Educating the Future: The Impact of Pedagogical Reform in Aerodynamics

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Outline

1. Overview of course and its evolution

2. Project-based learning

3. Conceptual learning

4. Student performance and evaluation data

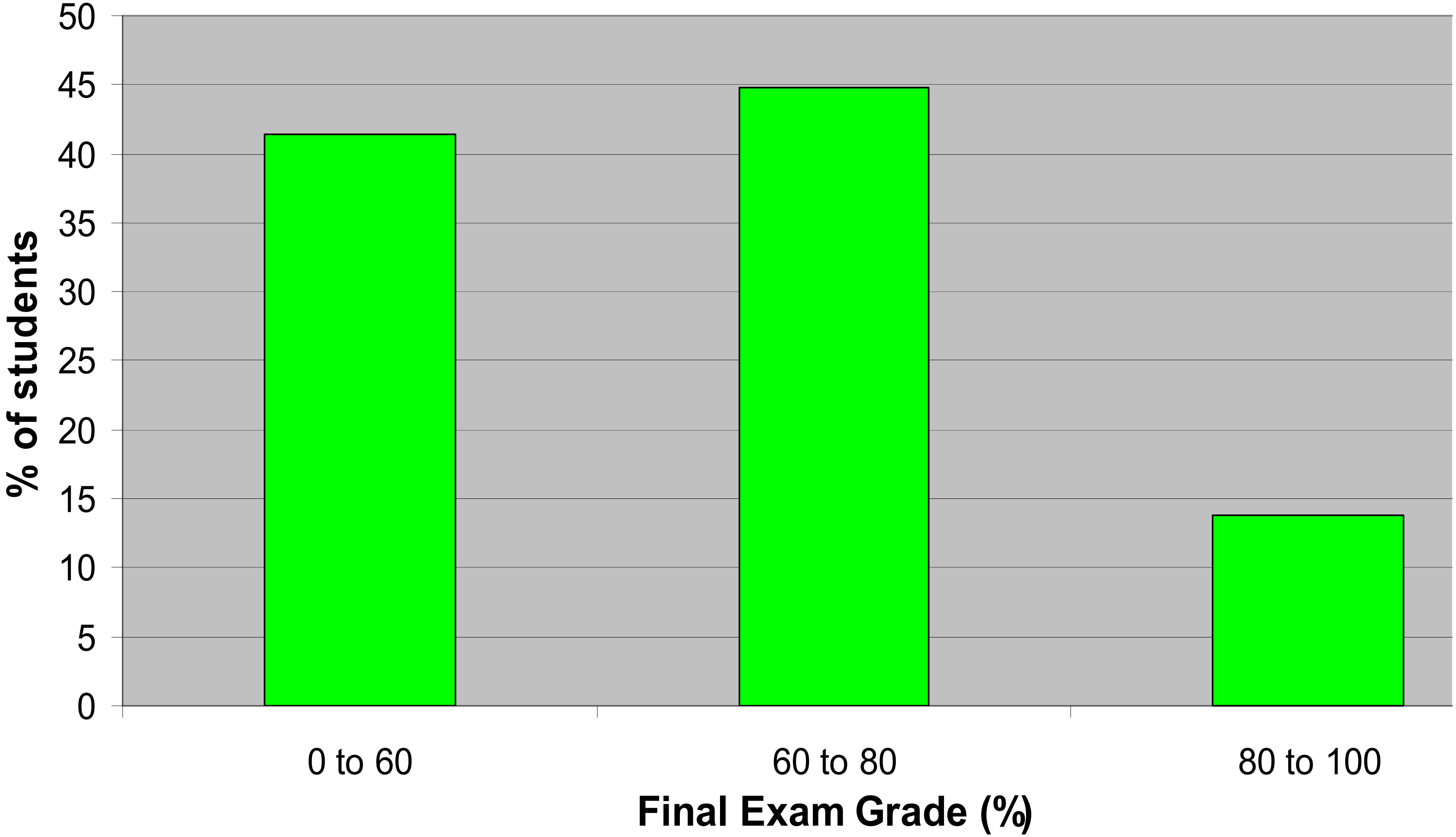
Course Overview (MIT 16.100)

- Disciplinary subject in aerodynamics (5 hours of class/week)
- Enrollment typically around 40 students (juniors and seniors)
- Students will have previous fluid dynamics:
  - conservation laws
  - 2-D potential flows
  - some basic aerodynamics
- Not quite a required course but 2/3's of students take it
- Course topics include:
  - Incompressible, subsonic, transonic, and supersonic flows
  - Viscous flows with an emphasis on boundary layers
  - Wind tunnel testing and computational methods

Impetus for Reform

- Desire within aeronautics for technically-strong engineers with a more product-oriented, systems background
- Increased role of computation in aerodynamic design
- Improved understanding of technical learning and effective pedagogy
- Poor student performance from previous years especially in conceptual understanding, ability to synthesize concepts, and solution of problems outside of subject experience

Results from 1998 Final Exam



Poor student performance on this exam that required application of concepts beyond previous experience and synthesis of concepts on complex problems

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Project Focus: Model-based Design

Develop Baseline Geometry → **Validate/Calibrate Aerodynamic Models on Baseline Geometry** → **Design with Calibrated Aerodynamic Models**

(Trade studies, optimization, etc.)

