# Course Development:
# An Example from Aerodynamics

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# Question & Discussion

*What do you hope to gain from this session?*

# Goals of Session

- Stimulate ideas on the incorporation of CDIO into disciplinary subjects, specifically:
  - Standard 7: Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal, interpersonal, and product and system building skills
  - Standard 8: Teaching and learning based on active experiential learning methods
  - Standard 11: Assessment of student learning in personal, interpersonal, and product and system building skills, as well as in disciplinary knowledge

- Demonstrate the impact of a course pedagogy incorporating these ideas

# Outline

1. Overview of course and its evolution
2. Project-based learning
3. Active learning
4. Student performance and evaluation data

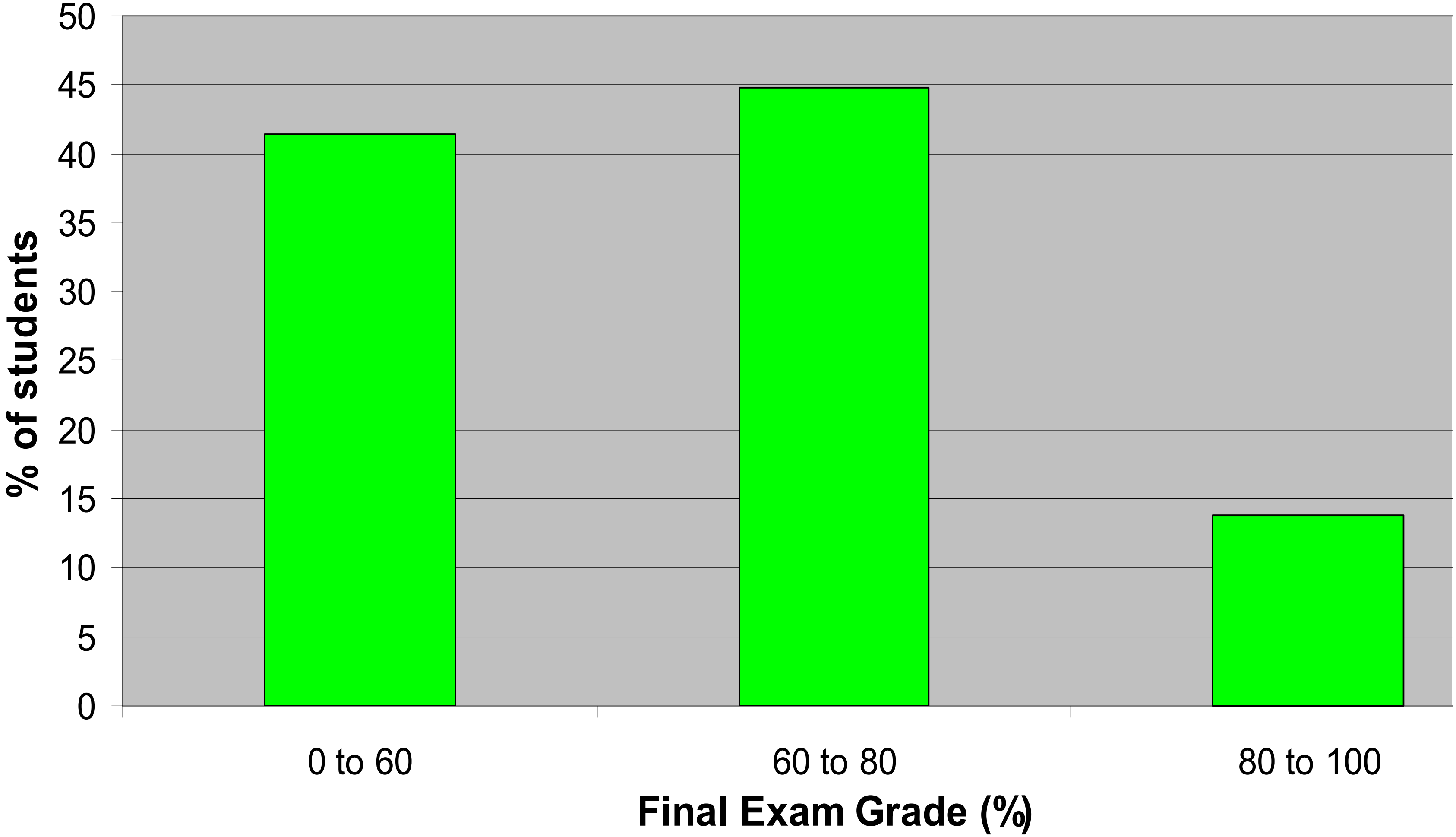
# Course Overview (MIT 16.100)

- 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

# Comments on Course Design

- Course design should be iterative and continual, and is most effective when driven by assessment:

  *The reform of 16.100 has been on-going for five years (though the most significant changes occurred during the first three years)*

- While the principles of effective pedagogy are relatively generic, the implementations can vary from discipline-to-discipline and from instructor-to-instructor

- Effective pedagogical strategies can be ruined by poor implementation

# 16.100: Learning Objectives

1. Formulate and apply aerodynamic models to predict the forces on and performance of realistic three-dimensional configurations

2. Assess the applicability of aerodynamic models to predict the forces on and performance of realistic three-dimensional configurations and estimate the errors resulting from their application

3. Perform an aerodynamic design on a realistic three-dimensional configuration together with members of a teams

**Comments**

- Displinary modeling (i.e. aerodynamics) is tied to system-level metrics (i.e. aircraft performance)
- Design and teamwork are explicit learning objectives
- Detailed measurable outcomes were also developed

# Steady-state 16.100 Pedagogy

- Concept questions & mini-lectures in most class periods
- Pre-class (graded) homework assignments
- All exams are oral: (a mid-term and a final)
- Semester-long, team-based design project

# Evolution of 16.100 Pedagogy

cdio

## Year 1:

- Concept questions & mini-lectures in some class periods
- Weekly quizzes with follow-up homeworks
- Semester-long, team-based design project: written & oral reports required
- Technical topics selected by students to address project needs
- Weekly student self-assessments with an end-of-semester portfolio

## Year 2 changes (including reason):

- Dropped weekly quizzes with follow-up homeworks; moved to weekly pre-class homeworks (improve student preparation for class)
- Use a written final exam (individual summative assessment)
- Use 1-hour/week of class for project work sessions (improve student-faculty interaction on project)
- Dropped oral project reports (scheduling constraints)
- Technical topics set by faculty (scheduling constraints)

# Evolution of 16.100 Pedagogy

Year 3 changes (including reason):

- Significant effort developing concept questions (improve quality and quantity of concept questions)
- Increased difficulty of pre-class homeworks (student engagement of technical material was superficial with previous, simpler homeworks)
- Use 2-hour/week of class for project work sessions (improve student-faculty interaction on project)
- Replace written final exam with mid-term & final oral exams (stress importance of conceptual understanding; more authentic experience)

No substantial changes in Years 4 & 5

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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.

