THE MANY FACES OF INDUCTIVE TEACHING AND LEARNING

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To state a theorem and then to show examples of it is literally to teach backwards.
(E. Kim Nebeuts)

ABSTRACT

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

I. INTRODUCTION

Most science courses are taught deductively. The instructor first grounds students thoroughly in 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.

A better way to motivate students is *inductive teaching*, in which the instructor begins with specifics, 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 and/or helps students figure things out for themselves. Bransford *et al.* [2000] survey extensive neurological and psychological 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 & 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 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 and review applications of inductive methods in engineering education. This paper provides a concise review of 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.

II. INDUCTIVE TEACHING METHODS

A. 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 but offers little or no direction. This extreme form of inductive teaching is seldom used at the undergraduate level and there is little empirical evidence for its effectiveness in higher education. More common are variants such as "guided discovery" in which the instructor provides more guidance [Spencer and Jordan, 1996]. Depending on the nature of the initial challenge and the scope of the guidance, these variants would fall into one or another of the categories that follow.

B. Inquiry-Based Learning

In *inquiry-based learning*, 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 it. Inquiry-based methods have been used in physics [Fencl & Sheel, 2005; McDermott, 1995; Thacker *et al.*, 1994; Heflich *et al.*, 2001; Workshop Physics Web site; SCALE-UP Web site], Biology [Chamanay & Lang, Web site; Londraville *et al.*, 2002] and chemistry [Jalil, 2006; Lewis & Lewis, 2005; Oliver-Hoyo *et al.*, 2004a; Oliver-Hoyo & Allen, 2005]. The *POGIL* (Process-Oriented Guided Inquiry Learning) Web site (<*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* (<*http://www.chemcollective.org/find.php*>) archives resources for inquiry-based chemistry instruction, including virtual laboratory experiments, concept tests, problem scenarios, and simulations. Lee *et al.* [2004] report on a series of inquiry-based courses in different disciplines at North Carolina State University, including chemistry and physics in large classes [Oliver-Hoyo & Beichner, 2004], microbiology [Hyman & Luginbuhl, 2004], and wood and paper science [Kirkman *et al*., 2004].

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 *et al.*, 2006; Shymansky *et al.*, 1990; Rubin, 1996; Oliver-Hoyo & Allen, 2005; Oliver-Hoyo *et al.*, 2004b; Colburn, Web site]. Colburn [Web site] 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 is the least structured and therefore the easiest to implement of all the inductive teaching methods. Any instruction that begins with a challenge for which the required knowledge has not been previously provided qualifies as inquiry-based. The scope of the inquiry may vary from a portion of a single lecture to a major term project. In this sense, all other 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.

C. Problem-Based Learning

In *problem-based learning* (PBL), students—usually working in teams—are confronted with an ill-structured, authentic (real-world) problem to solve. PBL originated and is extensively practiced in medical education and other health-related disciplines [Savin-Baden & Major, 2004]. PBL problems in chemistry and physics (among other fields) and guidance on how to use them are given in Duch *et al.* [2001] and on Web sites maintained at the University of Delaware (<*www.udel.edu/pbl/*>) and Samford University (<*www.samford.edu/pbl/*>), both of which provide links to many other 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 & 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 metacognitive 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 difficult and 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 solution, 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/or training could easily find themselves overwhelmed by the negative responses of their students.

D. 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 interpretation of the data. The culmination of the project is normally a written and/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 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 & Eyring, 1999; O'Hara *et al.,* 1999].

Strictly speaking, in project-based learning the 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, 2005; Tan *et al.,* 2003; Galand & 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 & Treagust, Web site]. Mills and Treagust [Web site] 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, the students may be less well 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 the 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). 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 are particularly challenging to implement.

E. Case-Based Teaching

In *case-based teaching*, students study historical or hypothetical cases involving scenarios likely to be encountered in professional practice. The students are challenged to explore their existing preconceptions and modify them to accommodate the realities of the cases [Lundeberg *et al.*, 1999]. Relative 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 Web site (<*http://edr1.educ.msu.edu/references/viewarticle.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 inductive methods only to problem-based learning if instructors must create and analyze the cases themselves.

Studies have found that relative to conventional teaching, case-based instruction significantly improves 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 *et al*., 2002]. Lundeberg & 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 vs. 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." Findings regarding the effects of case-based instruction on knowledge acquisition are inconclusive [Fasko, 2003; Katsikitis *et a*l., 2002].

F. 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 the 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 IUPUI, the U.S. Air Force Academy, and Davidson College, and can be combined with almost any in-class active learning approach [Modesitt *et al.*, 1999; Novak *et al.*, 1999].The *Just-in-Time Teaching Web site* [Web site] 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 & Novak [2004] found that the use of JiTT in a large-enrollment introductory biology course for non-majors 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 the 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 the 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 they must be made up by the instructor.

III. 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 and require more planning and possibly more resources, and they are also more likely to arouse student resistance and interpersonal conflicts [Felder & Brent, 1996]. 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 inexpert 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 I am 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 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.

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[b])	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[a])	Considerable[a]
Projects-based: teams	Facilities for experimental projects	Considerable (team management, facilities maintenance[b])	Considerable[a,b]
Problem-based	Problems	Considerable (existing problems), extensive (original problems)[a]	Major[c]
Hybrid (problem/ project- based)	Problems, facilities for experimental projects	Considerable (existing problems), extensive (original problems)[a,b]	Major[c]

[a] 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.

[b] Assuming that experimental facilities are required for student projects and that the instructor (as opposed to a technician) is involved in maintaining them.

[c] Resistance follows both from the burden of responsibility for their own learning placed on the students and the additional demands imposed by cooperative learning.[a] Hybrid methods may also involve problems of facilities maintenance.[b]

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