Basis for project

- Places students in typical aerodynamic design cycle
- Requires application of fundamental concepts to a realistic, complex aerodynamic analysis and design
- Demonstrates interaction of experimentation, theory, and simulation in design

Implementation of Project

- A semester-long, integrative team project developed with The Boeing Company concerning the aerodynamic analysis and design of a Blended-Wing Body (BWB) aircraft.

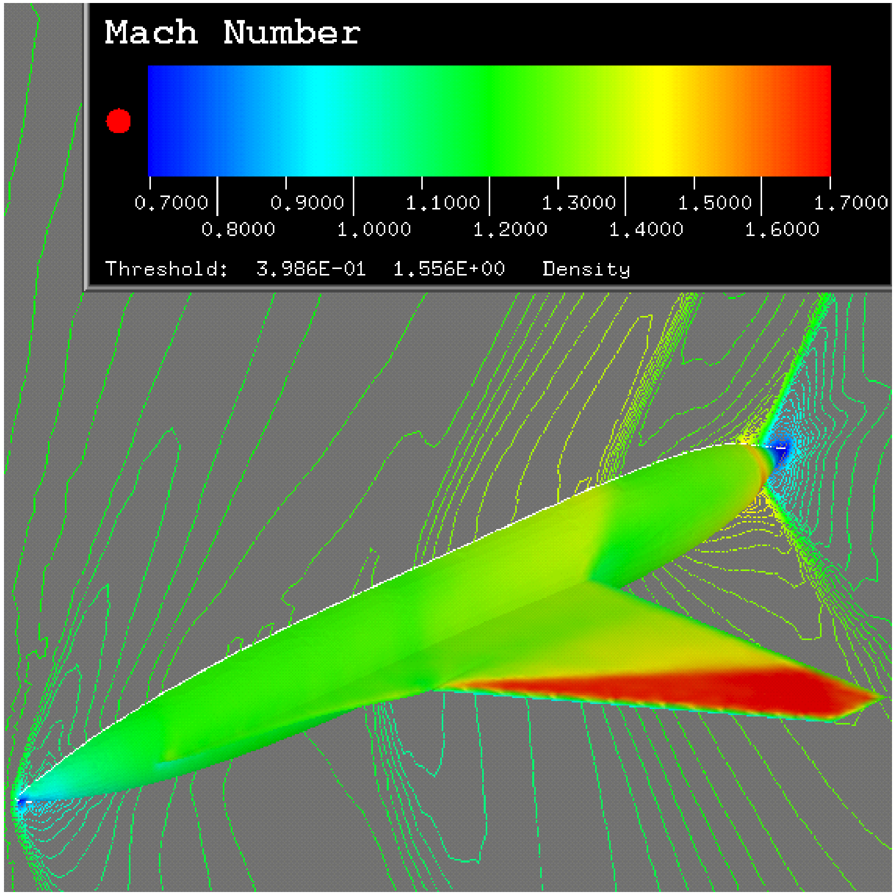
- Teams of approximately 4 students selected by staff to provide balance.

- Teams required to submit written interim & final reports:
  - Interim report focus: aerodynamic modeling,
  - Final report focus: correct modeling errors and design.

- Weekly two-hour group work sessions (required attendance). Staff is present to help answer questions.

Modern Computational Methods

- Exposure to modern computational aerodynamic methods (3-D Euler, vortex lattice)
- Emphasis given to:
  - Fundamental fluid dynamics
  - Assumptions
  - Applicability
  - Sources of error



M = 1.2, Angle of Attack = 7 degrees

Wind Tunnel Experiments

- Wind tunnel tests for validating low-speed modeling
- Flow visualization
- Emphasis given to:
  - Assumptions
  - Applicability
  - Sources of error

Design Requirements

- The design allows significant flexibility for the geometry modifications. To bound work, teams are required to:
  - Propose a specific design strategy for improving the performance including the aerodynamic rationale
  - Following the proposed approach, students utilize their aerodynamic models to determine if the performance is improved
  - If the approach fails, they must explain why this happened

- This hypothesis/design cycle is an important learning experience:
  - Students must apply conceptual understanding of aerodynamics before utilizing aerodynamic model (i.e. think-before-do)
  - Even if approach fails, students learn by uncovering what went wrong

Student Comments: Team Project

- The team project was a great way to actually use in practice the stuff we were learning from lectures and the book.
- I designed a whole plane with the BWB project! I also have a complete conceptual overview of all the tools – CFD, Vortex Lattice Method, etc – and of all their assumptions that I understand exactly how to use them, which ones to use where, and what the limitations are of each.
- My group floundered for a while with the BWB project. In the end, we got everything to come to together, but it was tough to get through. I’m not sure that I would have wanted it any other way… I learn best when I struggle with material for a while.