# Analysis Requirements

- Analysis combines computational simulations (panel methods or transonic Euler solutions) with theoretical corrections
- Low-speed wind tunnel testing is performed to validate aerodynamic models:
  - Wind tunnel model built for course by faculty, staff & students
  - Teams determine testing matrix, reduce data, and apply corrections
- Detailed grading of the interim project reports is critical to the learning process and quality of final design study

# 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

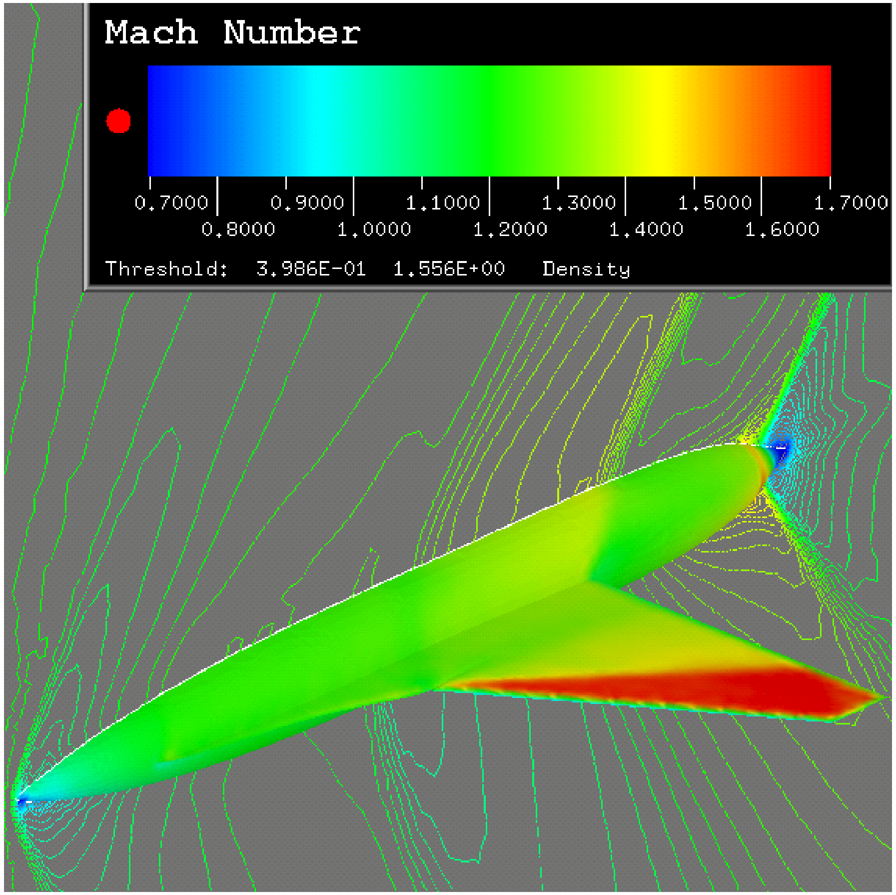
- This hypothesis/design cycle is an important learning experience:
  - Students must apply conceptual understanding of aerodynamics before utilizing aerodynamic model (i.e. think-before-do)
  - Even if approach fails, students learn by uncovering what went wrong

# Wind Tunnel Experiments

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

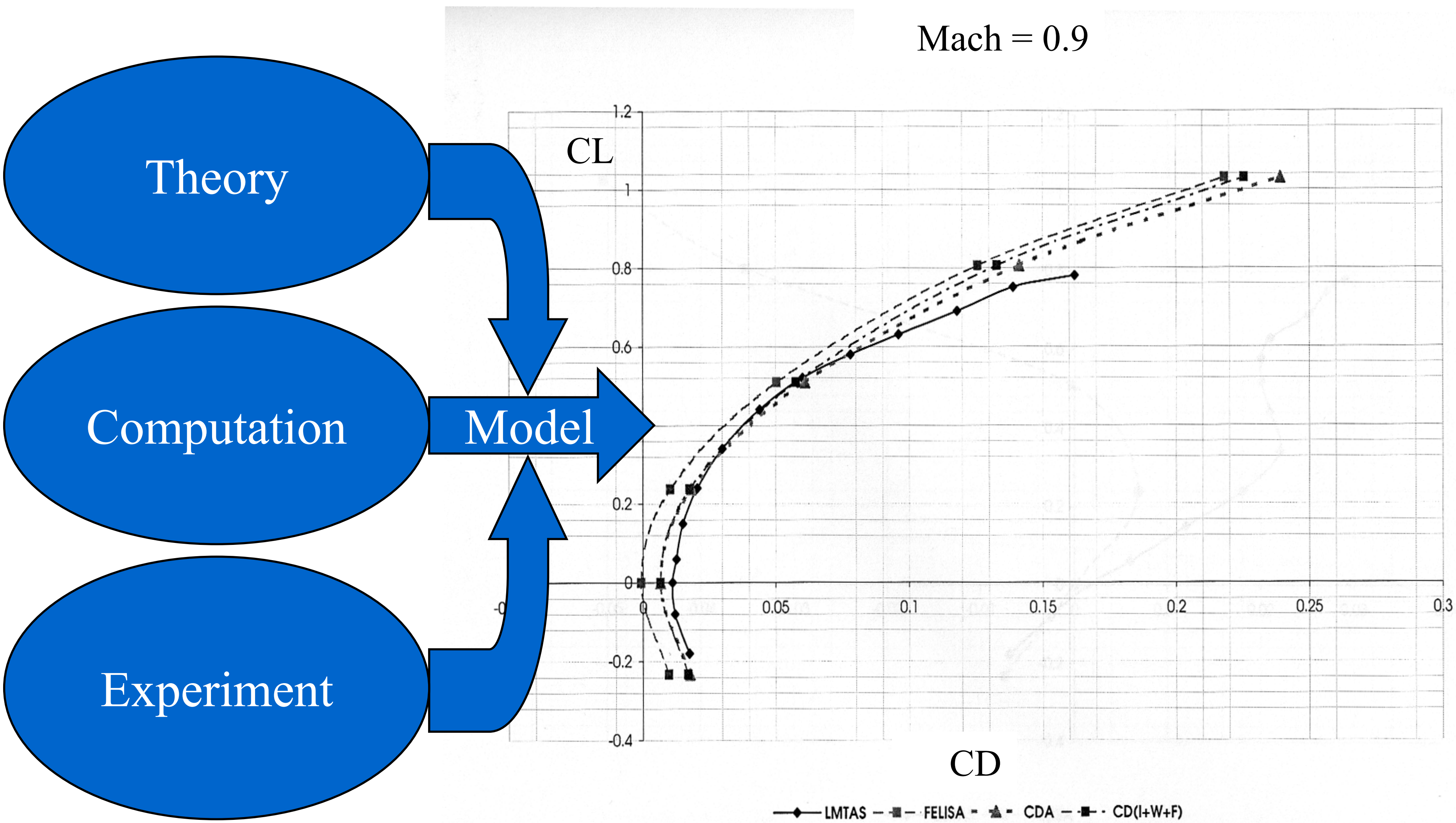
# Advanced Computational Methods

- Exposure to modern computational aerodynamic methods
- Emphasis given to:
  - Fundamental fluid dynamics
  - Assumptions
  - Applicability
  - Sources of error




M = 1.2, Angle of Attack = 7 degrees

# Synthesis of Theory, Experiment & Computation



# Grading of Project

- Measurable outcome for individual performance on project:

