinal effects of a student-centered active learning environment. *Journal of Chemical Education* 82 (6): 944–49.
- Oliver-Hoyo, M., D. Allen, D. and M. Anderson. 2004. Inquiry-guided Instruction. *Journal of College Science Teaching* 33 (6): 20–24.
- Oliver-Hoyo, M., D. Allen, W.F. Hunt, J. Hutson, and A. Pitts. 2004. Effects of an active learning environment: Teaching innovations at a research I institution. *Journal of Chemical Education* 81 (3): 441–48.
- Oliver-Hoyo, M., and R. Beichner. 2004. SCALE-UP: Bringing inquiry-guided methods to large enrollment courses. In *Teaching and learning through inquiry: A guidebook for institutions and instructors*, ed. V.S. Lee, 51–69. Sterling, VA: Stylus.
- Prince, M. 2004. Does active learning work? A review of the research. *Journal of Engineering Education* 93 (3): 223–31.
- Prince, M., and R.M. Felder. 2006. Inductive teaching and learning methods: Definitions, comparisons, and research bases. *Journal of Engineering Education* 95 (2): 123–38.
- Ramsden, P. 2003. *Learning to teach in higher Education*. 2nd ed. London: Taylor and Francis.
- Rubin, S. 1996. Evaluation and meta-analysis of selected research related to the laboratory component of beginning college level science. PhD diss., Temple University.
- Savin-Baden, M., and C.H. Major. 2004. *Foundations of problem-based learning*. Maidenhead, UK: Open University Press.
- Seymour, E., and N. Hewitt 1997. *Talking about leaving: Why undergraduates leave science*. Boulder, CO: Westview.
- Seymour, E., A.-B. Hunter, S.L. Laursen, and T. DeAntoni. 2004. Establishing the benefits of research experiences for undergraduates in the sciences: First findings from a three-year study. *Science Education* 88 (4): 493–534.
- Shymansky, J., L. Hedges, and G. Woodworth. 1990. A reassessment of the effects of inquiry-based science curricula of the 60's on student performance. *Journal of Research in Science Teaching* 27 (2): 127–44.
- Slunt, K.M., and L.C. Giancarlo. 2004. Student-centered learning: A comparison of two different methods of instruction. *Journal of Chemical Education* 81 (7): 985–88.
- Smith, D. 1996. A meta-analysis of student outcomes attributable to the teaching of science as inquiry as compared to traditional methodology. PhD diss., Temple University.
- Spencer, J.A., and R.K. Jordan. 1996. Learner-centered approaches in medical education. *British Medical Journal* 313: 275–83.
- Tan, O.S., P. Little, S.Y. Hee, and J. Conway, eds. 2002. *Problem-based learning: Educational innovation across disciplines*. Singapore: Temasek Centre for Problem-Based Learning.
- Tan, O.S., R.D. Parsons, S.L. Hinson, and D. Sardo-Brown. 2003. *Educational psychology: A practitioner-researcher approach (an Asian edition)*. Singapore: Thomson.
- Thacker, B., K. Eunsook, K. Trefz, and S. Lea. 1994. Comparing problem solving performance of physics students in inquiry-based and traditional introductory physics courses. *American Journal of Physics* 62 (7): 627.
- Thomas, J.W. 2000. *A review of research on project-based learning*. San Rafael, CA: Autodesk Foundation.

## Resources

- ChemCollective—[www.chemcollective.org/find.php](http://www.chemcollective.org/find.php).
- ChemConnections—<http://mc2.cchem.berkeley.edu>.
- Database of research articles—<http://edr1.educ.msu.edu/references/viewarticle.asp>.
- Just-in-time teaching—<http://web-physics.iupui.edu/jitt/jitt.html>.
- National Center for Case Study Teaching in Science, University of Buffalo—<http://ublib.buffalo.edu/libraries/projects/cases/case.html>.
- The POGIL project—[www.pogil.org](http://www.pogil.org).
- Problem-based learning (University of Delaware)—[www.udel.edu/pbl](http://www.udel.edu/pbl).
- Problem based learning (Samford University)—[www.samford.edu/pbl](http://www.samford.edu/pbl).
- SCALE-UP (Student-Centered Activities for Large Enrollment Undergraduate Programs)—[www.ncsu.edu/PER/scaleup.html](http://www.ncsu.edu/PER/scaleup.html).
- Workshop Physics—[http://physics.dickinson.edu/~wp\\_web/wp\\_overview.html](http://physics.dickinson.edu/~wp_web/wp_overview.html).