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Constructivist Model of Learning

(Piaget)

Argues that individuals learn by:

- Actively constructing their knowledge,
- Testing concepts on prior experience,
- Applying these concepts to new situations,
- Integrating the new concepts into prior knowledge.

Misconceptions: preconceptions that oppose principles being learned

Directly opposes the *'blank state'* view of how people approach learning

Pedagogical Elements to Address Conceptual Understanding

- Frequent formative assessments that make students' conceptions evident to themselves and to teachers

Utilize concept questions

- Summative assessments that target deep, conceptual understanding

Oral exams stressing conceptual understanding

- Coverage of fewer topics but in greater depth

Concept Questions

(Ellis, Landis, & Meeker, 2000; Mazur, 1997)

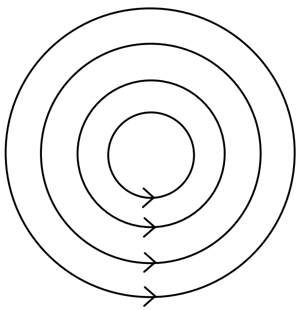
- Focus on a single concept
- Are not solvable (in time given) relying solely on equations
- Reveal common difficulties with the concepts
- Have more than one plausible answer based on typical misunderstandings

Using Concept Questions

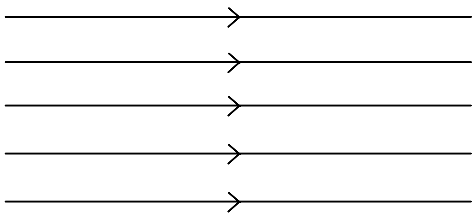
- Pose concept question
- Ask students to indicate their answers: we currently use handheld Personal Response System (PRS)
- If most have the correct answer, give a brief explanation, then move on
- Else, clarify concept:
  - have students discuss with neighbors,
  - give mini-lecture on concept and answers
- Take another poll of students’ answers
- A typical class period will include about 2-3 concept questions

Example Question: Irrotational flow

Given the following streamlines for a steady, 2-D flow:



(a)



(b)

Which of these flows is irrotational:

(1) Only (a)
(2) Only (b)
(3) Both (a) & (b)
(4) Neither
(5) Not enough information

Benefits of Concept Questions

(Ellis, Landis, & Meeker, 2000)

- Provides immediate feedback on class understanding
- Gives students practice in using terminology and concepts
- Confronts common misconceptions
- Enhances inter-personal and communication skills
- Improves class participation and motivation

Past work in physics, chemistry, and mathematics has shown significant learning gains through the use of active learning strategies