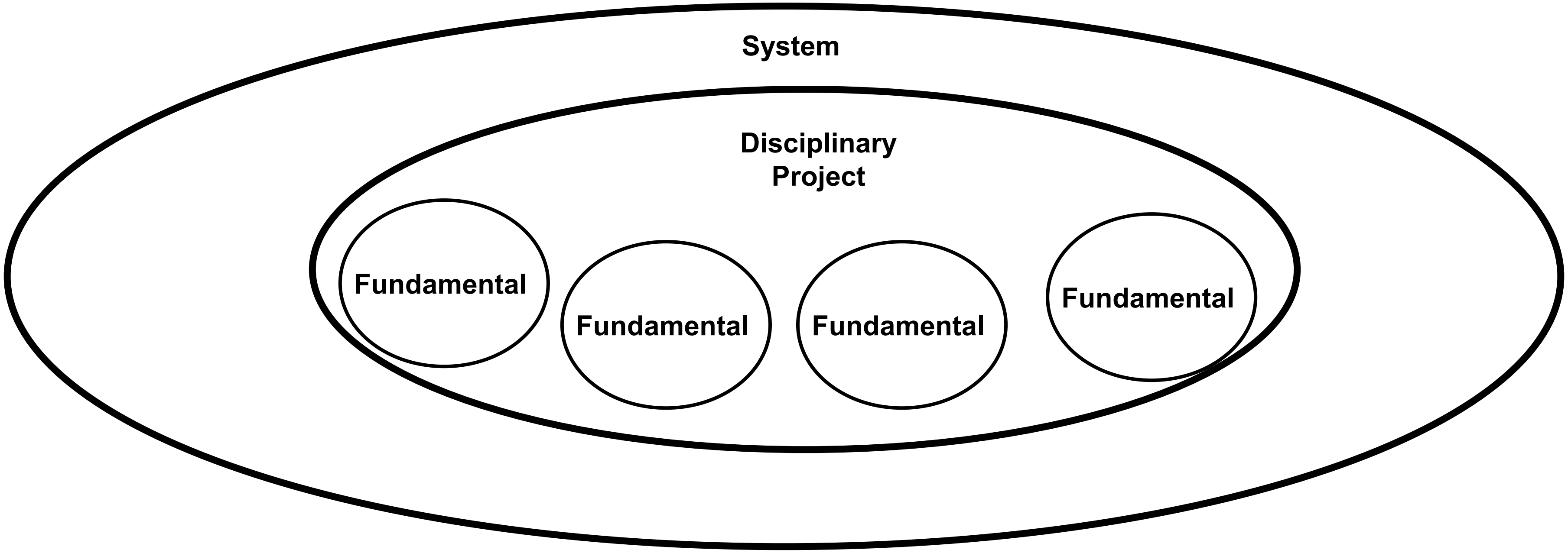
  *Contribute substantially as an individual to the aerodynamic analysis and design of a realistic 3-D configuration together with members of a team*

- 80% of grade based on individual effort; 20% of grade based on overall project technical quality. As a matter of practice, however, individuals on a well-functioning team receive the same grade on the projects.

- Individual grade is determined from three sources:
  1. Instructor interactions with the teams,
  2. Written evaluations by all team members of the contributions of each team member (including self-evaluations),
  3. Delineation within the written reports of an individual's contributions.

# Benefits of Project

- Provides context for learning of technical fundamentals
- Deal with uncertainties of applying fundamentals to complex problems
- Natural mechanism to demonstrate impact of discipline on system
- Introduces design strongly into curriculum



# 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.

# Question & Discussion

*How could you implement a project in your course?*

*What are your biggest concerns with doing this?*

# Outline

1. Overview of course and evolution of curriculum
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# Barriers to Conceptual Understanding

- *Misconceptions:* preconceptions that oppose principles being learned
- Traditional pedagogies stress analytic ability over conceptual understanding
- Traditional assessments stress analytic ability over conceptual understanding

# 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.

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

# Importance of Misconceptions

"The most important single factor influencing learning is what the learner already knows.  Ascertain this and teach him accordingly."

David Ausubel - Educational psychology: A cognitive approach, 1968.

# Aerodynamic Concept:
# Lift Generation by an Airfoil

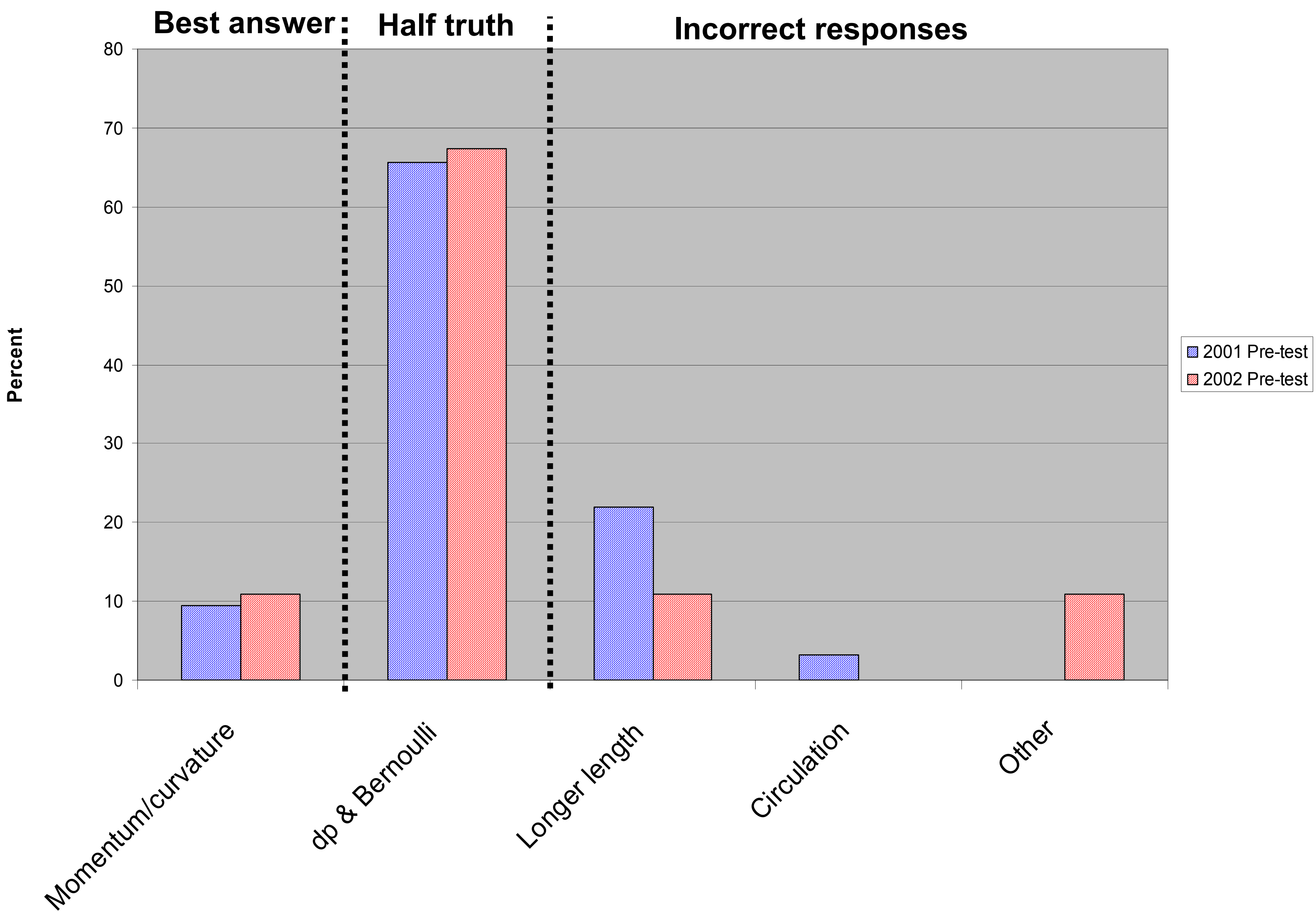
Students possess many myths & half-truths about lift generation

- Pressure differences generate lift…
- Pressure differences from Bernoulli effect…
- Upper surface longer than lower surface!

As they learn about aerodynamics, the situation gets muddier:

- Circulation creates lift
- Vortex sheets on the airfoil surface create lift

# Lift Generation: Pre-conception Data



# Pedagogical Elements to Address Conceptual Understanding

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

- Summative assessments that target deep, conceptual understanding

- In-depth coverage of fewer topics (this is a programmatic issue as well)

# 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

# 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

# Resource for Concept-based Instruction

Physics

Eric Mazur – Harvard

http://galileo.harvard.edu

Peer Instruction – www.prenhall.com

Richard Hake – http://www.physics.indiana.edu/~hake/

Chemistry

Chemistry ConcepTests - UW Madison

http://www.chem.wisc.edu/~concept

Video: Making Lectures Interactive with ConcepTests

ModularChem Consortium

http://mc2.cchem.berkeley.edu/

STEMTEC

Video: How Change Happens: Breaking the ‘Teach as You Were Taught’ Cycle. Films for the Humanities & Sciences. http://www.films.com

Thinking Together video:  http://www.fas.harvard.edu/~bok_cen/

## III. CONCEPTUAL TEST RESULTS

### A. Gain vs Pretest Graph - All Data

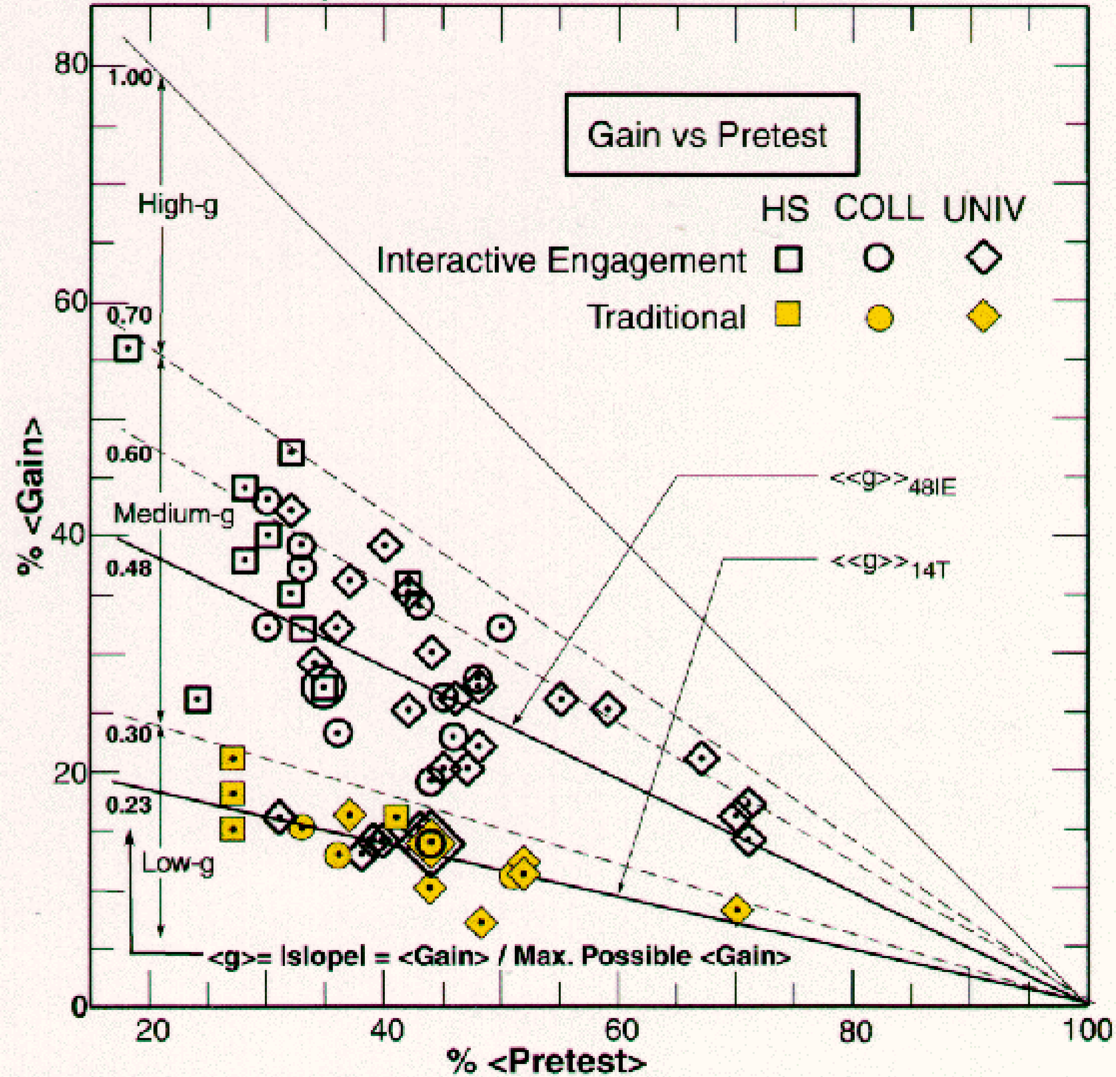


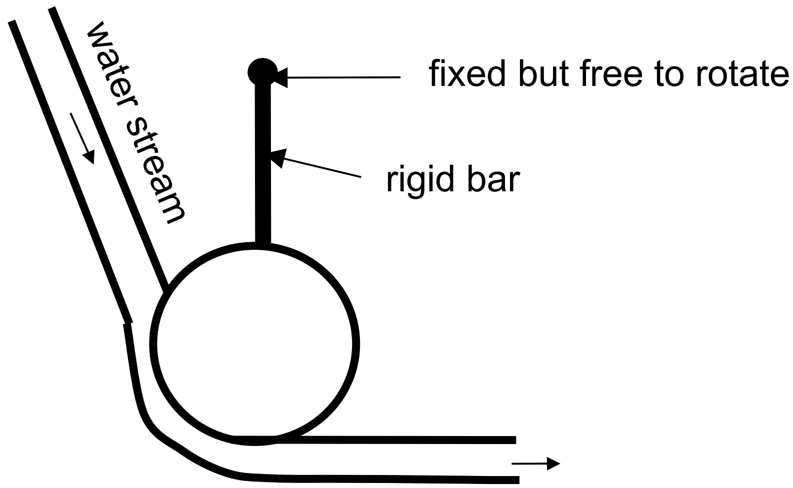

Fig. 1. %<Gain> vs %<Pretest> score on the conceptual Mechanics Diagnostic (MD) or Force Concept Inventory (FCI) tests for 62 courses enrolling a total N = 6542 students: 14 traditional (T) courses (N = 2084) which made little or no use of interactive engagement (IE) methods, and 48 IE courses (N = 4458)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

# Processes for Developing Concept Questions

- Derive from measurable outcomes
- Instructor knowledge
- Feedback from reading and homework
- Open-ended concept questions
- Oral exams and/or interviews

In my experience, developing good concept questions is the most difficult aspect of this technique

# Example:
# Lift Generation Concept Question




Given the water behaves as shown above, which direction will the cylinder rotate when the stream first makes contact with the cylinder?