III. CONCEPTUAL TEST RESULTS

A. Gain vs Pretest Graph - All Data

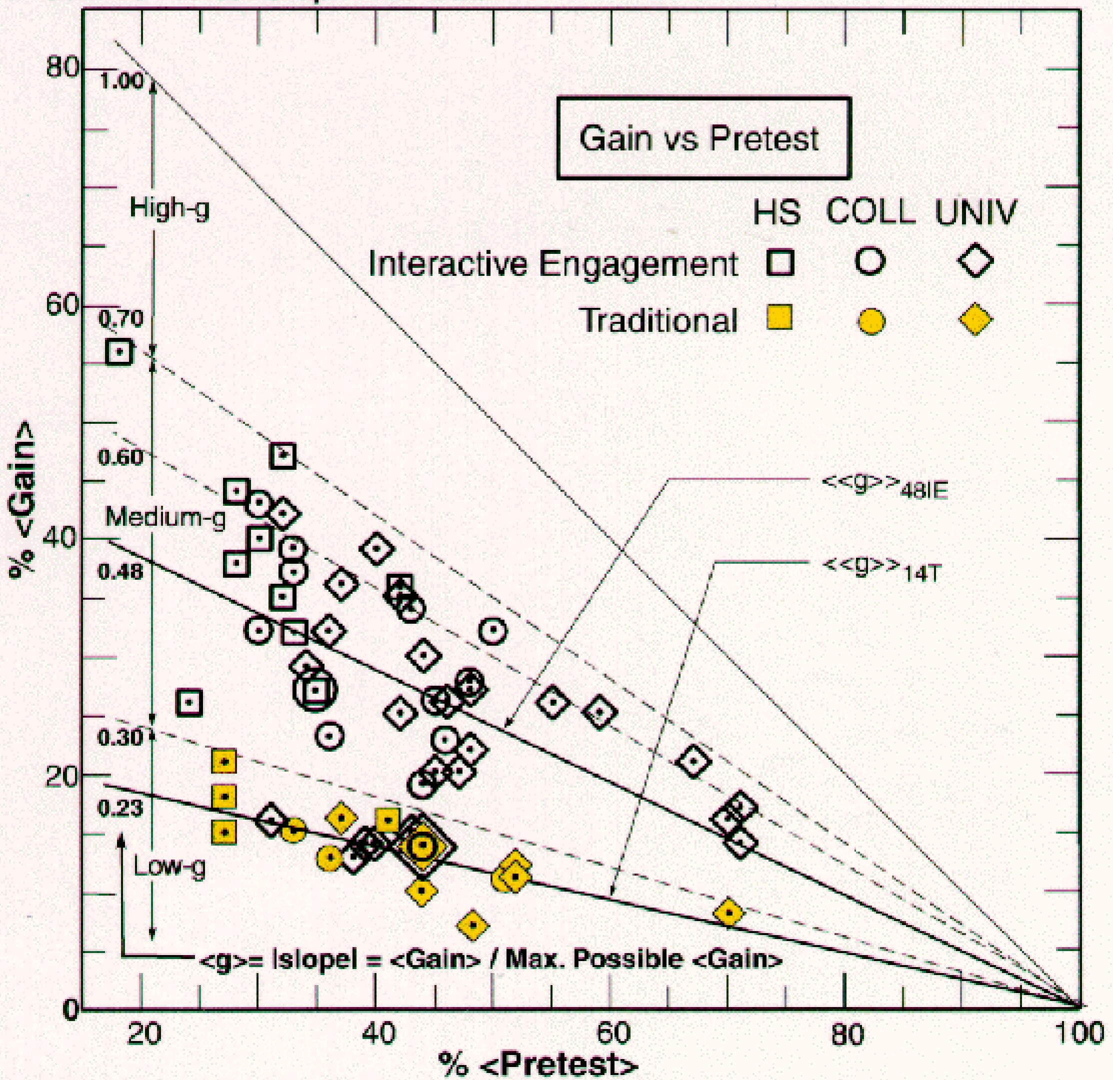


Fig. 1. %<Gain> vs %<Pretest> score on the conceptual Mechanics Diagnostic (MD) or Force Concept Inventory (FCI) tests for 62 courses enrolling a total N = 6542 students: 14 traditional (T) courses (N = 2084) which made little or no use of interactive engagement (IE) methods, and 48 IE courses (N = 4458) which made considerable use of IE methods. Slope lines for the average of the 14 T courses $\langle\langle g\rangle\rangle_{14T}$ and 48 IE courses $\langle\langle g\rangle\rangle_{48IE}$ are shown, as explained in the text.

Pre-class Assignments

- **Problem:** to address conceptual understanding in-class, students must begin learning beforehand
- **Solution:** Reading and homework assignments due prior to in-class discussion of material
- Homeworks are at same level as in past years when given after class
- Same amount of work for students, but front-loaded

Advantages of Pre-class Assignments

- Leverage existing resources for basics & derivations while permitting faculty to be value-added in classroom
- Classroom interactions can focus on concepts
- Encourage self-directed learning
- Improve feedback time
- Homeworks can be designed to demonstrate typical misconceptions

Active Assessment: Oral Examinations

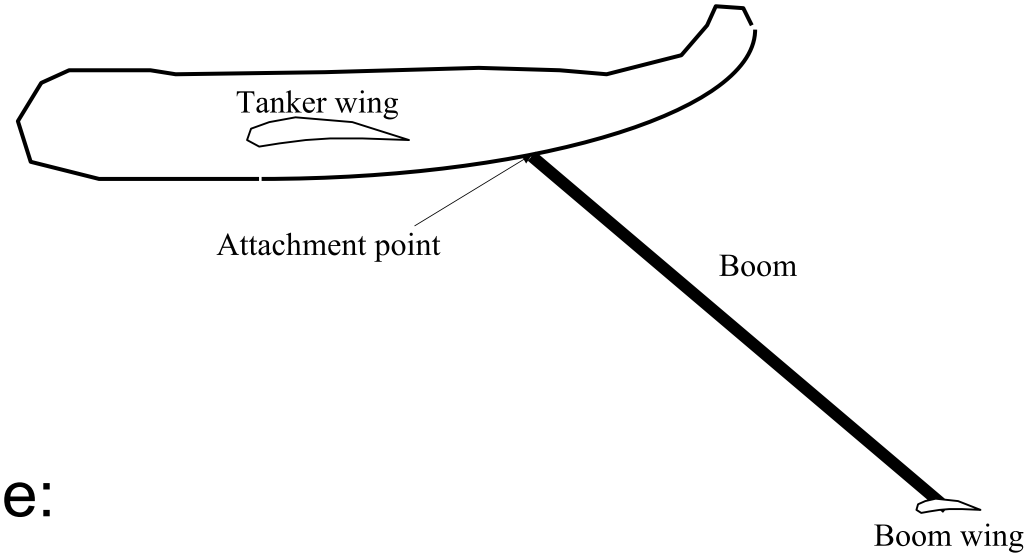
- Exams designed to require students to identify and apply concepts
- Oral exams are an active assessment method engaging students while they are thinking
- Improves likelihood of an accurate assessment by its dynamic nature
- Valuable, authentic experience for students
- Opportunity for faculty to learn more about misconceptions