1. Clockwise (into the stream)
2. Counter-clockwise (away from the stream)
3. Not enough information

# Cylinder-stream question:
# Is it effective?

- Single concept: force generation through momentum change of fluid (flow turning)
- Cannot be solved in 1-2 minutes by integral momentum
- Reveals common difficulties:
  - Students do not connect flow turning with force generation
  - Stream impingement on cylinder often leads to the conclusion of a counter-clockwise motion (i.e. a fire hose effect)
- Leads naturally to lift generation through flow turning and streamline curvature

# 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

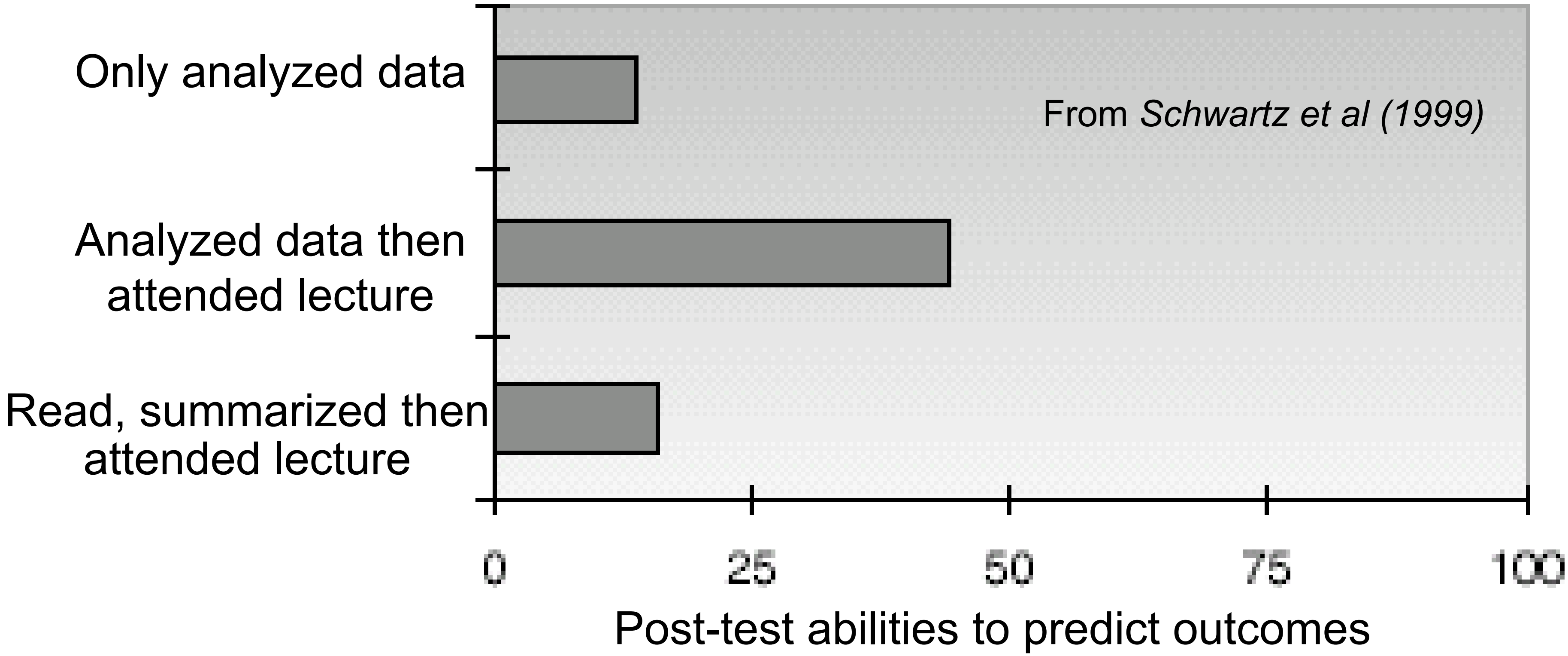
- Homeworks are at same level as in past years when given after class

- 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

# Impact of Homework and Lectures




Students were studying how people organize knowledge using schema and then were asked to predict outcomes

# Active Assessment: Oral Examinations

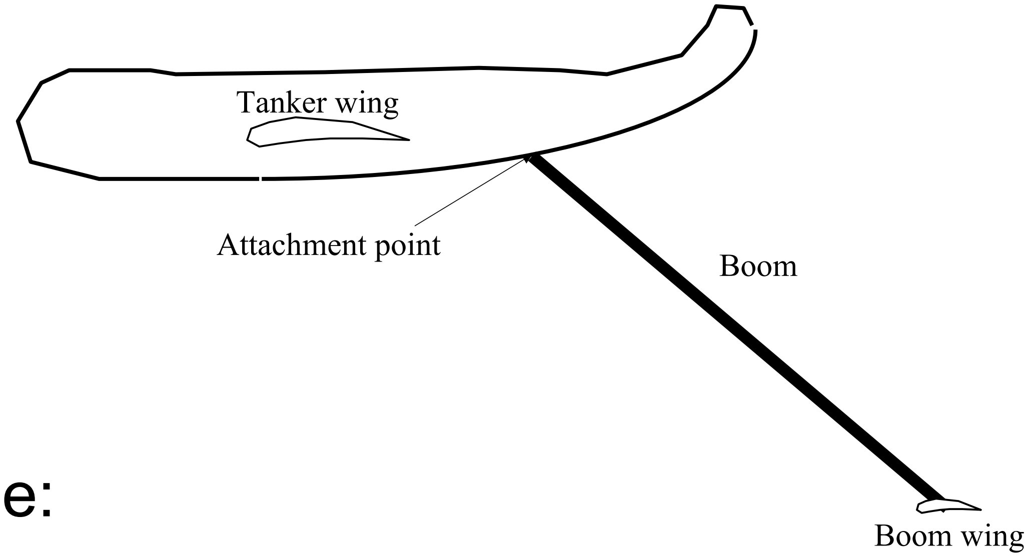
- Oral exams are an active assessment method engaging students while they are thinking
- Improves likelihood of an accurate assessment by its dynamic nature
- Valuable, authentic experience for students
- Opportunity for faculty to learn more about misconceptions

# Oral Exam: The Process

- All term 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

# Synthesis 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)

# Oral Exam: Grading Sheet

| Concepts | Percent possible | Explains clearly | Needed hints | Needed full explanation | Not asked | Grade | Comments |
|---|---|---|---|---|---|---|---|
| Dominant types of drag for problem (M.O 1, 3). | | | | | | | |
| * Induced important | 5 | | | | | | |
| * Skin friction important | 5 | | | | | | |
| * Pressure drag likely small | 5 | | | | | | |
| * Wave zero since Mach low | 5 | | | | | | |
| Tunnel test requirements (M.O. 1, 14) | | | | | | | |
| * M, Re matching | 10 | | | | | | |
| * Coefficients are the same | 10 | | | | | | |
| * Recognition that Re matching critical | 5 | | | | | | |
| *Model size constraints | 5 | | | | | | |
| Boundary layer concept (M.O. 5, 6) | | | | | | | |
| * thin layer | 5 | | | | | | |
| * molecular diffusion of momentum at wall | 5 | | | | | | |
| * typical velocity profile (attached) | 5 | | | | | | |
| * displacement thickness | 5 | | | | | | |
| * Pressure constant through b.l. | 5 | | | | | | |
| * Difference between lam. and turb. b.l. | 5 | | | | | | |
| Behavior of $c_f$ with x/c (M.O. 5, 6) | | | | | | | |
| * Decreases due to increased thickness | 5 | | | | | | |
| * Recognized b.l. would transition | 5 | | | | | | |
| * Increased cf for turb. b.l. due to mixing | 5 | | | | | | |
| Corrections to tunnel data (M.O. 14) | | | | | | | |
| * Wall effects | 5 | | | | | | |
| General comments: | | | | | | | |