Oral Exam: The Process

- All exams are oral
- Students given question(s) 30 minutes prior to oral exam
- Oral exam conducted for 30 minutes
- Grading sheet (tabular) developed listing each concept to be assessed and the level achieved

Sample Oral Exam Question

How would you model the aerodynamics of the boom and the boom wing?



Concepts include:

- Use of non-dimensional parameters (Re, M)
- Sources of drag (friction, induced, wave, separation)
- Transonic drag rise, critical Mach, and sweep effect
- Drag due to separation (on boom)
- Interference (downwash from tanker wing)

Student Comments: A Learning Transition Occurred

- I was initially opposed to the idea that I had to do reading & homework before we ever covered the subjects. Once I transitioned I realized that it made learning so much easier!!

- I was skeptical at first of new techniques like PRS, hw on material that hasn't been learned in lecture. In the end, it worked out very well. This has been a course where I really felt like I got my money's worth.

- I really like the format of the class, I think it's actually a very good way to format a course. At first I didn't like how the homework was really tricky and it always came before we went over the material in lecture, but after a little bit I didn't mind it.

- Doing homework before the lectures is good… makes actual learning in lectures possible.

Student Comments: Oral Exams

- The oral exams are an excellent measure of understanding.
- Oral exams [are the best part of the subject], I think these gave a good opportunity to show what you understand.
- Oral exams are also good. Pretty nerveracking, but good overall.
- I really like the idea of the oral final. Even though it is scary, it really shows how much you know about the subject, better than any exam would.
- The oral exams allow a true assessment of understanding better than pretty much anything else.

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Importance of Implementation

- Effective implementation of concept questions is not trivial and impacts entire pedagogy
- In Fall 2000, we implemented concept questions in-class but pre-reading assignments were too simplistic
- The Fall 2000 experience led directly to the current implementation

Impact of Implementation on Performance

In Fall 2000 and Fall 2003, gave very similar written final exams:

- 5 questions on the final exams
- 3 questions were identical
- 2 were of similar difficulty but different due to changed coverage

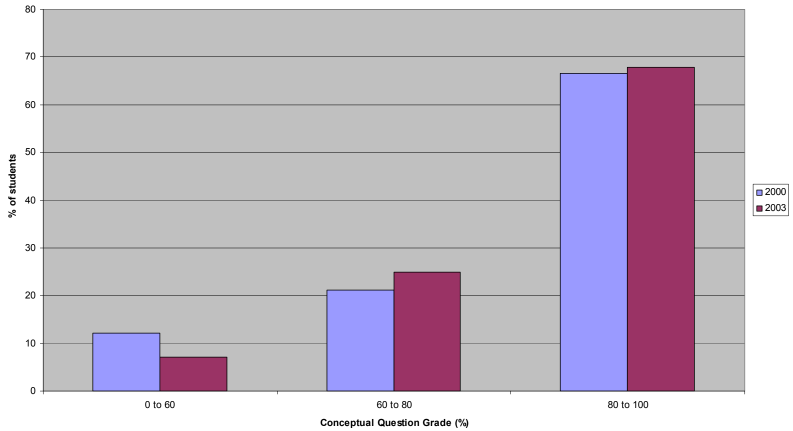
Of the three identical questions:

- Conceptual question on the differences in drag estimation between vortex lattice and Euler methods at subsonic and transonic speeds
- Quantitative question on the boundary layer estimation using Thwaites method
- Synthesis question on the development of a model for the aerodynamic forces on a refueling boom with a control wing

Note: Fall 2003 written final exam was a one-time exception to gather data

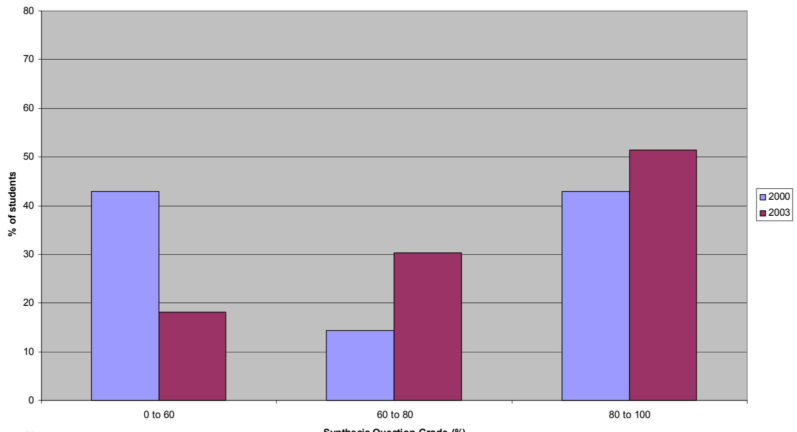
Impact of Implementation: Detailed Comparison