# 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.

# Question & Discussion

*How could you implement a concept-based pedagogy in your course?*

*What are your biggest concerns with doing this?*

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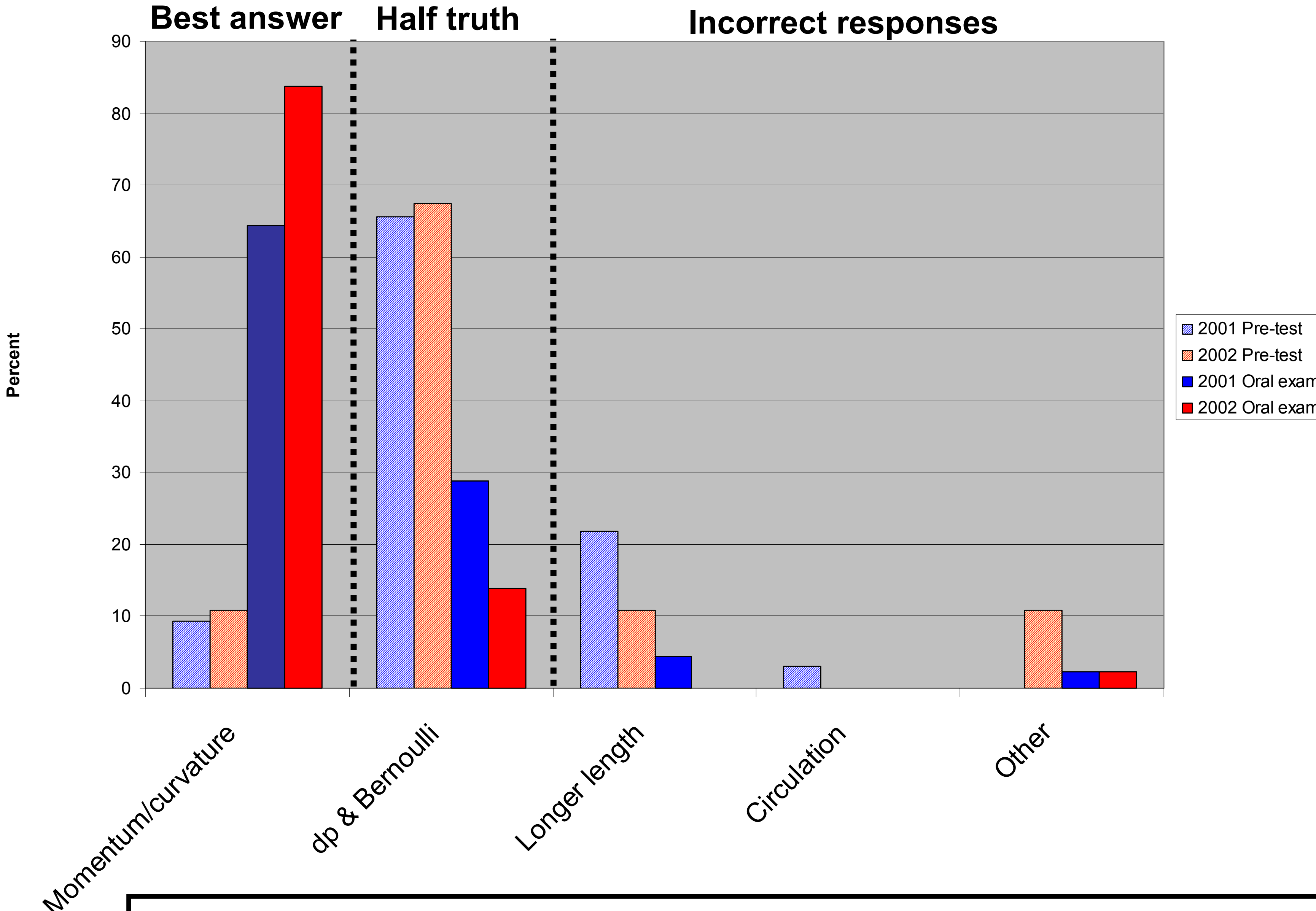
# Lift: Pre-conception & Exam Data




Conceptual understanding of lift significantly improved

# 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:

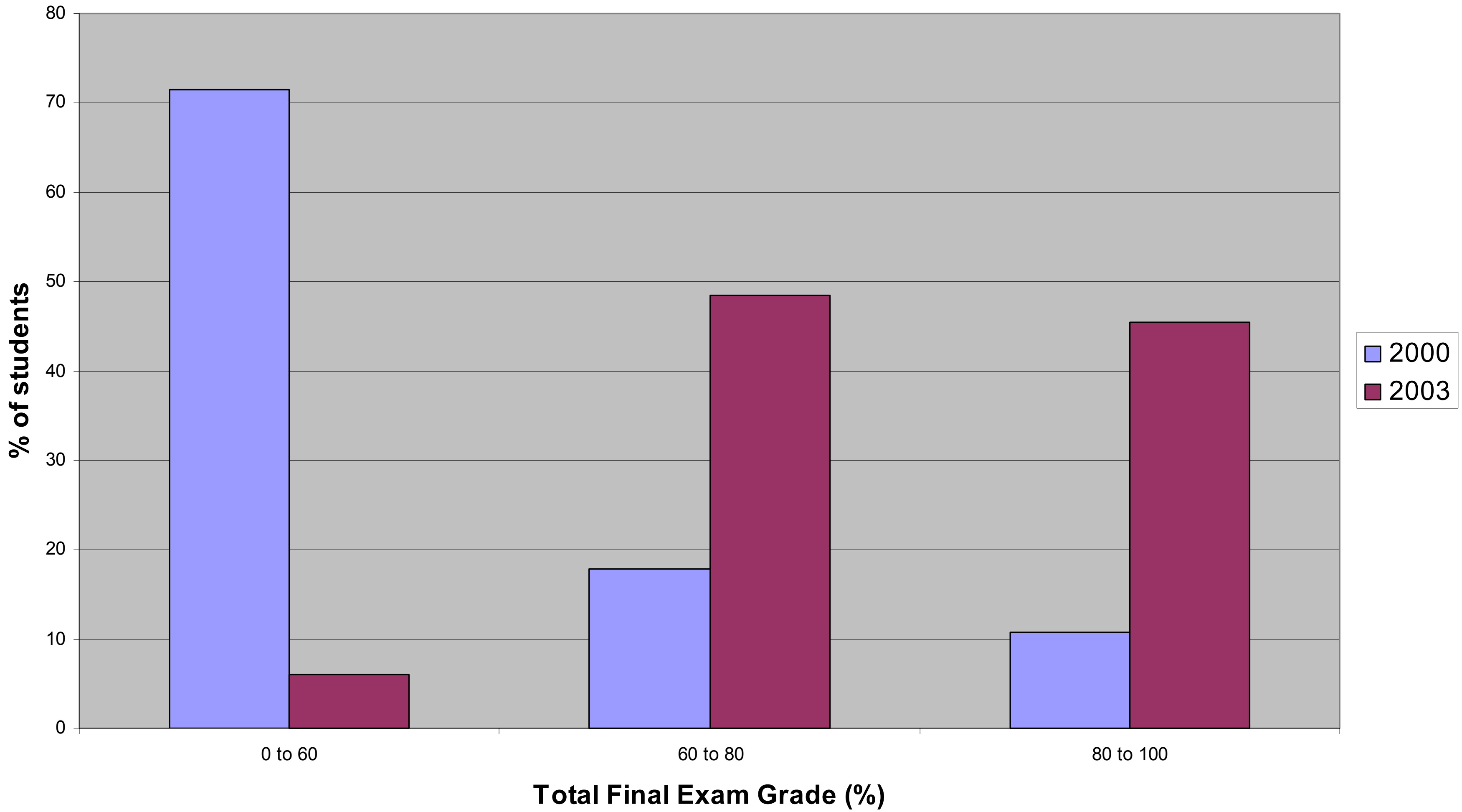
- 5 questions on the final exams
- 3 questions were identical
- 2 were of similar difficulty but different due to changed coverage