Conceptual



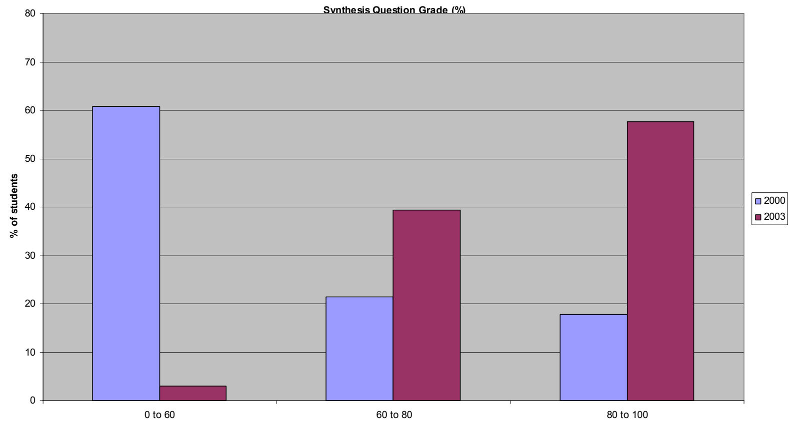
- Very similar performance on conceptual question

Synthesis



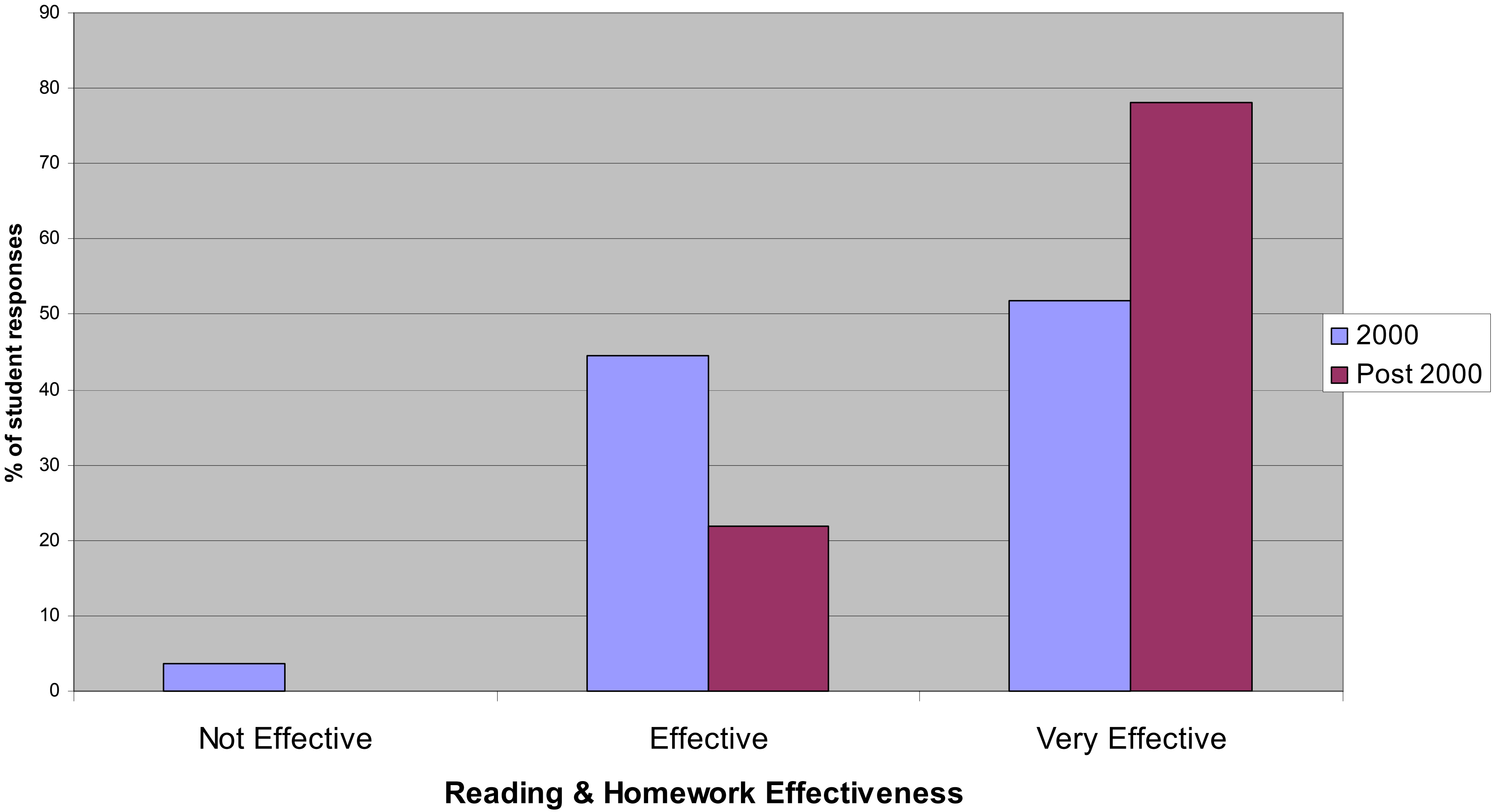
- Reduction in low performance (0-60% grade) from 2000 to 2003:
  - 2000: ~40% students
  - 2003: ~20% students

Quantitative



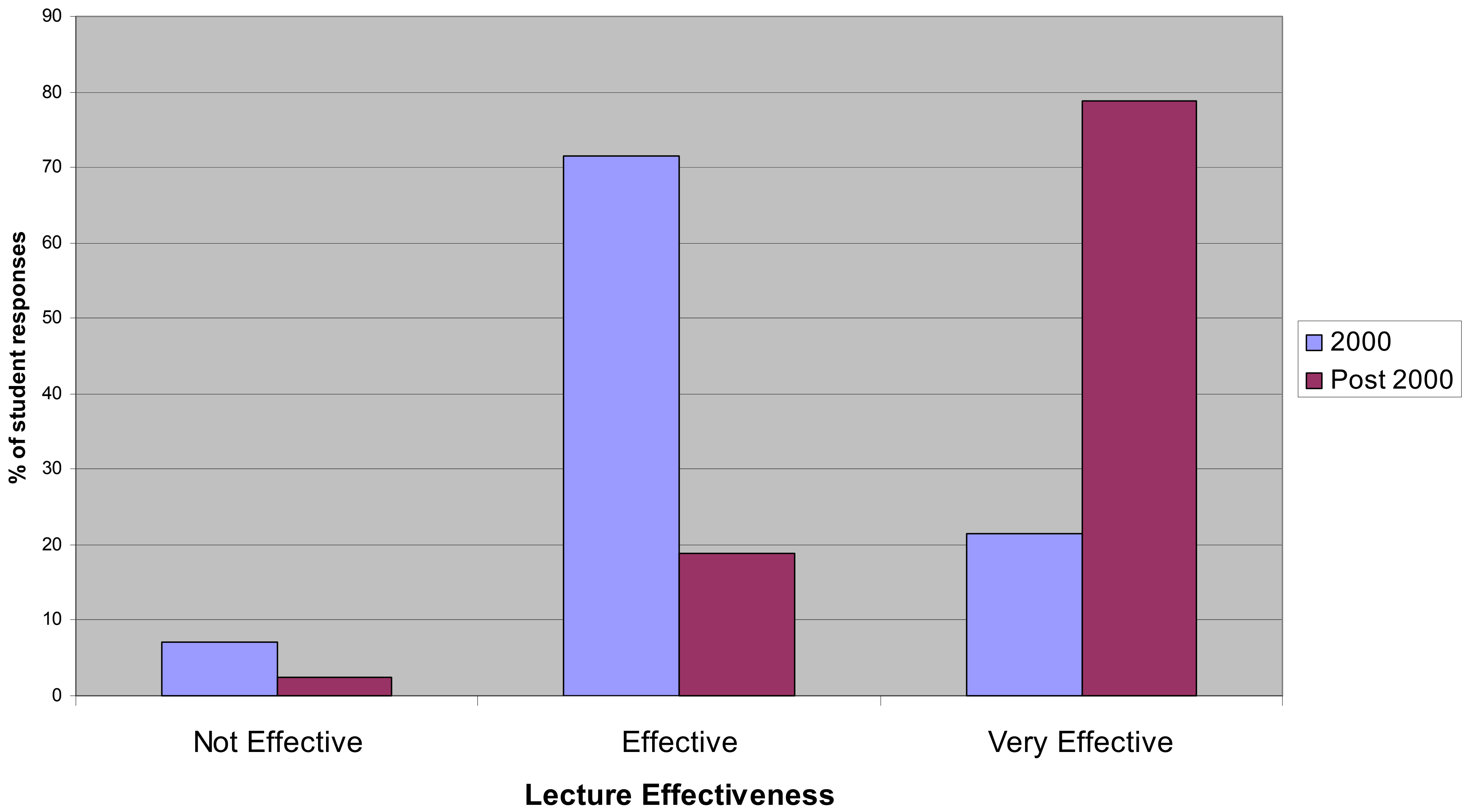
- Definite improvement in quantitative performance