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

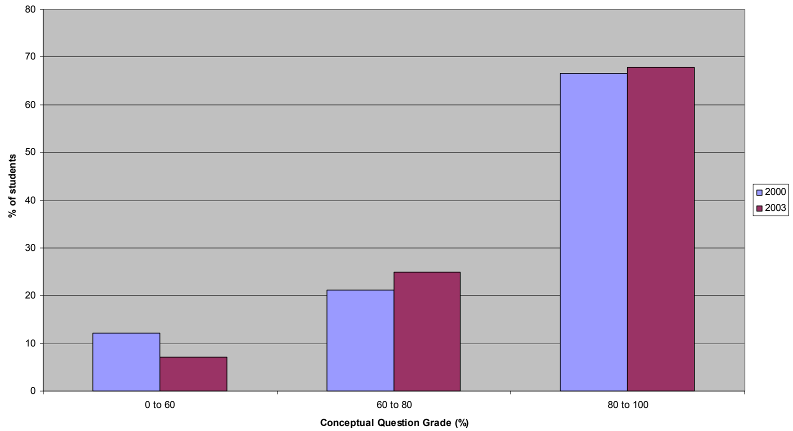
# Comparison of Final Exam Grades: Impact of Implementation



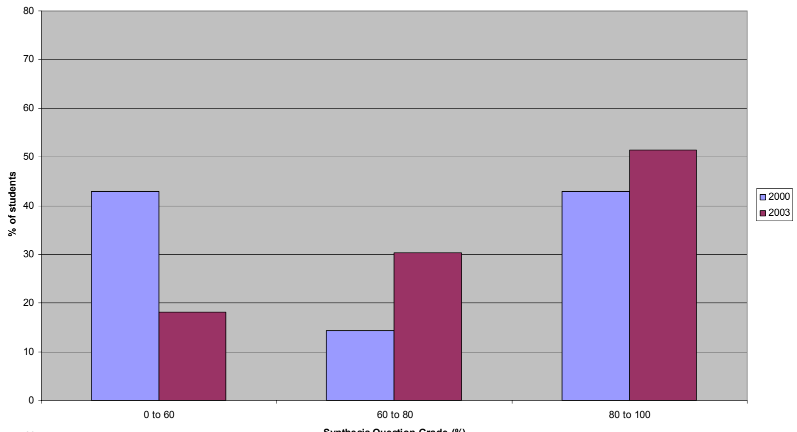

Significant improvement in overall performance from 2000 to 2003

# Impact of Implementation: Detailed Comparison

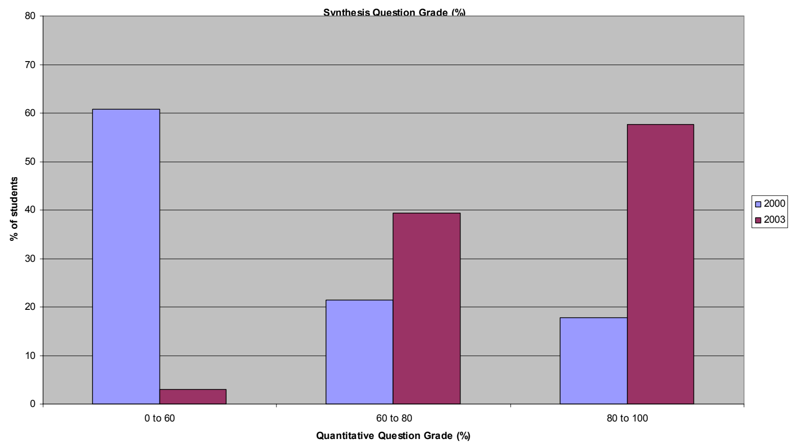
Conceptual




Synthesis

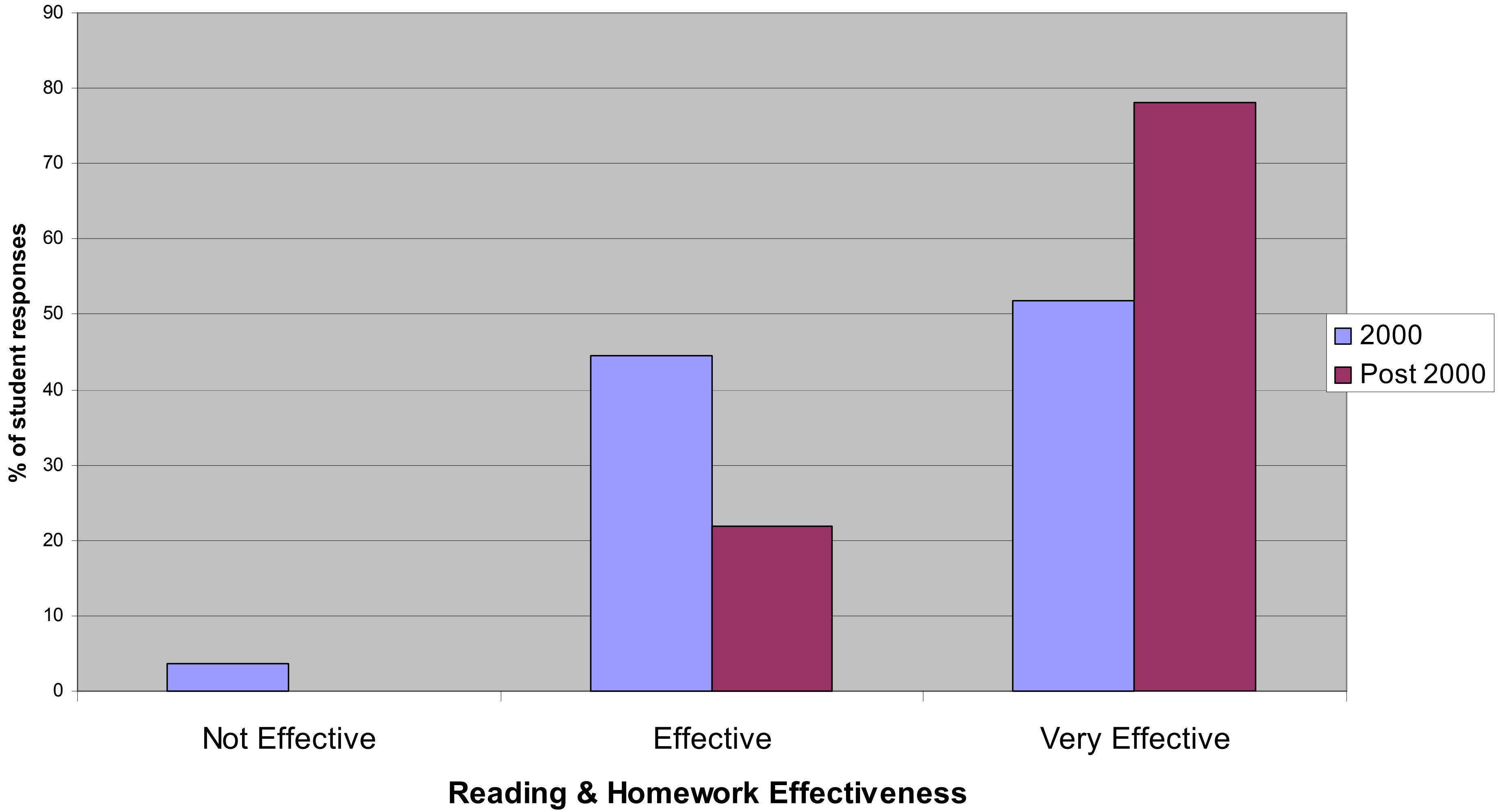



Quantitative



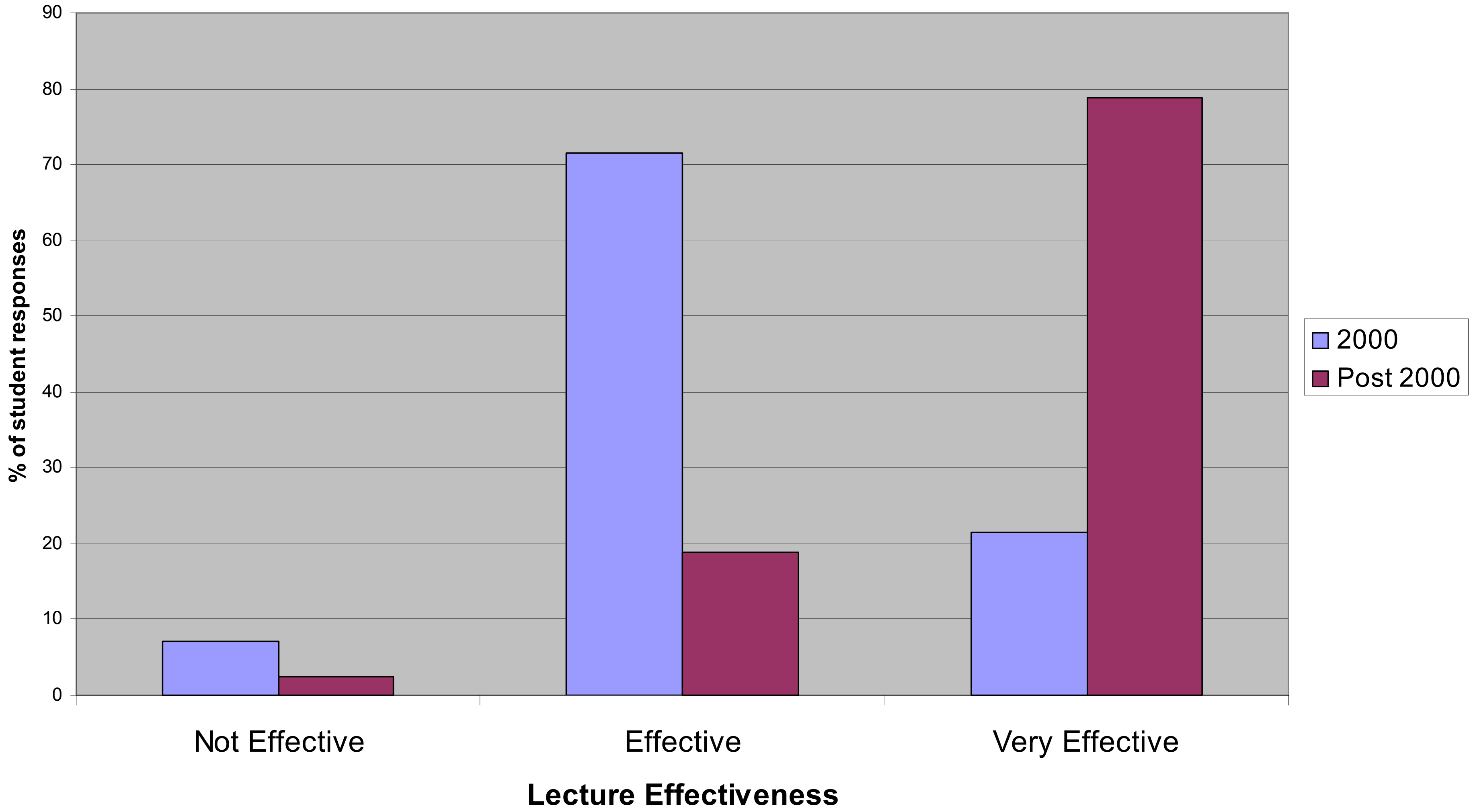

- Very similar performance on conceptual question
- Reduction in low performance (0-60% grade) from 2000 to 2003:
  - 2000: ~40% students