Student Evaluations of Pedagogy: Reading & Homework



Reading & homework more effective with increased difficulty

Student Evaluations of Pedagogy: Lecture



Lecture more effective with increased difficulty of pre-class homework

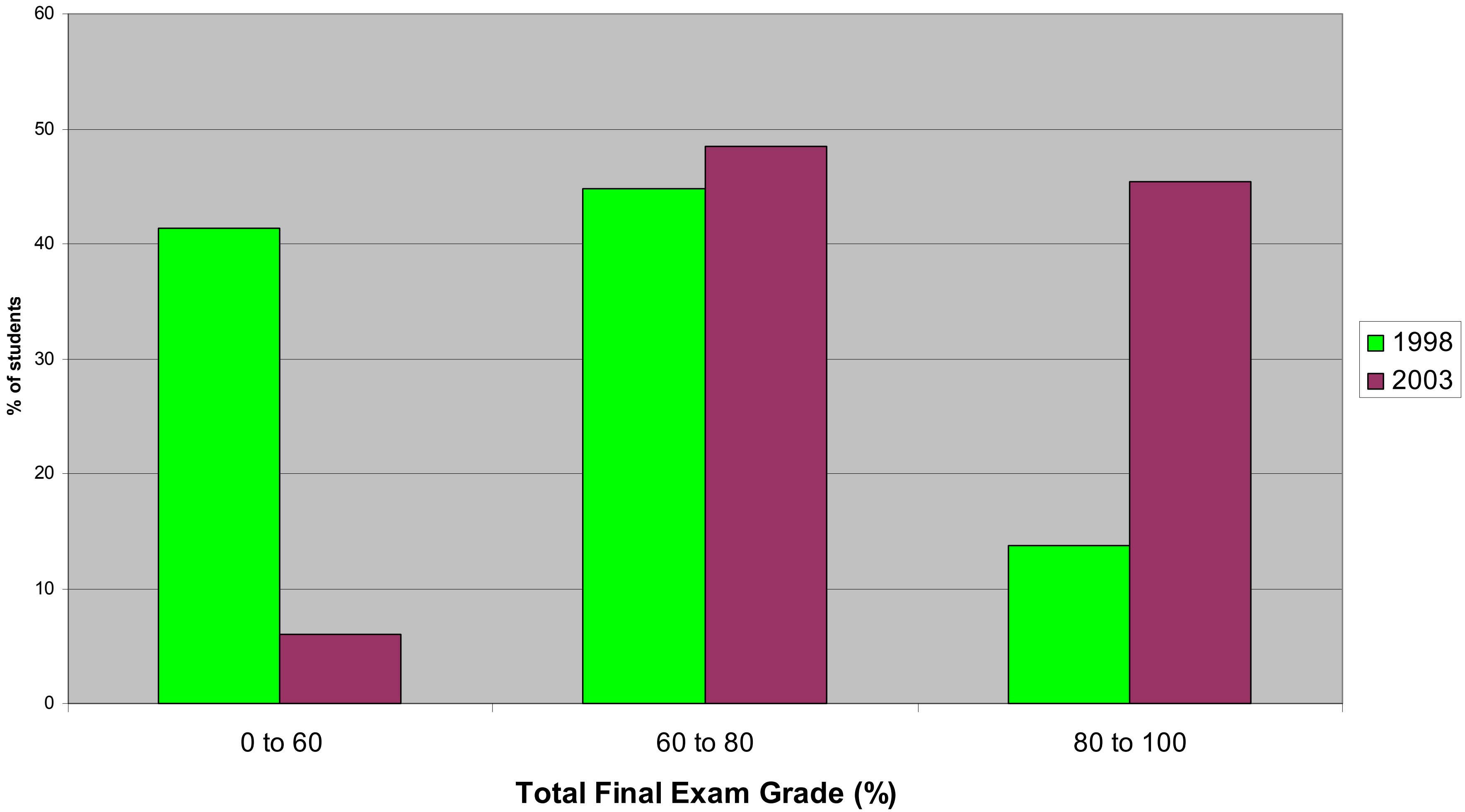
Impact of Pedagogy on Performance

Comparison of Fall 1998 and Fall 2003 written exams:

- 6 questions in 1998 vs. 5 questions in 2003
- 1 question (a synthesis question) was identical
- Other questions were of similar difficulty but different
- Extra credit questions were given in 1998

Note: Fall 2003 written final exam was a one-time exception to gather data

Comparison of Final Exam Grades: Impact of Pedagogy



Significant improvement in overall performance from 1998 to 2003

Conclusions

- Team projects can augment learning experiences and increase understanding of technical fundamentals
- In-class concept questions, pre-class assignments, and oral exams were found to be effective learning and assessment strategies, but implementation is critical.
- Identification of misconceptions and the development of good concept questions is difficult.
- Students recognize the benefits of these pedagogies when effectively implemented.