  - 2003: ~20% students
- Definite improvement in quantitative performance

# 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**

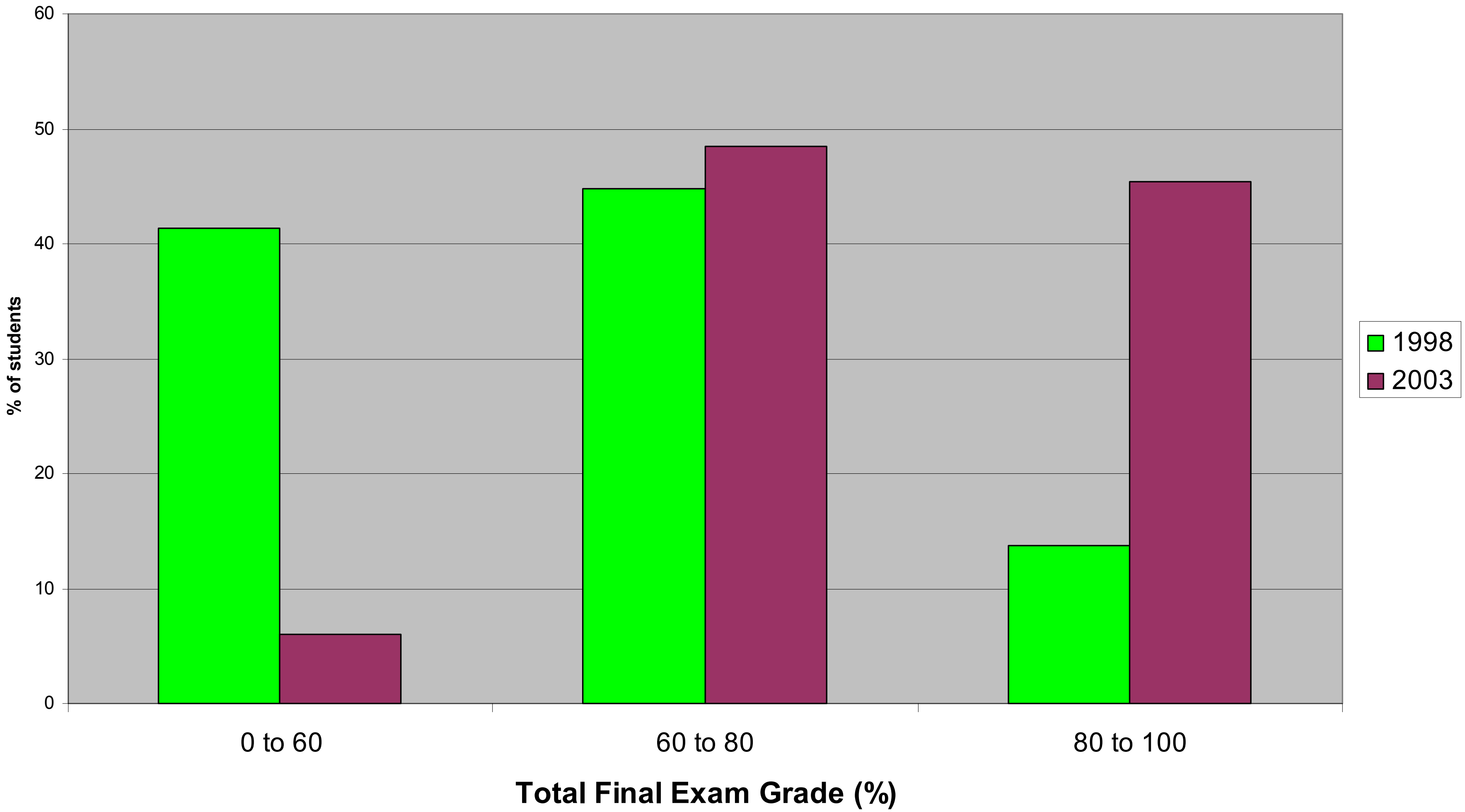
# Impact of Pedagogy on Performance

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 can be very effective, but implementation is critical.
- Identification of misconceptions and the development of good concept questions is difficult.
- Pre-class assignments and oral exams were found to be very effective learning and assessment strategies.
- Students recognize the benefits of these pedagogies when effectively implemented.